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VIRGINIA CONSERVATION COMMISSION

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ARTHUR BEVAN, *State Geologist*

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Geology and Mineral Resources of the Burkes Garden Quadrangle, Virginia

By

BYRON N. COOPER

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Northwest across Burkes Garden, from Garden Mountain. From left to right, Hutchinson Rock, Mill Gap, and Morris Knob.
(Photograph by Josiah Bridge.)

Northwest across Burkes Garden, from Garden Mountain. From left to right, Hutchinson Rock, Mill Gap, and Morris Knob.
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LETTER OF TRANSMITTAL

COMMONWEALTH OF VIRGINIA
VIRGINIA GEOLOGICAL SURVEY
UNIVERSITY OF VIRGINIA

CHARLOTTESVILLE, VA., December 15, 1943.

To the Virginia Conservation Commission:

GENTLEMEN:

I have the honor to transmit for publication as Bulletin 60 of the Virginia Geological Survey, the text, geologic map, and illustrations of a report on the *Geology and Mineral Resources of the Burkes Garden Quadrangle, Virginia,* by Dr. Byron N. Cooper, Associate Geologist of the Virginia Geological Survey.

The Burkes Garden quadrangle is a rectangular area of about 245 square miles, mainly in eastern Tazewell County but including the western part of Bland County and small parts of Smyth and Wythe counties. Burkes Garden has long been an area having much geologic and popular interest. The study of this area was made because of the need of detailed information on the mineral resources, chiefly limestones and dolomites, and a modern detailed geologic map of the bedrock formations in that part of the State. No geologic map of the quadrangle has been published since a reconnaissance map was issued in 1896. The geologic map in this report has as its base the detailed topographic map on the scale of 1:62,500, published in 1941.

This report should be of much value to geologists, to all who are interested in the geologic resources of that part of the State, and especially to teachers and other residents who wish information on the rocks, mineral deposits, land forms, and geologic origin of the features of southwestern Virginia.

Respectfully submitted,

ARTHUR BEVAN,
State Geologist.

Approved for publication:
Virginia Conservation Commission,
Richmond, Virginia, December 16, 1943.
R. A. GILLIAM, *Executive Secretary and Treasurer.*

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By Byron N. Cooper

ABSTRACT

The Burkes Garden quadrangle, located in southwestern Virginia, contains about 17,000 feet of exposed rocks, all of which are sedimentary. Forty-three formations are recognized, and most of them are delineated separately on the geologic map (Pl. 1). Their ages range from Middle Cambrian to early Pennsylvanian. Practically all of the rocks are of marine origin, having accumulated as clastic, organic, and biochemical sediments in relatively shallow waters in a geosynclinal trough which existed in western Virginia during Paleozoic time.

During the Appalachian revolution, the rocks were complexly folded and were broken by overthrust faults involving vertical and horizontal displacements of thousands of feet. Five principal overthrusts, thirteen anticlines, twelve synclines, a homocline, and numerous minor structures are discussed. The major structures are delineated on the geologic map and accompanying structure sections.

The pronounced uplift of the area at the close of Paleozoic time inaugurated stream and other erosion which is still in progress. Renewed uplifts have continued to maintain a condition of active erosion. No evidence was observed to demonstrate that stable crustal conditions prevailed for a sufficient time to allow degradation of the surface to a peneplain. Rather, the character and structure of the rocks are discussed as the controlling factors in the evolution of the land forms. Numerous scenic features are discussed in detail.

The mineral resources of present and potential industrial value include limestone, dolomite, coal, clay, shale, sand, building stone, barite, manganese, and iron. Limestone and dolomite are given special consideration, because they constitute the resources of greatest potential value.

The succession of geologic events that produced the rocks, structures, mineral resources, and land forms of the area is described.

INTRODUCTION

LOCATION OF THE AREA

The Burkes Garden quadrangle in southwestern Virginia (Fig. 1) comprises an area of approximately 245 square miles. It lies between 81° 15′ and 81° 30′ west longitude and between 37° and 37° 15′ north latitude. The greater part of the area is in eastern Tazewell County, but it also includes the western part of Bland County and parts of Smyth and Wythe counties. Although no incorporated towns are located wholly within the quadrangle, outlying sections of Tazewell and Bluefield, Virginia, are included. U. S. Route 19, "The Trail of the Lonesome Pine," crosses the northern part of the quadrangle and connects Tazewell with Bluefield, Virginia and West Virginia. The southern part is crossed by State Highway 42, "The Bluegrass Trail," which connects Sharon Springs and Ceres with Bland and Saltville. A road ascending Walker Mountain from Sharon Springs intersects U. S. Route 52 atop the mountain and provides ready access to Wytheville and other towns along U. S. Route 11 which is the main arterial highway of the southern Appalachian Valley. State Highway 61 connects Tazewell with Rocky Gap on U. S. Route 52, but this road is not hard-surfaced beyond the Tazewell-Bland county line near Cove Creek. A system of improved roads makes most parts of the quadrangle readily accessible, but the higher mountains are a considerable barrier to transportation. The Clinch Valley Division of the Norfolk and Western Railway crosses the northern part of the area and connects Tazewell with the coal lands to the west and also with Bluefield and other points on the main line of the railroad from Norfolk, Virginia, to Cincinnati, Ohio.

All of the quadrangle except a small area in the northwestern part is in the Appalachian Valley and Ridge province. The area northwest of Abbs Valley is in the Allegheny Plateau. Nine Appalachian ridges cross the quadrangle from northeast to southwest and these alternate with narrow parallel valleys cut in relatively nonresistant rocks. Clinch and Garden mountains divide the quadrangle into two distinct parts. Only one all-weather road connects the area southeast of these mountains with the area to the northwest.

The major drainage divide between the New-Kanawha and Tennessee watersheds crosses the area from north to south. Major

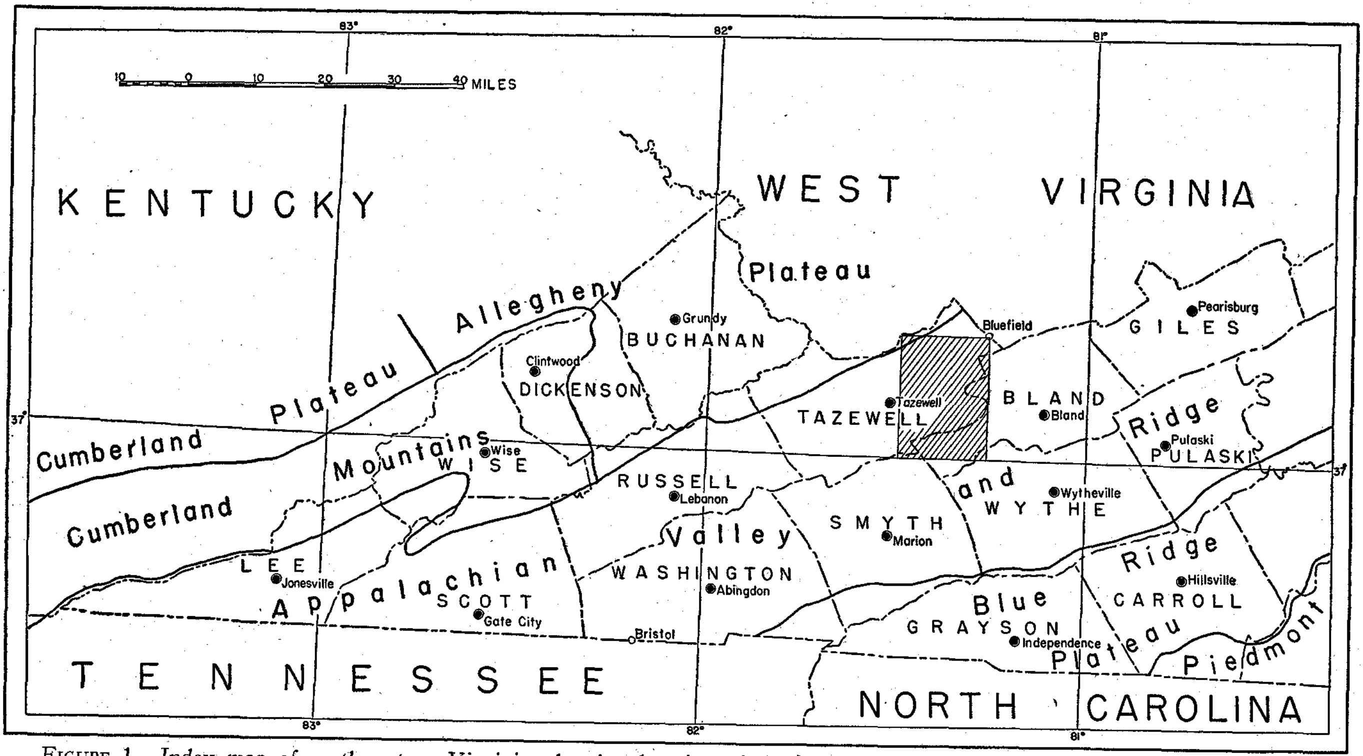

FIGURE 1.—Index map of southwestern Virginia, showing location of the Burkes Garden quadrangle and its relations to physiographic provinces.

tributaries of the New River head on the east side of this divide; headwaters of the Tug Fork of the New-Kanawha lie northwest of the divide near the border of the Allegheny Plateau, and Clinch River and the North Fork of Holston River head on the west and south sides of the divide. Because of its situation on a major drainage divide, the Burkes Garden quadrangle is somewhat higher and more rugged than most other parts of the southern Appalachian Valley.

SCOPE OF THE REPORT

This report discusses primarily the character of the rocks and mineral deposits exposed in the quadrangle. The stratigraphy and structure of the rocks are discussed in detail. In the discussion of mineral deposits, limestones and related rocks have been given special consideration, because they are believed to constitute the most valuable of the various mineral resources of the area. Considerable attention has also been given to the geological derivation of the many scenic features.

One of the chief purposes of this report is to describe in detail the natural resources, in order that they can be readily developed when the need arises.

ACKNOWLEDGMENTS

During the field season of 1938 the writer was capably assisted by Robert O. Bloomer of the University of North Carolina, and during the summers of 1939 and 1940 the writer had the able services of Chilton E. Prouty of Columbia University. Many valuable criticisms and suggestions were received during field work from various geologists, particularly from Dr. Charles Butts, retired geologist of the Federal Geological Survey and now geologist for the Virginia Geological Survey. Without his friendly help and encouragement the writer could not have gained an insight into the perplexing details of the stratigraphy in the time allowed for field work. Helpful suggestions and information were given by Dr. R. S. Edmundson of the Virginia Geological Survey and by Dr. Harry S. Ladd of the Federal Geological Survey. Unpublished information on the paleontology and stratigraphy of the Ordovician limestones was supplied by Dr. Josiah Bridge of the Federal Geological Survey and by Dr. G. Arthur Cooper of the United States National Museum during a field conference held in

June of 1941. Professor G. Marshall Kay of Columbia University spent several days in the field with the writer during the summer of 1940 and made valuable suggestions concerning revisions of the stratigraphic nomenclature and correlation of some of the Ordovician limestones. Professor Joseph K. Roberts of the University of Virginia and Professor W. F. Prouty of the University of North Carolina also gave constructive comments and suggestions in the field. The writer wishes to thank especially Dr. Arthur Bevan, State Geologist, for his directional guidance and advice during field work and during the preparation of this report. Helpful editorial comments were also made by Mr. William M. McGill, Assistant State Geologist, by Dr. R. S. Edmundson, and by Mr. Linwood H. Warwick, of the Virginia Geological Survey. S. E. Harris of the University of Iowa furnished detailed information on the areal geology of Mud Fork Valley.

Numerous residents of Tazewell and the Burkes Garden area generously supplied information and rendered friendly assistance. Their interest in the project is greatly appreciated. In this connection the writer wishes to acknowledge particularly the help and advice given by A. S. Higginbotham, J. Powell Royall, and S. J. Thompson of Tazewell; Dr. Jack Witten and Luther Dickenson of North Tazewell; and Blane Hanshew of Freestone Valley. Some of the photographs were supplied by Dr. Josiah Bridge, Professor Joseph K. Roberts, J. O. Cammack, and R. C. Oburn.

PREVIOUS WORK

The geology and mineral resources of the area covered by the Burkes Garden quadrangle (1941) were mapped and described by Campbell[1] in connection with the preparation of the Pocahontas folio. Some of the interesting physiographic features of the area are mentioned by Campbell[2] in another paper. Lesley[3] described some occurrences of coal and iron and correctly interpreted some of the geologic structures in the northern half of the Burkes Garden quadrangle. Stevenson[4] gave a more extensive account of

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[1] Campbell, M. R., U. S. Geol. Survey Geol. Atlas, Pocahontas folio (No. 26), 10 pp., 1896.

[2] Campbell, M. R., Drainage modifications and their interpretation: Jour. Geology, vol. 4, pp. 567-581, 657-678, 1896.

[3] Lesley, J. P., The geological structure of Tazewell, Russell, and Wise counties, in Virginia: Am. Philos. Soc., Proc., vol. 12, pp. 489-513, 1873.

[4] Stevenson, J. J., Notes on the geological structures of Tazewell, Russell, Wise, Smyth, and Washington counties of Virginia: Am. Philos. Soc., Proc., vol. 22, pp. 114-161, 1885; The faults of southwest Virginia: Am. Jour. Sci., 3d ser., vol. 33, pp. 262-270, 1887.

the structure of the northern part of the Burkes Garden quadrangle and named some of the faults. Occurrences of iron deposits were mentioned by Holden[5] in a regional discussion of the iron ores of the Appalachian Valley of Virginia. Bassler[6] described the limestones and shales near Five Oaks. The coal-bearing Pennsylvanian rocks were studied by Harnsberger[7] in connection with his survey of the coals of Tazewell County. His classification of the Pennsylvanian beds has been used without change by the writer. Ries and Somers[8] made a brief survey of the clays and shales which crop out along the Norfolk and Western Railway near Tiptop. The coal beds which crop out on Brushy Mountain are described by Campbell.[9] Holden[10] gives a brief description of the rocks and mineral resources of that part of the quadrangle which lies in Tazewell County. Many aspects of the areal geology, structure, and stratigraphy of the quadrangle are discussed and illustrated by Butts[11] in his regional papers on the geology of the Appalachian Valley of Virginia. Certain features of the development of the Pocahontas coal field which crosses the northwestern part of the quadrangle are discussed by Bishop.[12]

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[5] Holden, R. J., Iron, *in* Watson, T. L., Mineral resources of Virginia: Virginia Jamestown Exposition Commission, pp. 462-463, 1907.

[6] Bassler, R. S., The Cement resources of Virginia west of the Blue Ridge: Virginia Geol. Survey Bull. 2-A, pp. 210-216, 1909.

[7] Harnsberger, T. K., The geology and coal resources of the coal-bearing portion of Tazewell County, Virginia: Virginia Geol. Survey Bull. 19, pp. 80-95, 1919.

[8] Ries, H., and Somers, R. E., The clays and shales of Virginia west of the Blue Ridge: Virginia Geol. Survey Bull. 20, pp. 102-103, 1920.

[9] Campbell, M. R., and others, The Valley coal fields of Virginia: Virginia Geol. Survey Bull. 25, pp. 255-273, 1925.

[10] Holden, R. J., *in* Humbert, R. L., Industrial survey of Tazewell County, Virginia: Virginia Polytechnic Inst., Eng. Ext. Div., pp. 27-44, 1930.

[11] Butts, Charles, and others, Southern Appalachian region: XVI Internat. Geol. Cong. Guidebook 3, pp. 13, 64-74, pl. 28, 1932. Butts, Charles, Geologic map of the Appalachian Valley of Virginia with explanatory text: Virginia Geol. Survey Bull. 42, 56 pp., 1933; Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. 1, 568 pp., 1940.

[12] Bishop, W. A., Drainage Tunnel of the Pocahontas Fuel Company, Incorporated, 23 pp., 1936.

GEOGRAPHY

RELIEF AND DRAINAGE

The Burkes Garden quadrangle is one of the highest areas in the southern Appalachian Valley. Beartown Mountain (Pl. 19A), overlooking Burkes Garden, rises to an altitude of 4,705 feet. Many other mountain summits, including Chimney Rock, Dial Rock (Pl. 18C), Big Ridge, Chestnut Ridge on East River Mountain, "The Peak" (Pl. 18B) at the west end of Rich Mountain, and Hutchinson Rock (Pl. 18A) at the head of Thompson Valley, all have altitudes above 4,000 feet. Burkes Garden (Pl. 2) is a broad oval limestone valley about 3,150 feet above sea level. This unique valley is considerably higher in elevation than any other limestone valley in the southern Appalachian region. Burkes Garden is completely rimmed by mountains except for a narrow gap in Garden Mountain through which the surface drainage leaves the valley. The other limestone valleys in the quadrangle are relatively long and narrow. The valleys of the Clinch, Bluestone, Clear Fork of Wolf Creek, and the North Fork of the Holston, as well as Thompson Valley, Burkes Garden, Wrights Valley, and Abbs Valley (Pl. 19B), are floored with limestone and comprise the rich farm lands of the area. These valleys are largely cleared of timber and are rather thickly settled.

The Ohio-Tennessee watershed divide crosses the quadrangle from south to north and separates the tributaries of New River from those of the Holston and Clinch. Most of the higher knobs are on this divide. The headwaters of Tug Fork of Big Sandy River drain most of the plateau north of Abbs Valley. Tributaries of Horsepen Creek, which drains into Tug Fork, have diverted drainage at the head of Abbs Valley from Bluestone River. Drainage in Abbs Valley, Mud Fork Valley, and Wrights Valley empties into Bluestone River which heads near Divide Church on U. S. Route 19. West of Divide Church, Tiptop, and Gratton stretches the broad valley of Clinch River. The three forks of this river converge north of Benbolt. Burkes Garden is a broad, temporarily base-leveled area at the head of Wolf Creek which drains northeastward and empties into New River at Narrows, Giles County, Virginia. Clear Fork Valley, which opens northeast of Gratton, drains into Wolf Creek near Rocky Gap in Bland County. The high mountain summit known as Beartown not only separates the Ohio and Tennessee watersheds but also separates the waters of the Holston and Clinch. Maiden Spring Creek, a tributary of the Clinch, heads in the low gap immediately north of Hutchinson Rock, and Roaring Fork at the head of Laurel Creek, a tributary of the Holston, heads into Heninger Gap. The drainage divide between the Ohio and Tenessee rivers crosses the valley between Brushy and Walker mountains near Sharon Springs. Walker Creek flows northeast to join New River near Pembroke in Giles County. Southwest of the divide lies the valley of the North Fork of the Holston.

HISTORY AND EARLY SETTLEMENT[13]

One of the first white men to visit the Burkes Garden area was Charles Sinclair who lived near Seven Mile Ford in Smyth County, Virginia. He is reported to have led a party of explorers and surveyors, headed by Colonel Thomas L. Patton and Colonel William Preston, into Burkes Garden in the late fall of 1748. The trail which they followed led upstream along Laurel Creek in Freestone Valley[14], and across Garden Mountain through Walker Gap. According to the journal of Colonel Preston, the party had intended to make a survey of the valley prior to their return to Smyth County, but during the night following their arrival a heavy snow fell, which caused them to abandon the survey until the following year. Before the party left the Garden, a young axeman and chain-carrier, James Burke, spread potato peelings in a small clearing and covered them with brush. In the late spring of 1749 Colonel Patton, accompanied by Colonel John Buchanan and William Ingles, returned to make the survey and found a good growth of potatoes which had apparently sprung from the peelings spread by young Burke. The party thereupon named the valley Burkes Garden. William Ingles and James Burke settled in Burkes Garden in 1753, but Burke left the valley before the end of 1756.

Burkes Garden was known to the Indians as "The Great Swamp." When a company of the Sandy Expedition crossed Burkes Garden in 1756 the area was so densely forested that Mill Gap (Pl. 18D) was unnoticed. Apparently the party left the valley by way of Low Gap, into Little Valley, and thence crossed

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[13] The summary here presented is taken largely from Pendleton, W. C., History of Tazewell County and southwest Virginia, 1748-1920, pp. 107-605, Richmond, Va., W. C. Hill Co., 1920.

[14] The name Poor Valley, which appears on Plate 1 and on the Burkes Garden topographic map, was changed in 1940 to Freestone Valley by authority of the General Assembly of Virginia.

Rich Mountain to the divide between the South Fork of the Clinch and Clear Fork Creek. Instead of going southwestward down Clinch Valley, the party continued northwest over Buckhorn and Short mountains and down into the small valley below Dial Rock (Pl. 18C).

Dr. Thomas Walker of the Loyal Company probably traveled up the valley of Horsepen Creek and down Abbs Valley in 1750 on his return from an expedition to Cumberland Gap. He was one of the first to observe the coal deposits of the Pocahontas coal field. However, he did not locate any settlements in Clinch Valley or in any other part of Tazewell County.

By 1770 a few hermit hunters were residing in Tazewell County, but no families of settlers moved in until 1771. Thomas Witten was the first white man to move his family into the upper part of Clinch Valley. The route followed by him and by later immigrants was along Clear Fork Creek and the South Fork of the Clinch. Witten erected Crab Orchard Fort which was located southeast of Pisgah Church (about 4 miles west of Benbolt). This substantial refuge was used by the Witten family and by others in that vicinity until the cessation of Indian raids. William Wynne, another early settler, made a home for his family near the confluence of the forks of Clinch River. In 1772 Wynne erected a fort about 200 yards west of the present site of the Benbolt homestead east of Tazewell. Abbs Valley (Pl. 19B) began to be settled about 1774, and within five years all the other principal valleys in the quadrangle were settled. Indian massacres and atrocities harrassed the early pioneers until the 1790's.

By 1800, the number of pioneer families had increased only slightly from what it had been during the previous 15 years. Development and settlement of the area continued to be slow until the latter part of the 19th century when the Clinch Valley Division of the Norfolk and Western Railway was extended across the area. With the coming of the railroad and with the gradual improvement of the road system farmers were able to market their farm products at rather distant places. Since that time farming has become a profitable enterprise. Mining developments have contributed greatly to the growth of the lumbering industry. The peak of lumbering has been passed in the Burkes Garden area, and practically every good stand of timber has been cut. Most of the Burkes Garden quadrangle is rather remote from a railroad, and for that reason industrialization has not taken place.

CLIMATE

Because of its high altitude, Burkes Garden has the lowest mean annual temperature of any valley area in the State. The length of the average growing season is barely 150 days, which is three to four weeks shorter than the average growing season of other sections of the Appalachian Valley in Virginia. Killing frosts occur ten days to two weeks earlier than in other parts of the State, and in the fall the first frost comes a week to 10 days earlier. Summer temperatures are delightfully cool, and the maximum recorded temperature is 97° Fahrenheit. The lowest July temperature recorded in the State was in Burkes Garden. Burkes Garden is among the few places in the State which have recorded the minimum temperature of –27° Fahrenheit. The average rainfall is slightly above 45 inches. (See Table 1.)

In the other valleys of the quadrangle, the temperatures are somewhat cooler than those which prevail in lower parts of the Appalachian Valley of Virginia but are not as low as those recorded in Burkes Garden. The average number of rainy days is 160, but according to reports of several local citizens Beartown, west of Burkes Garden, has approximately 200 rainy days per year.

TABLE 1.—*Weather data for Burkes Garden, Virginia*[15]

Length of record	40 years
Temperatures (in degrees Fahrenheit)	
January average	32.6
July average	67.0
Maximum	97
Minimum	−27
Killing frosts (average dates)	
Last in spring	May 8
First in fall	Oct. 5
Growing season	150 days
Average precipitation (in inches)	
Average	3.81
February	3.54
March	4.67
April	3.88
May	4.21
June	4.69
July	4.44
August	4.43
September	3.43
October	3.12
November	2.86
December	3.62
Annual	46.70

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[15] Hibbard, F. N., Climate of Virginia; *in* Climate and Man: 1941 Yearbook of Agriculture, U. S. Dept. Agr., pp. 1159-1169, 1941.

STRATIGRAPHY

GENERAL FEATURES

All of the rocks exposed in the Burkes Garden quadrangle are sedimentary and nearly all of them are of marine origin. They comprise a rather complete depositional record from Middle Cambrian to early Pennsylvanian time. The total thickness of the exposed section is about 17,000 feet (Pls. 5, 8, 14, 15; Figs. 2, 3, 4, 5). The succession is divisible into 43 geologic units or formations. On Plate 1, the areas of outcrop of the various formations are delineated by means of different colors and patterns.

The oldest rock formation in the quadrangle is exposed along Road 651[16] about three-fourths of a mile north of Wittens Mills. This is not the oldest sedimentary rock deposited in the Appalachian geosyncline. Near the west foot of the Blue Ridge the same red shales which crop out north of Wittens Mills are underlain by several thousand feet of sandstone, shale, and limestone, all of which are Lower Cambrian. In the Burkes Garden quadrangle the Middle and Upper Cambrian series are represented by about 2,750 feet of dolomite, limestone, shale, and sandstone (Fig. 3).

Ordovician strata have a total thickness of about 4,000 feet (Pls. 5, 8). The lowermost 750 to 1,000 feet is chiefly dolomite. Next above the dolomite is about 800 feet of limestone, some of which is relatively pure. A 300-foot succession of red shales and mudrocks overlies the limestone and is succeeded by shales and intercalated limestones aggregating about 1,500 feet. The topmost division of the Ordovician is composed of red sandstone and shale which averages about 350 feet thick.

The Silurian system is relatively thin, but it includes the most resistant strata exposed in the Burkes Garden quadrangle. Seven of the nine principal ridges in the area are made by Silurian sandstones, and all of the highest knobs are capped with white sandstones which occur in the lower part of the system. The Silurian system in the Burkes Garden quadrangle is about 500 feet thick (Fig. 4).

Devonian beds, having a total thickness of about 3,000 feet, are principally sandstones and shales (Pl. 14). Practically all of the Devonian strata is nonresistant and erosion has dissected their outcrop into a maze of minor ridges and knobs. Devonian beds crop out in valleys of synclinal structure.

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[16] Roads numbered in the six-hundreds are parts of the State-maintained system of secondary roads.

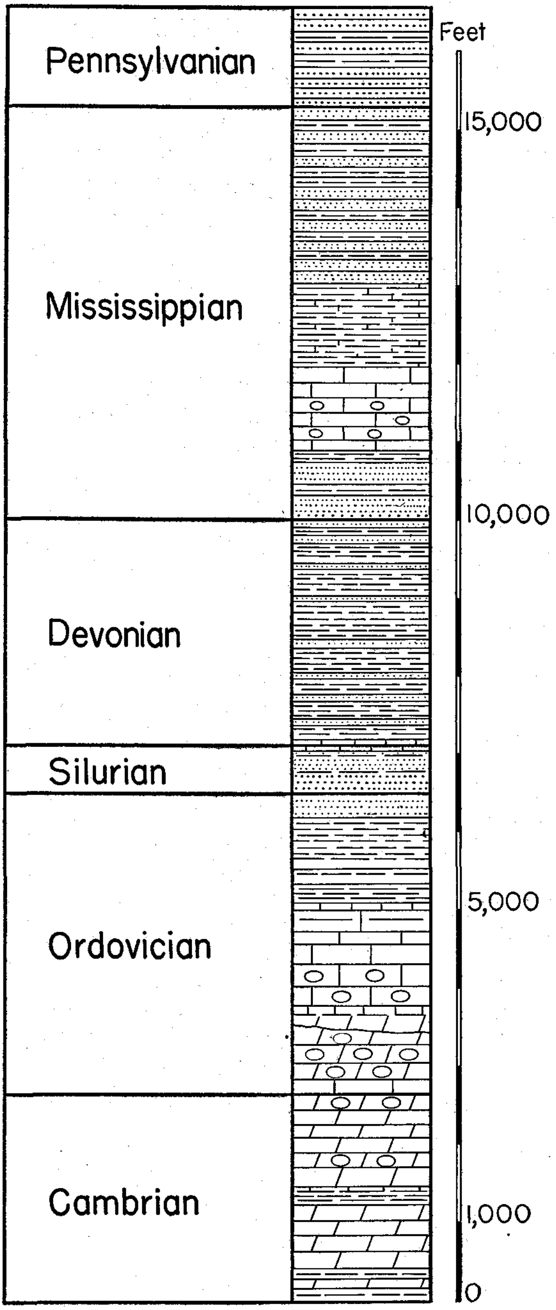

FIGURE 2.—Generalized columnar section of the bedrock formations in the Burkes Garden quadrangle, Virginia.

The Mississippian system includes diverse types of sedimentary rock totalling about 5,000 feet thick (Pl. 15). The lower 750 feet of the succession is composed of sandstone and shale. Thin coal beds which occur about the middle of this portion are exposed on the southeast slopes of Brushy Mountain, a low ridge upheld by resistant sandstones near the base of the system. The same beds are exposed near Bluefield, Virginia, but do not contain coal. North and west of Bluefield, these sandstones and shales are overlain by about 1,000 feet of limestone which forms the floors of Wrights and Abbs valleys. Nearly all of the upper part of the Mississippian is shale and sandstone. Possibly some of the Upper Mississippian rocks, particularly those directly associated with thin coal seams, are of nonmarine origin.

Pennsylvanian rocks (Fig. 5) crop out in the plateau north of Abbs Valley. They are the youngest bedrock in the Burkes Garden quadrangle. The lower part of the system is buried beneath Mississippian strata along a great overthrust fault. The upper part of the system has been completely removed by erosion; however, approximately 1,250 feet of Pennsylvanian rocks are exposed in the quadrangle. Something of the character of the buried part of the system has been revealed by subsurface coring and by mining. The thickest beds of the Pocahontas coal field occur below drainage. They have been explored all the way from Pocahontas southwest to Dry Fork near Bishop, Tazewell County, Virginia. The thickest of the buried coal beds, the Pocahontas No. 3, is about 450 feet below drainage at the head of Horsepen Creek.

Although the stratigraphic section is unusually complete, several important hiatuses are evident from studies of the fossils and from comparisons of the local succession with standard sections in other parts of the United States.

CAMBRIAN SYSTEM

MIDDLE CAMBRIAN SERIES

ROME FORMATION

Name.—The Rome formation was named from exposures in the vicinity of Rome, Georgia[17].

Distribution.—Outcrops of the Rome (Pl. 1) are confined to two small areas north of Wittens Mills and near the western border of the

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[17] Hayes, C. W., *Overthrust faults in the southern Appalachians*: Geol. Soc. America Bull., vol. 2, p. 143, 1891.

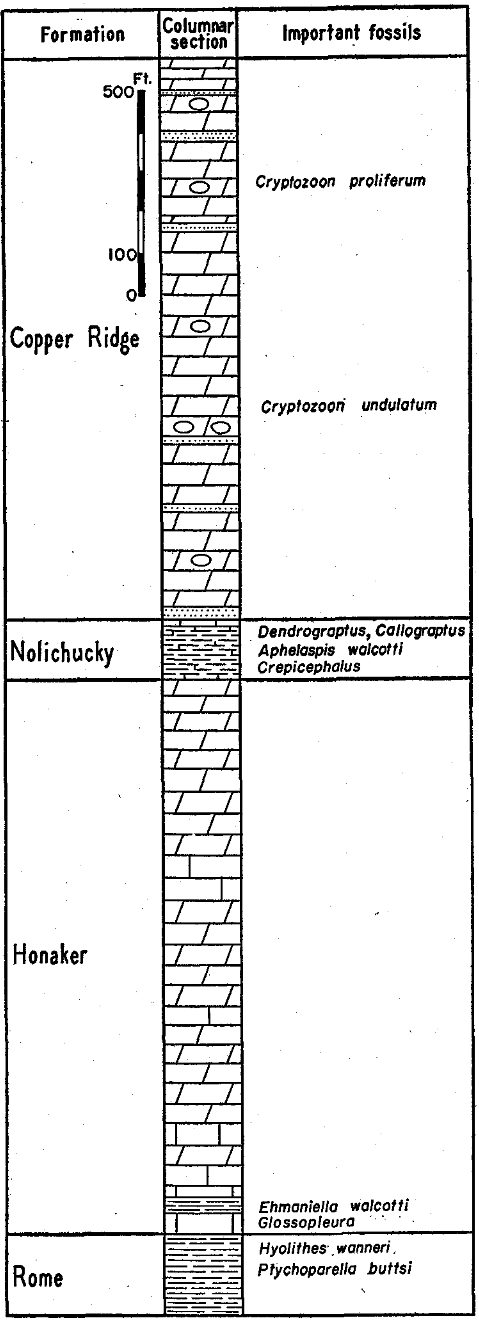

FIGURE 3.—Columnar section of the Cambrian formations in the Burkes Garden quadrangle, Virginia.

quadrangle. Each of these areas is bounded on the northwest side by a thrust fault of small displacement. During the folding of the rocks local ruptures developed in a broad arch which included the Honaker and Rome formations, and wedges of the latter were thrust up into the Honaker.

Lithology.—Elsewhere in Virginia the Rome formation is known to be at least 2,000 feet thick, but in the Burkes Garden quadrangle only the uppermost 200 feet is exposed (Fig. 3). Here as elsewhere in the Appalachian Valley, maroon-drab fissile shales are the most conspicuous type of rock. Associated with the red beds are dark-green, olive-drab, and light-buff shales and gray argillaceous mealy-weathering dolomites. Aside from the dolomite layers, the only calcareous beds are buff shales, but these are commonly leached on weathered exposures. In the section exposed along Road 651 north of Wittens Mills the upper 65 feet is composed predominantly of red shale. The rest of the exposed Rome is mealy-weathering gray dolomite containing thin intercalations of maroon-drab and buff shale.

Fossils.—*Pytchoparella buttsi* Resser, *Olenellus* cf. *O. rudis* Resser, *Linnarssonella* sp., *Solenopleurella* sp., and *Hyolithes wanneri* Resser and Howell occur in olive-drab and buff shales about 22 feet below the top of the Rome along Road 651 north of Wittens Mills. *Linnarssonella* cf. *L. tennesseensis* Walcott and numerous trilobite pygidia were found in thin sandy glauconitic streaks in dolomite about 50 feet lower in the section. The characteristic Rome fauna of *Olenellus romensis* Resser and Howell and its associates does not occur in the Rome exposed north of Wittens Mills.

Age and correlation.—Resser[18] considers the Rome to be the uppermost formation of the Lower Cambrian series, but other geologists regard the upper part of the Rome as Middle Cambrian. The Rome was formerly called the †Russell formation in this part of southwestern Virginia. Northeast of Roanoke the same beds are known as the Waynesboro formation. The Rome is the same as the †Watauga shale of Tennessee and the †Montevallo and †Choccolocco shales of Alabama.

HONAKER FORMATION

Name.—The Honaker formation was originally described by Campbell,[19] from exposures near Honaker, Russell County, Virginia.

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[18] Resser, C. E., Cambrian system (restricted) of the Southern Appalachians: Geol. Soc. America Bull., Special Paper 15, pp. 7-10, 1938.

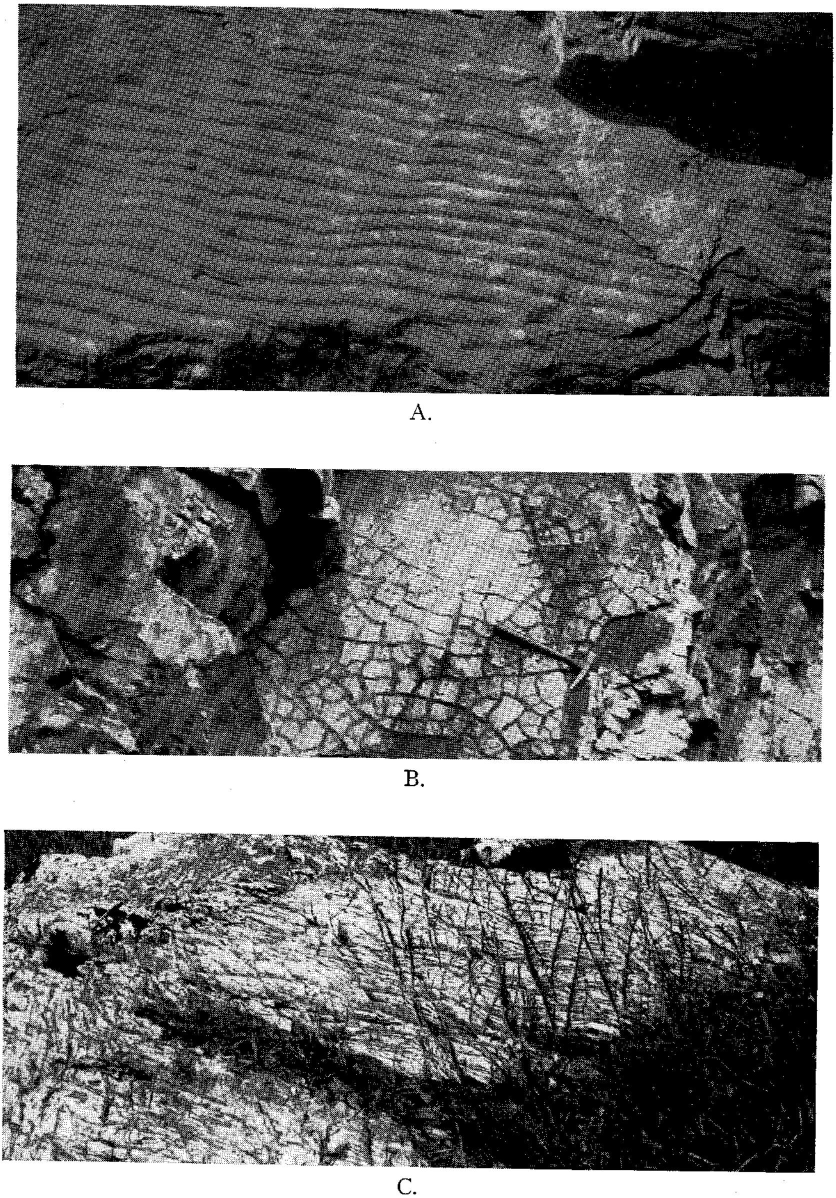
[19] Campbell, M. R., U. S. Geol. Survey Geol. Atlas, Tazewell folio (No. 44), p. 2, 1897.

Distribution.—The Honaker occurs in four outcropping belts in the Burkes Garden quadrangle. The northern belt averages about 1 mile wide and forms the northwestern edge of the St. Clair fault block from the west edge of the quadrangle northeast nearly to Road 656. Good exposures of the formation can be seen along the roads north of Wittens Mills; along the Springville-Tiptop road; and along the Norfolk and Western Railway from Wittens Mills northeast nearly to Wrights Valley. The Honaker also crops out along the southeast base of Buckhorn Mountain from Cox Branch northeast to and beyond the eastern border of the quadrangle. Parts of this belt are exposed along the roads which extend back to the mountain from State Highway 61 between Kinzer Church and Cove Creek. Two belts of Honaker lie south of Brushy Mountain. One forms the northwestern edge of the Saltville-Bland fault block. Good exposures are plentiful along the roads which cross Shewey Valley. The southernmost belt of the Honaker crops out along State Highway 42 between Ceres and Sharon Springs. Only the upper part of the formation is exposed between these two towns, because the Honaker formation is cut out by a southern branch of the Saltville-Bland fault. Several good sections of the formation can be seen along the roads leading south from State Highway 42.

Lithology.—The Honaker is composed principally of dolomite and limestone (Fig. 3). Several types of dolomite are present, but the most characteristic variety is a dark, bluish-gray, finely granular rock containing numerous vugs and veins of secondary calcite. Such beds are generally platy or blocky and weather light-gray. They contain up to 5 per cent of clay and silt which causes them to have a mealy appearance on weathered surfaces. This type of dolomite is displayed along the Norfolk and Western Railway northeast of Wittens Mills and also in the fields north of Sharon Springs.

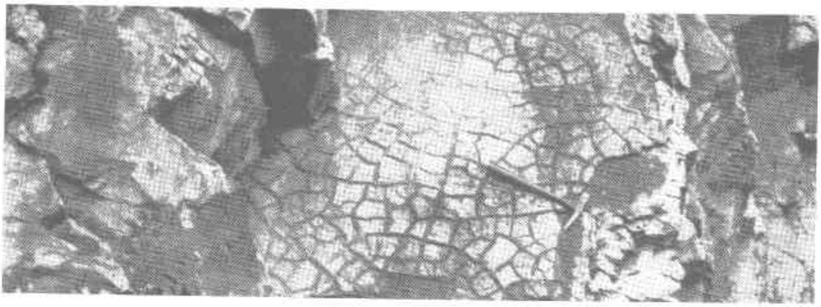
Light-gray to creamy-white, medium-grained dolomites are common in the upper 500 feet of the formation in the northernmost belt of its outcrop. This type of dolomite is rather thick bedded and weathers a distinctive reddish-brown. The best exposure of this type of rock is along Road 651, north of Wittens Mills, and a few yards south of the St. Clair fault. It is also prominent along the northwestern margin of the Honaker outcrop in Shewey Valley.

Drab-gray, medium-bedded, granular dolomites are almost as abundant as the dark bluish-gray variety, and in the southern belts, particularly, comprise about half the total thickness of the



A, Current-ripple marks in Copper Ridge dolomite; half a mile east of Cove Creek School, 5 miles south of Bluefield, Virginia. B, Mud cracks on bedding surface of Copper Ridge dolomite; along State Highway 61, near Perry Branch of Clear Fork. C, Furrowed surface of Beekmantown dolomite, produced by differential weathering of minute calcite veins; near Ceres, Virginia.

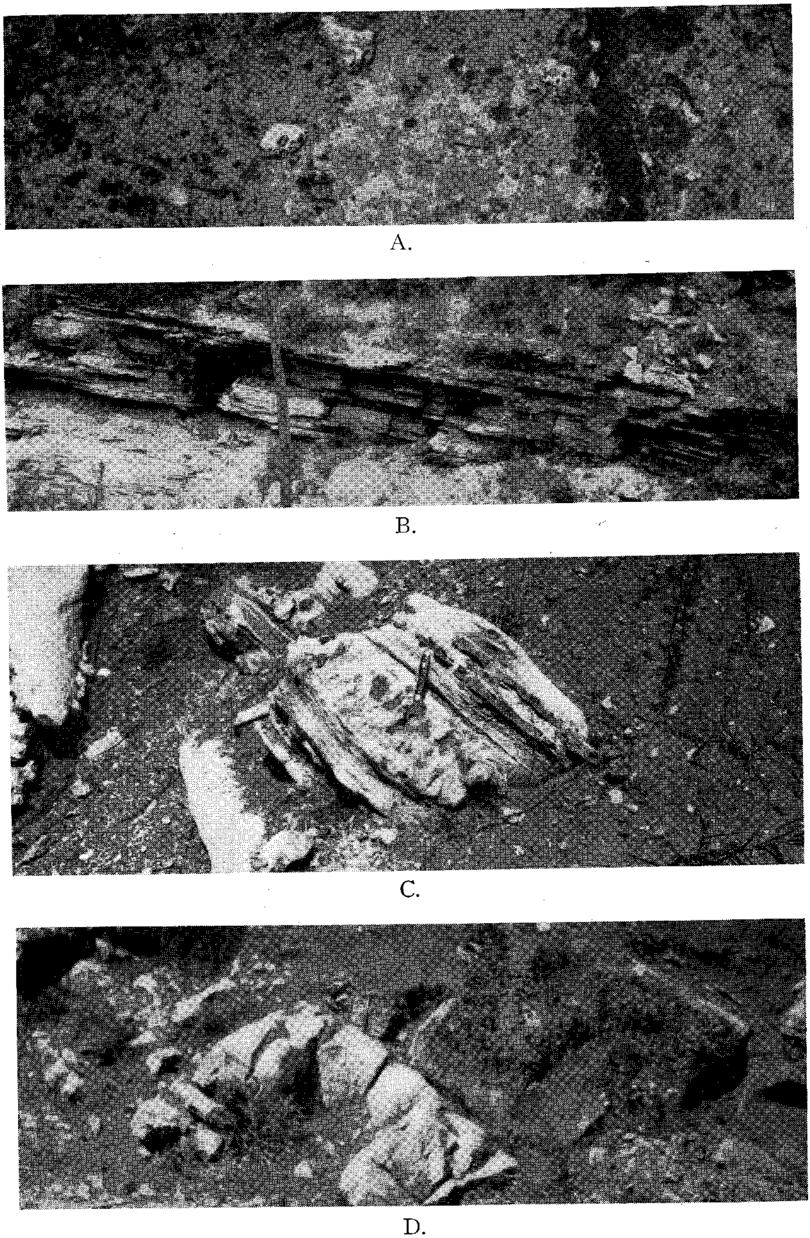
A.



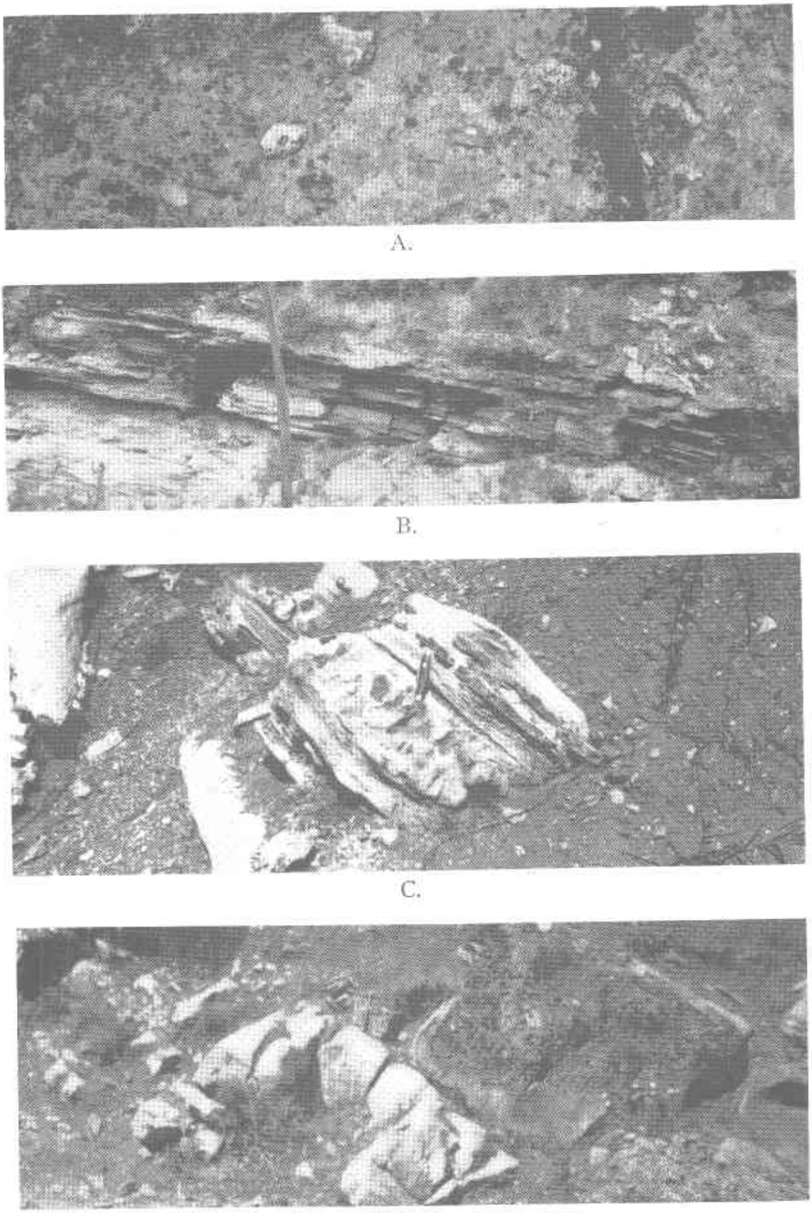
B.

C.

A, Current-ripple marks in Copper Ridge dolomite; half a mile east of Cove Creek School, 5 miles south of Bluefield, Virginia. B, Mud cracks on bedding surface of Copper Ridge dolomite; along State Highway 61, near Perry Branch of Clear Fork. C, Furrowed surface of Beekmantown dolomite, produced by differential weathering of minute calcite veins; near Ceres, Virginia.



A, Chert breccia in basal clastics of the Blackford member; near Five Oaks. B, Ash-gray shale of the Blackford member; along State Highway 78 in Burkes Garden. C, Blocky chert in argillaceous limestone of the Blackford member; along Lincolnshire Branch, near Five Oaks. D, Contact between Five Oaks member and the overlying Lincolnshire member; near Wittens Mills.



A, Chert breccia in basal clastics of the Blackford member; near Five Oaks. B, Ash-gray shale of the Blackford member; along State Highway 78 in Burkes Garden. C, Blocky chert in argillaceous limestone of the Blackford member; along Lincolnshire Branch, near Five Oaks. D, Contact between Five Oaks member and the overlying Lincolnshire member; near Wittens Mills.

formation. Weathered surfaces are rough and welted. Some of the layers contain crinkled wavy laminations of dark, rusty-brown silt and sand. These laminations are especially prominent in the uppermost 330 feet of the Honaker north of Wittens Mills.

Limestones of the Honaker are dark, bluish-gray, fine grained, and argillaceous. Most of the clay occurs in thin wavy seams between laminae of pure limestone. Differential weathering of the clayey and limy bands reduces the beds to a rubble of limestone slabs. These limestones are the most distinctive and characteristic type of rock in the formation. They occur in several zones near the top and in the lower part of the formation. Good exposures of Honaker limestone are plentiful along the roads northeast of Wittens Mills.

In addition to shaly partings between the limestone and dolomite layers, shale forms a zone about 30 feet thick near the base of the Honaker of the northernmost belt. The shale is greenish-gray, noncalcareous, and very fossiliferous. Its base is about 60 feet above the Rome-Honaker contact. The full thickness of the zone is exposed along Road 651 north of Wittens Mills. Similar shales occur higher in the Honaker but in zones less than three feet thick and without the fossils of the lower shaly zone.

The total thickness of the Honaker is 1,000 to 1,400 feet. Only a part of the total thickness of the formation is exposed in Clear Fork, Shewey, and Holston valleys, but in Shewey Valley at least 1,000 feet is present. In the southern belts about 95 per cent of the exposed beds are high-magnesium dolomite, but in the northern belt about 20 per cent of the total thickness is laminated limestone.

Geologic Section 1.—Honaker formation along Roads 650 and 651 north of Wittens Mills, Tazewell County, Virginia

	Thickness Ft.	 In.
Nolichucky shale		
Honaker formation (1,383 feet)		
19. Dolomite, medium-gray, coarse grained, granular, silty	20	
18. Dolomite, medium bedded, dark brownish-gray, weathers saccharoidal	63	6
17. Dolomite, cuneiform jointed, medium grained, brownish-gray	46	

	Thickness	
	Ft.	In.
16. Dolomite, dark-gray, medium grained, with crinkled laminations of silt and clay; weathers rusty	21	9
15. Dolomite, dark bluish-gray, ferruginous, medium bedded; weathers brownish gray	67	9
14. Dolomite, light-gray, granular, compact; weathers saccharoidal, flaggy, and rusty-brown; crinkly laminations of silt and clay project from weathered surfaces	156	6
13. Limestone, dolomitic, dark-gray, silty, argillaceous	32	6
12. Covered interval, composed of two kinds of dolomite; one is light-gray, compact, and creamy-white; the other is rusty-brown, coarse grained, and weathers ash-gray; about 65 per cent of the thickness is composed of the second type	224	
11. Dolomite, bluish-black, argillaceous, blocky; weathers mealy; several intercalations of ribbon-banded argillaceous limestone, composing about 20 per cent of the total thickness	551	
10. Dolomite, thin bedded, bluish-black, finely granular; contains numerous vugs of white calcite; a few thin intercalations of platy limestone containing *Obolus* cf. *O. minimus*	39	6
9. Limestone, bluish-gray, argillaceous, irregularly banded	19	
8. Dolomite, bluish-gray, granular, weathers mealy	34	
7. Dolomite, brownish-gray, shaly partings	12	
6. Limestone and buff shale, interbedded	11	
5. Shale, olive-drab to buff; contains *Ehmaniella* fauna	23	6
4. Dolomite, medium-gray, granular	6	
3. Limestone, ribbon banded, argillaceous	44	
2. Limestone, interbedded with silty shale	8	
1. Limestone, bluish-gray, granular, contains oolitic laminae; contains *Solenopleurella*	3	6

Rome formation

Fossils.—No fossils have been found in the Honaker southeast of Brushy Mountain. The following forms were collected from zones 5 and 6 of the foregoing section:

Acrotreta rudis Walcott
Alokistocare sp.
Ehmania dubia Resser
Ehmaniella cowanensis Resser
Ehmaniella walcotti Resser
Obolus cf. O. rodgersvillensis Resser

Lingulella ino Walcott and poorly preserved trilobites of the genera *Glossopleura* and *Solenopleurella* occur just above the base of the Honaker. A species of *Obolus,* probably *O. minimus* (Walcott), occurs in laminated limestone about 100 feet above the Rome.

Age and correlation.—Southwest of Honaker, Virginia, the Honaker dolomite changes facies and three distinct units can be recognized: the Rutledge limestone, the Rogersville shale, and the Maryville limestone. The lowermost formation, the Rutledge, is a banded limestone about 200 feet thick, which contains the trilobites *Glossopleura* and *Prozancanthoides.* The Rogersville shale is about 100 feet thick and carries *Ehmaniella* in abundance. The Maryville limestones are banded argillaceous rocks with minor intercalations of dolomite. Butts[20] states that the three formations are not distinct northeast of Russell County, and he thinks that the Rogersville pinches out near the town of Honaker. It now appears that the Rogersville persists as far northeast as the Burkes Garden quadrangle, where it is represented by about 30 feet of shale carrying *Ehmaniella.* The Honaker limestones and shales above the Rome and beneath the *Ehmaniella* zone are linked by lithology and fossils with the Rutledge limestone, and the more than 1,200 feet of limestone and dolomite above the *Ehmaniella* zone probably correlates with the Maryville, although the post-*Ehmaniella* part of the Honaker north of Wittens Mills is considerably thicker than the Maryville of Russell County. Also, the succession is predominantly dolomite, whereas the typical Maryville is a limestone. Possibly a part of the 1,200 feet above the *Ehmaniella* zone and below the Nolichucky shale is younger than any part of the type Maryville. It seems inadvisable to subdivide the Honaker into thinner formations north of Wittens Mills, because the *Ehmaniella* zone can not be identified farther

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[20] Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. 1, pp. 67-74, 1940.

northeast. The Honaker corresponds to the major part of the Elbrook formation recognized in the southeastern belts of the Appalachian region and also to a part of the Conasauga formation of Alabama.

Stratigraphic relations.—Although the Honaker and Rome are separated by a bed of conglomerate, the two are considered to be essentially conformable. The Rome north of Wittens Mills carries a *Ptychoparella* fauna which invariably occurs high in the formation and is followed by a thin zone which is lithologically and faunally similar to the Rutledge limestone. In all four belts of the Honaker, the formation is overlain without apparent disconformity by the Nolichucky shale.

UPPER CAMBRIAN SERIES

NOLICHUCKY SHALE

Name.—Keith[21] gave the name Nolichucky to a succession of calcareous shales and shaly limestones, which overlies the Maryville limestone and underlies the Knox dolomite along Nolichucky River in Greene County, Tennessee. The name first appeared in print in a report by Campbell[22] on an area in Virginia.

Distribution.—Four belts of the Nolichucky shale are present in the Burkes Garden quadrangle. The northernmost one enters the area about 1 mile northwest of Drytown and extends northeastward nearly to Road 656, where it terminates against the St. Clair fault. Good exposures of the formation are along the road up Lincolnshire Branch, west of the railway trestle at Wittens Mills Station, along the Springville-Tiptop road, and on the northwest side of Lynn Hollow.

Another belt extends from Cox Branch northeast along the southeastern base of Buckhorn Mountain. Most of the roads running north from State Highway 61 show good exposures of the formation.

The third and fourth belts lie southeast of Brushy Mountain, one in Shewey Valley and the other along State Highway 42 between Sharon Springs and Ceres. The only good exposure in the Shewey Valley belt of Nolichucky is along Road 623 north of Sharon Springs. Here the Nolichucky underlies a thick sandstone at the base of the Copper Ridge formation. The belt south of State Highway 42 ends against a branch of the Saltville-Bland

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[21] Keith, Arthur, Description of the Morristown sheet: U. S. Geol. Survey Geol. Atlas, Morristown folio (No. 27), p. 2, 1896.

[22] Campbell, M. R., Description of the Estillville sheet: U. S. Geol. Survey Geol. Atlas, Estillville folio (No. 12), p. 2, 1894.

fault. Good exposures are present along Road 625 south of Ceres and also along Road 626 which follows Page Branch. A small faulted wedge of Nolichucky occurs in the village of Ceres (Pl. 1).

Lithology.—The Nolichucky is composed of olive-drab to greenish-gray, siliceous shales, bluish-gray limestones and calcareous shales, ribbon-bedded limestones, and silty dolomites (Fig. 3). In the southern belts beds of edgewise conglomerate, composed of pebbles of limestone and shale set in a matrix of oolitic limestone, occur locally near the base of the formation. Limestones compose all of the upper 20 feet. The most characteristic rock in the Nolichucky is olive-drab, noncalcerous, siliceous shale. Most of the calcareous beds are deeply leached and yellowish-brown.

Along Lincolnshire Branch northwest of Drytown, the Nolichucky is composed almost wholly of greenish-gray noncalcareous shale, 129 feet thick. In the Clear Fork belt, limestones predominate in the upper part with a total thickness about the same as in the northern belt.

Geologic Section 2.—Nolichucky shale along Page Branch near Ceres, Bland County, Virginia

	Thickness Feet
Copper Ridge formation	
Nolichucky shale (147 feet)	
7. Transition beds, composed of thin, ribbon-bedded silty dolomites with shaly partings and intercalations of ribbon-bedded, bluish-gray argillaceous limestone	43
6. Limestone, bluish-gray, fine grained, with shaly partings. Beds weather dull rusty-brown. Minor intercalations of granular dolomitic limestone; contains *Aphelaspis* sp.	47½
5. Shale, olive-drab, noncalcareous, fissile; with *Crepicephalus goodwinensis* and *Coosia* sp.	22½
4. Shale, olive-drab, contains lenses of edgewise conglomerate the matrix of which is oolitic	8
3. Shale, olive-drab, noncalcareous, with *Holstonia* and other trilobites	6

	Thickness Feet
2. Limestone, dark bluish-gray, and calcareous shale in ribbon beds. Thin seams of noncalcareous fissile shale near the base	6
1. Limestone, bluish-gray, ribbon bedded, with intercalations of bluish-gray calcareous shale	14

Honaker formation

Fossils.—The uppermost 50 feet of the Nolichucky carries a trilobite fauna referable to the *Blountia* zone as recognized by Resser[23] in the New River-Tennessee sector of the Appalachian region. The following is a composite list of fossils identified from Nolichucky shale north of Shawver Mill:

Aphelaspis walcotti Resser
Aphelaspis quadrata Resser
Aphelaspis cf. A. laxa Resser
Blountia cf. B. brevis Resser
Coosia latilimbata Resser
Crepicephalus sp.
Crepicephalus rectiformis Resser
Dicellomus appalachia Walcott
Lingulella buttsi (Walcott)
Lingulepis walcotti Resser
Raaschella sp.
Tricrepicephalus walcotti (Lochman)

Along the east fork of a lane running north from State Highway 61 and about 1½ miles east of Gratton, graptolites occur in prolific abundance in bluish-gray calcareous shales and ribbon-bedded limestones. Species identified from these beds include:

Acanthograptus sp.
Callograptus antiquus Ruedemann
Dendrograptus cf. D. hallianus (Prout)
Dendrograptus edwardsi major Ruedemann
Haplograptus cf. H. vermiformis Ruedemann

Apparently this graptolite zone occurs at the very top of the Nolichucky and certainly well above the *Aphelaspis-Blountia* zone. In the Page Branch section, olive-drab shales about 90 feet below the Copper Ridge

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[23] Resser, C. E., Cambrian system (restricted) of the Southern Appalachians: Geol. Soc. America Bull., Special Paper 15, p. 30, 1938.

formation carry some representatives of the *Crepicephalus* zone of Resser. Two species of this genus, *C. greendalensis* Resser and *C. goodwinensis* Resser, together with *Coosia latilimbata* Resser and a species of *Dicellomus* also occur in beds near the base of the Nolichucky south of Bell Hill. Some of the limy beds of the Ceres-Sharon Springs belt contain *Holstonia holstonensis* Resser, *Dicellomus* sp., and *Linnarssonella knoxvillensis* Walcott. This zone was not identified in the belts northeast of Brushy Mountain.

Age and correlation.—The Nolichucky shale of the Burkes Garden quadrangle probably does not include the lowest beds of the type Nolichucky shale of Tennessee, but the middle and upper parts appear to be fully represented. The fact that the *Cedaria, Crepicephalus,* and *Aphelaspis-Blountia* zones occur in the Eau Claire member of the Dresbach formation of Wisconsin[24] indicates the age of the Nolichucky to be early St. Croixan. Apparently some confusion exists as to the age of the graptolite zone at the top of the formation. According to Ruedemann[25] the occurrence of *Dendrograptus edwardsi* in the Nolichucky of Tennessee " . . . is of importance in indicating a possible close age-relationship between the Elbrook (Nolichucky) formation of Tennessee and the Trempealeau formation as well as close paleogeographic relations between the two formations." Resser[26] believes that the Copper Ridge, which overlies the Nolichucky, corresponds to the Franconia-Trempealeau succession of the Upper Mississippi Valley.

The Nolichucky is believed to be equivalent to the upper part of the Elbrook formation of the southeastern Appalachian belts and to the upper part of the Conasauga formation of Alabama.

COPPER RIDGE FORMATION

Name.—The Copper Ridge dolomite was named by Ulrich[27], from exposures on Copper Ridge in northwestern Knox County, Tennessee.

Distribution.—Four belts of the Copper Ridge are present in the Burkes Garden quadrangle (Pl. 1). One extends from the west border of the quadrangle northeast through Wittens Mills and Springville to the vicinity of St. Clair School where it is cut off by a branch fault of the St. Clair overthrust. Northeast of Springville the outcrop of the

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[24] Twenhofel, W. H., Raasch, G. O., and Thwaites, F. T., Cambrian strata of Wisconsin: Geol. Soc. America Bull., vol. 46, pp. 1694-1696, 1935.

[25] Ruedemann, Rudolf, The Cambrian of the Upper Mississippi Valley, pt. 3, Graptolitoidea: Milwaukee Pub. Mus. Bull., vol. 12, no. 3, p. 314, 1933.

[26] Resser, C. E., op. cit., p. 20.

[27] Ulrich, E. O., Revision of the Paleozoic systems: Geol. Soc. America Bull., vol. 22, pp. 548, 635-636, pl. 27, 1911.

formation widens considerably and forms the limbs and crest of a broad anticline. In Clear Fork Valley a belt of Copper Ridge extends down the middle of the valley as far southwest as Cox Branch where it terminates against a branch fault of the Narrows overthrust. The northeastern end of a broad anticlinal belt of the formation occupies the middle part of Thompson Valley. Another belt of Copper Ridge dolomite crops out in the valley between Walker Mountain and Brushy Mountain. Southwest of Sharon Springs a branch fault of the Saltville-Bland thrust splits the belt into two parts.

Lithology.—The Copper Ridge is a thick succession of dolomites with numerous zones of quartz sandstone, chert, siliceous shale, and argillaceous limestone (Fig. 3). Where accurate measurements can be made the formation is about 1,250 feet thick. The Copper Ridge at Wittens Mills is 1,289 feet thick; south of State Highway 42 near Redoak School, 1,177 feet thick; and north of Shawver Mill, 1,080 feet thick. About 600 feet of the formation is exposed in the Thompson Valley belt. Parts of the formation are well exposed along State Highway 61 and U. S. Route 19, but there are no continuously exposed sections of the Copper Ridge in the entire quadrangle.

Dolomites of the formation are even bedded in layers 6 to 12 inches thick. Several color and textural varieties are distinguishable. The most abundant type is medium grained, compact, light-gray, and laminated with thin streaks of siltstone and sand. On weathered surfaces the crinkled laminae of silt project as wavy ridges. Almost equally abundant are dark-gray, fine-grained dense dolomites. Many beds of this type contain partings of blocky chert and dolomitic, siliceous shale. Another variety of dolomite is very light-gray with pinkish streaks and mottlings and is coarse grained. Many of these beds are clastic dolomites. Isolated sand grains and sandy streaks occur in all the dolomites, particularly the coarse-grained beds.

Oolitic beds, both dolomitic limestones and cherts, are intercalated in the dolomites but are not as prominent as the oolitic beds of the overlying Beekmantown. Most of the oolites have nuclei of sand grains.

Quartz sandstones comprise the most distinctive type of rock in the Copper Ridge. They are not common in any other dolomite formation in the quadrangle. Most of the sandstones are coarse grained, saccharoidal, and weather a bright rusty-brown. The sand grains are 0.1 to 2 mm. in diameter with grains 0.2 to 0.5 mm. forming the major grade. Most of the exposures of Copper Ridge sandstones are deeply weathered and the rocks are considerably disintegrated. In a few road cuts where the rock is relatively fresh, the beds are firm and compact and are cemented with calcite and dolomite. Many of the sandstones are ripple marked. In the northern belts, in Clear Fork Valley, Bluestone Valley, and Thompson Valley, most of the sandstones occur in the upper 600 feet of the formation. Some of the zones are more than 40 feet thick. One sandstone zone is well exposed along U. S. Route 19 southwest of Ebenezer Church. West of Wittens Mills a prominent 15-foot zone of sandstone occurs about 150 feet above the Nolichucky. Along the Norfolk and Western Railway south of Wittens Mills station several thin sandstones occur high in the Copper Ridge. None of the sandstones seem to persist more than a few miles along the strike. One of the best displays of Copper Ridge sandstones is along State Highway 61 beginning about 1 mile east of Shawver Mill and extending northeastward a quarter of a mile beyond Perry Branch. In Thompson Valley a sandstone zone 20 to 45 feet thick is exposed 0.6 of a mile southwest of Thompson School and 100 yards north of the intersection of Roads 602 and 604. Another good exposure is along Road 602 about 1 mile southwest of Thompson School. The thickest and most persistent sandstone occurs in the Copper Ridge belts southeast of Brushy Mountain. This zone forms the base of the formation. Near Sharon Springs it is 60 to 75 feet thick and makes a low ridge extending southwest along State Highway 42 beyond the southern limits of the quadrangle. Exposures along Page Branch show the zone to be 75 feet thick. A sandstone near the top of the Copper Ridge is well exposed in the vicinity of Redoak School. It can be followed along the south side of Foglesong Valley to Bucks Branch at the southern border of the quadrangle. In northern belts, particularly, Copper Ridge sandstones carry pyrolusite and psilomelane, as well as iron oxides. Only the thicker sandstones are topographically conspicuous.

Chert beds are rather common in the Copper Ridge but are not as abundant as they are in the overlying Beekmantown. Much of the chert is banded black and white, and some of it is oolitic. A characteristic of these cherts is that they break into small pieces 1 to 4 inches in diameter. Chert fragments litter the areas underlain by the formation, particularly in outcrops on the northwest sides of hills. Masses of brecciated chert, containing manganese oxides, occur along a branch of the St. Clair overthrust east of Road 656. Locally in Lynn Hollow northeast of Wittens Mills, the Copper Ridge is exceedingly cherty and unusually large masses of chert litter the surface. Most of these blocks show algal structures.

Limestones are not prominent in the Copper Ridge. All of those seen in the northern belts are notably dolomitic, but in Foglesong Valley beds of relatively pure limestone occur in the uppermost 250 feet of the formation. No fossils were seen in these beds.

Mud cracks cover the bedding surfaces of many of the finer-grained dolomites. A fine display of them is seen along State Highway 61 southwest of Perry Branch (Pl. 3B). Larger mud cracks in argillaceous dolomite are exposed along the northwest slope of a low ridge north of U. S. Route 19 between Wittens Mills and Divide Church.

Along the roadside half a mile northeast of the mouth of Cove Creek is a remarkable display of current-ripple marks in the Copper Ridge (Pl. 3A). The ripples have an amplitude of about 2 inches and a length of about 8 inches. They occur on a bedding surface which dips toward the road at an angle of about 55 degrees. Ripple marks of smaller size and less well preserved are common in the Copper Ridge in the Burkes Garden quadrangle. The clastic textures of the dolomites and the abundance of current markings indicate a turbulent, shallow-water environment of deposition. Since few, if any, organisms secrete dolomite in large quantities, the dolomite rhombs may have crystallized directly from sea water. Prior to final deposition, the accumulating dolomite grains were swept about and abraded by marine currents.

Fossils.—The only fossil found in any abundance in the Copper Ridge is *Cryptozoon.* Excellent specimens can be collected along the roadside in Lynn Hollow. Smaller but otherwise similar *Cryptozoon* were found along the southeast side of Big Ridge about one and a quarter miles southeast of Ceres.

Age and correlation.—The Copper Ridge is Upper Cambrian and probably equivalent to all or nearly all of the Franconia-Trempealeau-Jordan succession of the type St. Croixan. In the vicinity of Natural Bridge, Virginia, and also in the northern part of the State near Winchester, the limy facies of the Copper Ridge contains *Tellerina* trilobites such as occur in the Lodi shale of the Upper Mississippi Valley. Southwest of the Burkes Garden quadrangle, the Copper Ridge contains fossils present also in the St. Lawrence dolomite of Wisconsin. The postulated late Cambrian age of the Copper Ridge of the Burkes Garden area is based partly upon observable continuity of the beds with the *Tellerina* and *Scaevogyra* zones to the northeast and southwest, respectively, and also upon its stratigraphic position. Butts[28] has established

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[28] Butts, Charles, Geologic map of the Appalachian Valley of Virginia with explanatory text: Virginia Geol. Survey Bull. 42, p. 9, 1933.

the fact that the Copper Ridge and Conococheague are facies equivalents. A part of the Copper Ridge is equivalent to the upper part of the Conasauga formation of Alabama.

Stratigraphic relations.—In Alabama a considerable thickness of dolomite, comprising the Brierfield, Ketona, and Bibb formations, overlies equivalents of the Nolichucky shale and underlies the Copper Ridge. Since it is not yet known whether the Copper Ridge of Virginia includes representatives of the Brierfield-Ketona-Bibb succession, the presence of an unconformity between the Copper Ridge and Nolichucky has not been definitely established. No physical evidences of an unconformity were noted.

The stratigraphic relations of the Copper Ridge to the overlying Beekmantown are likewise obscure. Sandstone beds, believed to be characteristic of the Copper Ridge, occur directly beneath *Lecanospira*-bearing limestones which are characteristic of the middle division of the Beekmantown in the Appalachian region. About 25 miles southwest of the Burkes Garden area, at Marion, Smyth County, Virginia, about 300 feet of Chepultepec limestone (lower Beekmantown) intervenes between the Conococheague (Copper Ridge equivalent) and the *Lecanospira* beds of the Beekmantown. The Chepultepec carries a distinctive fauna of primitive cephalopods. Neither the limestone zone nor any of its contained fossils have been identified in the Burkes Garden quadrangle between the Copper Ridge and middle Beekmantown strata. This may indicate the absence of the Chepultepec; on the other hand it is possible that the Chepultepec is represented by unfossiliferous dolomites and sandstones in the upper part of the Copper Ridge.

ORDOVICIAN SYSTEM

CANADIAN SERIES

BEEKMANTOWN FORMATION

Name.—The Beekmantown, named by Clarke and Schuchert,[29] is now used as the name of a group which includes all the Ordovician formations below the Chazy of New York State. The most nearly complete section of the Beekmantown formation in the Appalachian region is in central Pennsylvania. Four subdivisions are recognized: the Stonehenge limestone, Nittany dolomite, Axe-

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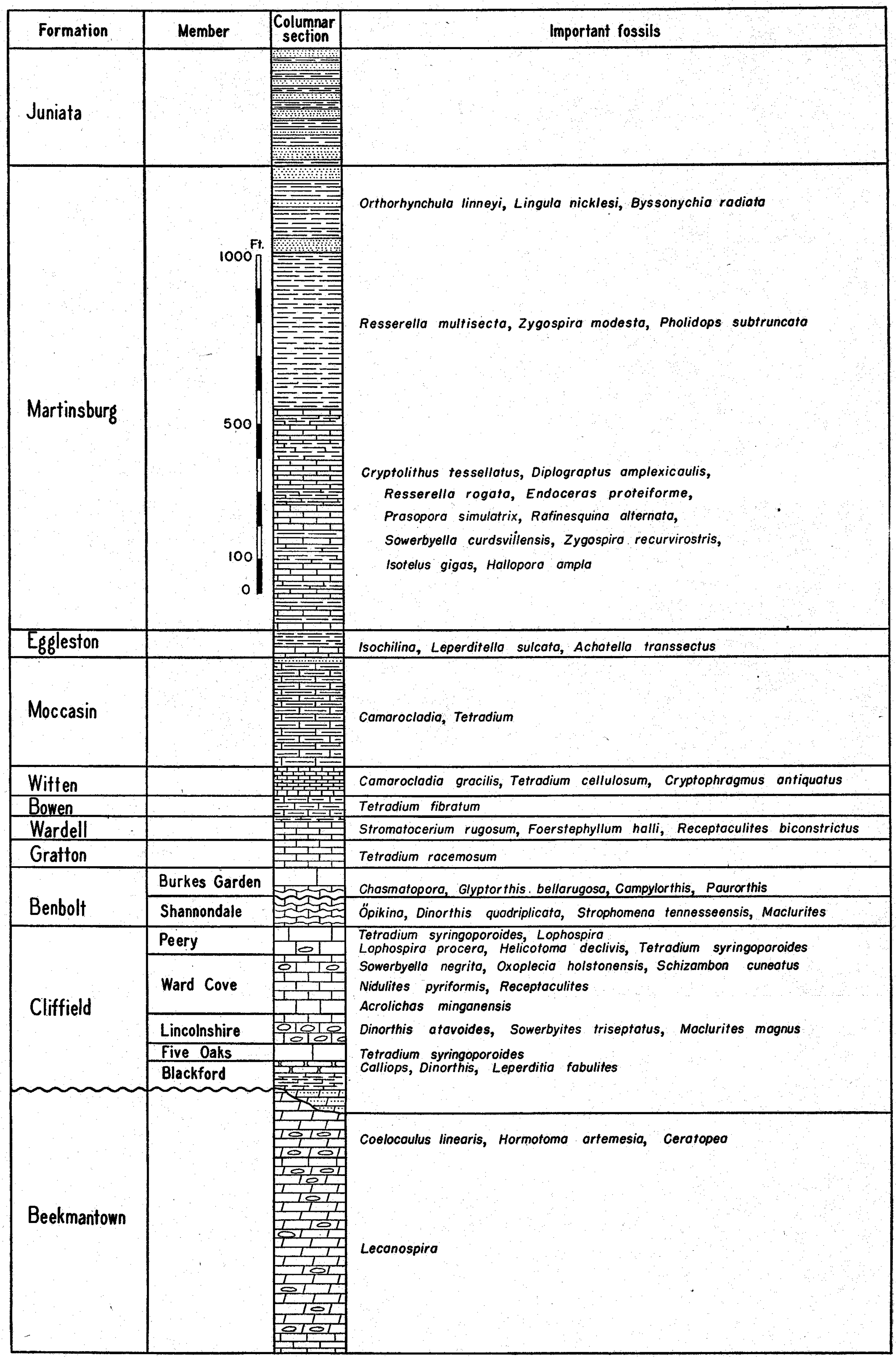
[29] Clarke, J. M., and Schuchert, Charles, The nomenclature of the New York series of geological formations: Science, new ser., vol. 10, pp. 874-878, 1899.

mann limestone, and Bellefonte dolomite. Equivalents of all except the Axemann are found in the Appalachian Valley of Virginia.

In the Burkes Garden area equivalents of the Nittany and Bellefonte are present, but the Stonehenge or its equivalent, the Chepultepec, does not appear to be present. Both the Bellefonte and Nittany are cherty and dolomitic, but their faunas are very distinctive. Most of the fossils found in the Beekmantown beds are in blocks of loose chert and can not be used to distinguish the Bellefonte and Nittany in the field.

Distribution.—Beekmantown beds are exposed in 7 belts in the Burkes Garden quadrangle (Pl. 1). The northernmost belt lies between branches of the St. Clair overthrust. Another belt begins south of St. Clair School and extends west paralleling U. S. Route 19. Southwest of the divide between Clinch and Bluestone rivers, the belt crosses the highway and continues along the northwest side of Clinch Valley. Good exposures of the Beekmantown can be seen along U. S. Route 19 west of Divide Church and also south of Shannondale. Most of the Beekmantown is exposed along Lincolnshire Branch north of the roadside quarry. Another belt of Beekmantown is well exposed along State Highway 61 near Marys Chapel. In this vicinity, the formation forms the core of a broad anticline, but northeast of Gratton the belt becomes homoclinal. Beekmantown belts occur on either side of Thompson Valley and converge about 1 mile northeast of Thompson School. The upper part of the Beekmantown crops out in an anticlinal belt on the southeast side of Burkes Garden. Very few beds are exposed in this belt, but southeast of Blue Spring the Bellefonte division crops out along a tributary of Blue Spring Creek. Not more than 300 feet of the formation crops out in Burkes Garden, and probably most of the exposed beds are referable to the Bellefonte division. Another belt lies between the branches of the Saltville-Bland overthrust. A few good exposures are present along the road leading north from Ceres. The southernmost belt extends along the northwest base of Walker Mountain.

Lithology.—The Nittany is predominantly dolomite but contains zones of rather pure limestone (Pls. 5, 8). Two principal types of dolomite are recognized. One is fine grained, dense, even bedded, and pearly-gray. These beds are argillaceous and silty; weathered surfaces are rusty-brown. The most distinctive feature of the dolo-



Formation	Member	Columnar section	Important fossils
Juniata			
Martinsburg			*Orthorhynchula linneyi, Lingula nicklesi, Byssonychia radiata* *Resserella multisecta, Zygospira modesta, Pholidops subtruncata* *Cryptolithus tessellatus, Diplograptus amplexicaulis, Resserella rogata, Endoceras proteiforme, Prasopora simulatrix, Rafinesquina alternata, Sowerbyella curdsvillensis, Zygospira recurvirostris, Isotelus gigas, Hallopora ampla*
Eggleston			*Isochilina, Leperditella sulcata, Achatella transsectus*
Moccasin			*Camarocladia, Tetradium*
Witten			*Camarocladia gracilis, Tetradium cellulosum, Cryptophragmus antiquatus*
Bowen			*Tetradium fibratum*
Wardell			*Stromatocerium rugosum, Foerstephyllum halli, Receptaculites biconstrictus*
Gratton			*Tetradium racemosum*
Benbolt	Burkes Garden		*Chasmatopora, Glyptorthis bellarugosa, Campylorthis, Paurorthis*
	Shannondale		*Öpikina, Dinorthis quadriplicata, Strophomena tennesseensis, Maclurites*
Cliffield	Peery		*Tetradium syringoporoides, Lophospira* *Lophospira procera, Helicotoma declivis, Tetradium syringoporoides*
	Ward Cove		*Sowerbyella negrita, Oxoplecia holstonensis, Schizambon cuneatus* *Nidulites pyriformis, Receptaculites* *Acrolichas minganensis*
	Lincolnshire		*Dinorthis atavoides, Sowerbyites triseptatus, Maclurites magnus*
	Five Oaks		*Tetradium syringoporoides*
	Blackford		*Calliops, Dinorthis, Leperditia fabulites*
Beekmantown			*Coelocaulus linearis, Hormotoma artemesia, Ceratopea* *Leconospira*

Columnar section of the Ordovician formations northwest of Clinch Mountain, in the Burkes Garden quadrangle, Virginia.

mites is the furrowed, welted surfaces developed by weathering (Pl. 3C). During folding the brittle dolomites were closely fractured. Later these cracks were welded by secondary dolomite and calcite. Bedding surfaces of the fine-grained dolomites are very even and regular.

Floating sand grains and thin stringers of sand are found in some of the higher beds of the Beekmantown, but none of the stringers is thick enough to be confused with sandstone beds of the Copper Ridge formation.

Fine-grained, pearly-gray dolomites comprise about 65 per cent of the total thickness of the Beekmantown in this quadrangle. Most of them are in the lower and upper parts of the formation.

The other variety of Beekmantown dolomite is unevenly bedded, light-gray, and coarsely granular. These beds weather saccharoidal and show distinct clastic textures. Some are cross laminated and ripple marked. Coarse-grained dolomites comprise about 25 per cent of the Beekmantown and occur at several different horizons. Good exposures of clastic dolomites can be seen along State Highway 61 near Shawver Mill and in Bluestone Valley south of Shannondale.

Distinctive limestones also occur in the Beekmantown. Light bluish-gray, thick-bedded calcilutytes[30] are especially common. Thin intersecting stringers of siliceous and argillaceous material form a characteristic fretwork on weathered surfaces. Some of the limestones are mottled with pink and green, whereas others are edgewise conglomerates of variable color. Nearly all of the limestones contain distinctive, planispirally coiled gastropods. This type of limestone forms the basal member of the Beekmantown south of Pulaski, Virginia[31], where it is known as the Oglesby member. The Oglesby facies of the Beekmantown is particularly well developed along State Highway 61 between Gratton and Benbolt. In this area about 50 feet of opalescent-gray calcilutyte occurs about 150 to 200 feet below the top of the Beekmantown. The zone is fully exposed in an old quarry a quarter of a mile southwest of Gratton and about 800 feet west of the Gratton-Burkes Garden road. West of Marys Chapel the zone is about 55 feet thick but thins westward to less than 30 feet toward Benbolt. Reddish and greenish mottled beds occur near the top of the Beekmantown half

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[30] Calcilutyte is a cryptocrystalline, very compact variety of limestone resulting from the accumulation of "lime" mud.

[31] Cooper, B. N., Geology of the Draper Mountain area, Virginia: Virginia Geol. Survey Bull. 55, pp. 17-19, 1939.

a mile west of Kinzer Church and also along Clear Fork near Shawver Mill. In Thompson Valley 20 to 100 feet of the Oglesby type of limestone forms the base of the Beekmantown and lies directly above Copper Ridge sandstone beds. This zone is best developed beyond the western border of the quadrangle, but a feather edge of the zone extends as far northeast as Thompson School. On the northwest side of the valley zones of limestone are intercalated in fine-grained dolomites of the lower 300 feet of the Beekmantown, but none of the zones is more than 10 feet thick. Few limestones were noted in the Beekmantown exposed in Burkes Garden. In the belt exposed along the southeast side of Foglesong Valley thin zones of calcilutyte occur near the base of the Beekmantown. At least 75 feet of limestone containing Nittany fossils is exposed at the base of the Beekmantown one and a quarter miles east-southeast of Ceres. This is the horizon at which the Chepultepec should occur, but that formation appears to be absent. At the eastern border of the quadrangle south of Effna, reddish and greenish limestones occur near the base of the Beekmantown. Limestone beds near the top of the Beekmantown are well exposed along the road half a mile north of Ceres. None of the Beekmantown limestones, except those near the base of the formation, are persistent.

Chert is especially abundant in the Beekmantown, but little is seen in fresh exposures. Most of it occurs in large, irregular blocks or "cauliflower-shaped" masses in the surface mantle. Weathered blocks are commonly dolocastic and porous. Apparently the chert has been formed by the silicification of a coarse-grained carbonate rock. In some pieces, the original rhombic shape of the grains is still apparent although the carbonate has been replaced by silica. Relatively fresh pieces of chert are dense. Microscopic examination of compact cherts from the Beekmantown invariably discloses a relatively large percentage of the mass to be composed of isolated dolomite rhombs. Another variety of Beekmantown chert occurs in the form of porous, highly dolocastic, "worm-eaten" masses which are rusty brown on weathered surfaces and white where fresh. This type of chert is very fossiliferous, but the fossils are different from those found in the "cauliflower" chert. The "worm-eaten" chert comes from beds in the uppermost 250 feet of the Beekmantown where that formation has a total thickness of more than 750 feet. "Worm-eaten" chert is found north of the stone quarry at Five Oaks, along the southeast slope of the low ridge south of State Highway 61 between Gratton and Marys Chapel, and in chert piles atop the hills north of the Tazewell County Farm. It is also found along the crest and north slopes of Banks Ridge in Burkes Garden.

In the belts of Beekmantown north of Burkes Garden, the lower 200 to 300 feet of Beekmantown contains thin beds of oolitic chert which is apparently of primary origin. The chert oolites are about 1 mm. in diameter and almost round. Commonly the oolite beds break into rectangular blocks about the size of bricks, and a few pieces generally can be found in every pile of Beekmantown chert. Oolitic cherts are especially abundant along the west bank of the first creek east of Cox Branch and a third of a mile north of State Highway 61.

In Foglesong Valley beds of sparsely oolitic chert near the top of the Beekmantown contain an abundance of floating sand grains. Some of the sand grains are nuclei of large oolites which are 2 to 4 mm. in diameter. The smaller oolites are hollow. Probably these had nuclei of carbonate, which have been subsequently dissolved. Zones of hollow oolites are practically confined to the topmost 100 feet of the Beekmantown in areas where the total thickness of the formation exceeds 750 feet.

Variations in thickness.—The maximum thickness of the Beekmantown is about 1,000 feet. Prior to deposition of the next overlying formation, the Beekmantown was subjected to erosion, and in one place as much as 400 feet of beds has been removed. In the Clinch-Bluestone belt the thickness of the Beekmantown ranges from 787 feet at Wittens Mill to 760 feet south of U. S. Route 19 at Shannondale. In the belt between Buckhorn and Rich mountains, the formation is somewhat thinner. The maximum thickness measured near Cove Creek School is about 885 feet. At Kinzer Church the formation is only 565 feet thick. In Thompson Valley the thickness of the Beekmantown does not seem to vary more than 100 feet, and an average of about 900 feet is present. The total thickness of the formation in Burkes Garden can not be ascertained because the base of the formation is not exposed. Local irregularities at the top of the Beekmantown have a maximum relief of about 75 feet. Variations in thickness of the Beekmantown in belts south of the Saltville-Bland fault are more prominent than in any of the northern belts. North of Ceres along Soap Creek, a thickness of 490 feet was measured, but one-fourth of a mile northeast of that place the Beekmantown is 910 feet thick. The striking change in thickness takes place within a distance of 175 feet along the strike of the beds. South of Redoak School, two erosional trenches are evident at the top of the Beekmantown. One is about 100 feet and the other about 175 feet deep. The two trenches are filled with limestones of the next overlying formation, and were made presumably during the post-Beekmantown, pre-Chazy erosional interval.

Fossils.—Two distinct faunas (Pls. 5, 8) occur in the Beekmantown where that formation has its maximum development. The lower fauna occurs in limestone intercalations and in chert masses belonging to the lower 700 to 750 feet of the formation. The upper is identifiable only where the Beekmantown is relatively thick and is confined to the uppermost 50 to 250 feet of the formation. *Lecanospira* is most abuntant and characteristic in the lower fauna. Several species of this genus, including *L. compacta* (Salter), *L. conferta* Ulrich and Butts, and *L. sigmoidea* Ulrich and Bridge are equally abundant in the limestone beds. *L. biconcava* Ulrich and Bridge is common in the weathered cherts. Associates of *Lecanospira* are *Roubidouxia umbilicata* Ulrich and Bridge, *Cameroceras* sp., and fragments of the trilobite *Petegurus*. The "worm-eaten" cherts contain *Ceratopea, Ophileta solida* Butts, *Coelocaulus linearis* Billings, *Hormotoma artemesia* (Billings), *Bathyurus* sp., a large coiled nautiloid similar to *Campbelloceras* sp., and *Eurystomites* cf. *E. kellogi* (Whitfield). *Orospira bigranosa* (Shumard) and *Ceratopea* are the two fossils most commonly found in the uppermost beds of the Beekmantown. No Bellefonte fossils were found in places where the total thickness of the Beekmantown is less than 700 feet. Presumably, all of the Bellefonte beds were eroded locally soon after Beekmantown time.

Age and correlation.—The Beekmantown of the Burkes Garden quadrangle does not contain equivalents of all of the Beekmantown divisions recognized in Pennsylvania. The Tribes Hill, or Stonehenge, which forms the base of the Beekmantown group in northern Virginia, Maryland, Pennsylvania, and New York, is absent. Where the Beekmantown is less than 700 feet thick, the entire succession contains the *Lecanospira* fauna of the Nittany. Where greater thicknesses are present, the upper part of the Beekmantown invariably carries the Bellefonte fauna. This part is equivalent to the Fort Cassin beds of New York. The Beekmantown of the Burkes Garden quadrangle corresponds to the Longview and Newala formations of Alabama.

MAJOR DISCONFORMITY

By far the most conspicuous stratigraphic break in the Paleozoic rocks exposed in the Burkes Garden quadrangle occurs at the top of the Beekmantown formation. Local irregularities of the upper contact, produced by erosion, cause the thickness of the formation to vary as much as 400 feet. The local absence of the *Ceratopea* beds in many places along each of the seven belts of the formation is another indication of post-Beekmantown erosion. Immediately overlying the erosional surface at the top of the Beekmantown are coarse, chert breccias and dolomite conglomerates composed of fragments derived from the Beekmantown.

At several places where the upper Beekmantown contact is well exposed, striking irregularities of the old erosion surface are apparent. Along the southeast slopes of Buckhorn Mountain about half a mile north of Marys Chapel, a tongue of Beekmantown about 200 feet long and 100 feet thick projects into the overlying limestones of the Cliffield formation. This projection represents an overhanging ledge of dolomite which was subsequently covered by the seas of Cliffield time. Since its burial, the overhanging ledge of dolomite, together with the associated breccias, conglomerates, and limestones of the Cliffield formation have been turned up on end and erosion has worn away all but the originally overhanging part. Since about 50 feet of the Cliffield underlies the overhanging tongue of dolomite the top of the ledge must have stood about 150 feet above the base of the cliff.

Along Road 625 north of Ceres, the Beekmantown is only 490 feet thick and *Lecanospira*-bearing limestones occur almost at the top of the formation. About a quarter of a mile northeast of this locality the thickness of the Beekmantown suddenly increases to 910 feet. These variations in thickness (Pl. 1) suggest that a deep, steep-sided erosional trench was cut into the Beekmantown prior to the deposition of the overlying formation.

South of Redoak School along Road 622 two rather striking erosional irregularities at the top of the formation are evident (Pl. 1). From the bottom of the western trench to its east rim, the upper Beekmantown contact rises stratigraphically 165 feet in a horizontal distance of 450 feet. The same approximate relief was measured in the eastern trench.

The time break involved in the formation of this erosional surface is apparently much shorter than might be inferred from the deep dissection which took place. The Beekmantown sea evidently did not retreat until after the Bellefonte was deposited. In Missouri the Bellefonte equivalent, the Cotter formation, is overlain by the Powell, Smithville, and Black Rock formations of late Canadian age. None of these formations, except possibly the Powell, is present in the Appalachian region. The post-Beekmantown unconformity involves, therefore, at least the time required to deposit the three post-Bellefonte formations of the Beekmantown found in Missouri. The beds which cover the erosional surface at the top of the Beekmantown in the Burkes Garden quadrangle are probably Chazy. It appears that the seas withdrew from this area during late Beekmantown time and advanced again during Chazy time.

MIDDLE ORDOVICIAN SERIES

GENERAL STATEMENT

Detailed study of the lower Middle Ordovician limestones of Tazewell County, Virginia, shows that the conventional classification of these beds is incorrect. According to Butts[32], the succession of formations above the Beekmantown and below the Trenton in southwestern Virginia is as follows:

- Black River group
  - Eggleston limestone
  - Lowville-Moccasin limestone
- Blount group
  - Ottosee limestone
  - *Hiatus;* Tellico sandstone absent
  - Athens shale (absent northwest of Clinch Mountain)
  - Whitesburg limestone (absent northwest of Clinch Mountain)
  - Holston limestone
- Stones River group
  - Lenoir limestone
  - Mosheim limestone
  - Murfreesboro limestone

The conventional classification of the Ordovician limestones not only in Tazewell County but elsewhere in the Appalachian Valley needs to be reexamined and evaluated in the light of the facts recently pre-

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[32] Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. 1, pp. 119-201, 1943.

sented by Cooper and Prouty[33]. These facts, therefore, are summarized as follows:

(1) The names, Mosheim, Lenoir, Holston, and Ottosee have been used in Virginia despite the fact that none of them was ever well defined or described in its type locality.

(2) None of the four names has been consistently applied to any one succession of beds in Tazewell County.

(3) The name Murfreesboro has been applied in Tazewell County to beds which do not contain the fauna of the type Murfreesboro. Use of that name has been extended into Virginia despite the fact that the base of the type Murfreesboro has not been seen.

(4) The superposition of the Mosheim with respect to the Murfreesboro, as postulated by Ulrich and Butts, is based upon their study of the section along Yellow Branch, Lee County, Virginia. At this locality, two zones of Mosheim-type limestone occur. One overlies beds containing *Polylopia billingsi,* a supposedly Murfreesboro guide fossil; the other occurs beneath the Murfreesboro fauna. Butts has not indicated reasons for identifying the upper zone of Mosheim-type limestone as the Mosheim, rather than the lithologically identical zone below the Murfreesboro fauna.

(5) In Tazewell County, particularly in exposures half a mile west of Wittens Mills, two zones of Mosheim-type limestone occur in a succession remarkably like that exposed along Yellow Branch, Lee County, Virginia. The higher zone of Mosheim-type limestone overlies the Murfreesboro fauna and is classed with the Ottosee formation by Butts. The lower zone of Mosheim-type limestone is identified by him as the Mosheim. Careful tracing of the upper zone northeast to St. Clair, near Bluefield, Virginia, shows that it is the same unit identified by Butts as the Mosheim[34].

(6) Nodular limestones, exposed along U. S. Route 19 and Little Indian Creek and described by Butts as "characteristic of the Ottosee,"[35] have been traced northeast toward Tazewell where they overlie limestones containing *Tetradium cellulosum* and *T. racemosum.* According to Butts[36] both these fossils are valid guides to the Lowville.

(7) Inconsistent identifications of the Mosheim and Lowville have resulted in inconsistent identifications of the Murfreesboro, Lenoir, Holston, and Ottosee.

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

[34] Butts, Charles, op. cit., p. 128.

[35] Idem., Pl. 33-A.

[36] Idem., p. 189.

(8) Butts' Moccasin of Tazewell County is not the same as the type Moccasin of Campbell, near Gate City, Scott County, Virginia[37].

New formation and member names have been given to beds formerly classified under the Murfreesboro, Mosheim, Lenoir, Holston, Ottosee, and Lowville. The character, fauna, and variation of the new units have been recently described by the writer and C. E. Prouty[38].

CLIFFIELD FORMATION[39]

Name.—The Cliffield formation comprises a succession of basal clastics and limestones which are well exposed in Tazewell County, Virginia, and in neighboring areas northwest of Clinch Mountain[40]. The name is taken from Cliffield Station on the Norfolk and Western Railway, about 8 miles southwest of North Tazewell. The type section of the formation is along Pounding Mill Branch and adjacent highways near Pounding Mill, Tazewell County, Virginia (Pl. 1). In many places in the county the Cliffield is divisible into several distinct members, but in other localities the major part of the formation can not be subdivided because of the faunal and lithologic similarity of the beds. In the Burkes Garden quadrangle, only two localities have been found where the Cliffield can not be subdivided into members.

BLACKFORD MEMBER

Name.—Butts[41] proposed the name "Blackford facies" of the Murfreesboro formation for the red beds, chert conglomerates, gray shales, and chert beds, which overlie the Beekmantown formation at Blackford, Russell County, Virginia. The assignment of these beds to the Murfreesboro is incorrect, according to the writer's interpretation[42]. The name Blackford member has been retained as the name of the lowest member of the Cliffield formation and as thus used applies to exactly the same succession mentioned by Butts. However, he thought that this succession was equivalent to part of the Middle Ordovician limestone succession. Butts' Blackford facies is not equivalent to any other facies or succession in southwestern Virginia but constitutes a distinct member.

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[37] Cooper, B. N., Moccasin formation in southwestern Virginia (abstract): Geol. Soc. America Bull., vol. 53, pp. 1799-1800, 1942.

[38] Cooper, B. N., and Prouty, C. E., op. cit., pp. 861-886.

[39] The rocks described under this heading occur only in belts northwest of Clinch Mountain and the southern rim of Burkes Garden (Pls. 1 and 5). Equivalent beds in the valley between Brushy and Walker mountains are described under the heading Cliffield group (Pls. 1 and 6).

[40] Cooper, B. N., and Prouty, C. E., op. cit., pp. 862-868.

[41] Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. 1, pp. 126-127.

[42] Cooper, B. N., and Prouty, C. E., op. cit., pp. 862-863.

Lithology.—The lowest zone of the Blackford member is composed of chert breccias and dolomite-pebble conglomerates (Pl. 4A). The chert fragments, generally less than 2 inches in diameter, are enclosed in a matrix of maroon-drab silty dolomite. In a few local areas beds of pearly-gray to greenish-gray dolomite, similar to beds in the underlying Beekmantown, are intercalated in the breccias and conglomerates. Northwest of Brushy Mountain the coarse clastics at the base of the Cliffield are overlain by silty dolomites and dolomitic mudrocks, which range from dark-maroon to hyacinth-gray. Some of the layers are mottled red and green. Some of the mottlings are chemically reduced zones surrounding organic nuclei but others are clearly fragments of dolomite or plastic dolomitic sediment which was reworked. The red beds of the Blackford member, together with the chert breccias and dolomite conglomerates, form the initial deposit laid down on the post-Beekmantown erosion surface and fill only the "lows" on that erosion surface. The basal clastics have their thickest development in the Clinch-Bluestone belt. At Five Oaks (Pl. 21B), the zone is 78 feet thick, and in Clear Fork Valley half a mile southeast of Mt. Olivet Church at Gratton the thickness is approximately the same. In the northwestern part of Thompson Valley 25 to 70 feet of red beds and coarse clastics were measured. Only one exposure of basal clastics occurs in Burkes Garden, namely, at the east end of Banks Ridge. The thickness measured there was about 60 feet.

Geologic Section 3.—Basal clastics of the Blackford member at Five Oaks, Tazewell County, Virginia

	Thickness	
	Ft.	In.
Basal clastics zone (78½ feet)		
11. Mudrock, reddish-brown, silty	1	7
10. Mudrock, pale-green and purplish blotched, very silty	14	2
9. Dolomite, granular, maroon-drab, with greenish-gray blotches	1	6
8. Mudrock, soft, mealy, brick-red	3	8
7. Dolomite conglomerate, maroon-drab matrix surrounding pebbles of grenish-gray crystalline dolomite	2	3
6. Dolomite, maroon-drab, silty, with small angular inclusions of white chert	11	7

	Thickness Ft.	Thickness In.
5. Siltstone, brick-red, dolomitic, with pale-green blotches; contains a few pebbles of greenish-gray dolomite and white chert	2	3
4. Mudrock, reddish-brown, very silty	5	6
3. Dolomite, light-brown in lower part and brick-red in upper part. Contains isolated pebbles of light-gray granular dolomite	4	10
2. Chert breccia, matrix of light pinkish-gray dolomite. Chert fragments are very angular and less than 2 inches in diameter. Weathers rusty-brown	28	5
1. Conglomerate, matrix of light-gray dolomite, pebbles of dolomite and dolocastic chert up to 4 inches in diameter	2	10

Geologic Section 4.—Basal clastics of the Blackford member near Mt. Olivet Church, Gratton, Tazewell County, Virginia

	Thickness Ft.	Thickness In.
Basal clastics zone (83 feet)		
6. Mudrock, maroon-drab, dolomitic	8	0
5. Dolomite, slightly conglomeratic, coarse grained, purplish-red, medium bedded	13	6
4. Mudrock, maroon-drab, silty, dolomitic with large irregular greenish-gray spots	28	4
3. Breccia, angular fragments of chert in light-brown dolomite matrix	8	2
2. Dolomite conglomerate, brick-red matrix surrounds pebbles of light-gray dolomite	11	6
1. Chert conglomerate, matrix of red dolomite and angular pebbles of white chert	13	4

The red beds of the Blackford member are overlain by a distinctive zone of platy mealy calcareous shales which weather ash-gray. These shales contain a small amount of dolomite in the form of isolated euhedral rhombs. Silt-sized particles comprise about 15 per cent of the rock and together with the dolomite rhombs cause the mealy character of the shales. In parts of Burkes Garden and Thompson Valley the shales contain small flattened pellets of calcium phosphate 1 to 2 mm. in diameter. Interbedded in the shales are thin beds of light-gray argillaceous limestone, and near the top a few intercalations of nodular black chert are generally present. This zone forms a continuous deposit which is well exposed along all the Ordovician limestone belts in the quadrangle. The thickest section of ash-gray shale is found where the underlying basal clastics are thickest. The average thickness of the zone is 30 feet, but locally 75 feet is present. The ash-gray shales are well exposed along State Highway 78 in Burkes Garden about 1 mile southeast of Central Church (Pl. 4B). The uppermost beds and transitional contacts with overlying limestones are fully exposed along State Highway 61, 2½ miles northeast of Gratton. A thin development of the zone is exposed just north of the roadside quarry along Lincolnshire Branch west of Five Oaks. In this locality red beds are apparently absent and the ash-gray shale directly overlies Beekmantown dolomites.

The third and uppermost zone of the Blackford member is composed of dark-gray to black chert which bleaches white on weathering (Pl. 4C). The chert is bedded and breaks into rectangular blocks. Where fresh it is dense, but weathering leaches numerous included carbonates and produces a porous texture. Light-gray, thin-bedded calcilutyte composes about 60 per cent of the total thickness of this zone but is almost never seen except in fresh exposures. The best exposure of the blocky chert zone is along State Highway 78 about 1 mile southeast of Central Church. Another good exposure is at the north end of the limestone quarry at Five Oaks.

Fossils.—A few detrital fossils occur in the basal layers of chert breccia, but all are Beekmantown species. Practically all of the fossils in the Blackford member are found in the blocky cherts. The forms collected from this zone include a large *Dinorthis* closely akin to *D. atavoides, Dinorthis holdeni* (Willard), *Leperditia fabulites* (Conrad), *Leperditella* sp., *Ophiletina* sp., and *Calliops* sp. All of these fossils are abundant along the roadside a mile southeast of Central Church.

FIVE OAKS LIMESTONE MEMBER

Name.—The Five Oaks limestone member of the Cliffield formation was named by the writer and C. E. Prouty[43] from exposures in the limestone quarry at Five Oaks.

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[43] Cooper, B. N., and Prouty, C. E., op. cit., p. 863.

Lithology.—Medium- to thick-bedded calcilutytes compose the greater part of the Five Oaks member (Pls. 4D, 21C). The beds are dark dove-gray, but weathered surfaces are characteristically lighter gray. These limestones contain insets of euhedral rhombs of calcite 0.5 to 4 mm. in diameter, which give the rock a spangled appearance. Stylolites[44] mark many of the bedding planes. The limestones break with a distinctive conchoidal fracture like that of many so-called lithographic limestones. Kindle's term vaughanite[45] has been applied to this type of limestone by Butts. Because of prior usage, calcilutyte is the preferable term. The average thickness of the Five Oaks limestone member is about 25 feet. It is very persistent throughout several belts in the Burkes Garden quadrangle. In Burkes Garden the only good exposure of the member is along Snyder Branch 1½ miles northeast of Central Church. About half a mile west of Marys Chapel the Five Oaks limestone is 75 feet thick, and in the lime quarry at Five Oaks it is 50 feet thick. In the roadside quarry on Lincolnshire Branch about 30 feet of calcilutyte represents the Five Oaks. This thickness is the average development of the member noted in other localities in the Burkes Garden quadrangle.

Fossils.—The following fossils have been collected and identified from the Five Oaks member:

- Corals
  - Tetradium syringoporoides Ulrich
- Gastropods
  - Ecculiomphalus cf. E. continguus Ulrich
  - Hormotoma sp.
  - Lophospira (several species)
  - Trochonema sp.
- Ostracodes
  - Leperditia fabulites (Conrad)
- Trilobite fragments
  - Homotelus sp.

Most of the specimens of *Tetradium* are replaced by secondary calcite. These show on weathered surfaces as "birdseyes" and contribute to the distinctive lithology of this type of limestone.

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[44] Stylolites are irregular, fluted sutures or seams developed parallel or nearly so to bedding. They are common in limestones, and are believed to have been formed by differential pressure and solution.

[45] Kindle, E. M., Nomenclature and generic relations of certain calcareous rocks: Pan-Am. Geologist, vol. 39, p. 370, 1923.

LINCOLNSHIRE LIMESTONE MEMBER

Name.—The Lincolnshire limestone member of the Cliffield formation was named by the writer and C. E. Prouty[46] from exposures in the roadside quarry along Lincolnshire Branch west of Five Oaks.

Lithology.—Black to brownish-gray, medium-grained, irregularly bedded limestones comprise this member which has generally a thickness of about 60 feet (Pl. 4D). Nearly all of the beds contain nodules of black chert (Pl. 6B), which are especially prominent on weathered surfaces. Bedding surfaces are commonly marked by bituminous, clayey streaks which cause the beds to weather cobbly. In the lower 30 feet of the member limestone beds exhibiting a distinctive "worm-eaten" appearance generally occur (Pl. 6C). Some of the limestone beds contain considerable pyrite and clay. Most of the fossils occur in these layers. In the type section on Lincolnshire Branch the member is 102 feet thick, but this is an abnormally thick development. Elsewhere the thickness ranges from 35 to 75 feet. Southeast of Brushy Mountain the Lincolnshire limestone is thin and poorly exposed. Only two good exposures are known, one north of Ceres and the other about three-fourths of a mile east of the 2,545-foot bench mark on the North Fork of Holston River, south of Ceres. A fine exposure of the Lincolnshire member is in the old roadside quarry along State Highway 61 about 2½ miles northeast of Gratton. The overhanging ledge in the lime quarry at Five Oaks is made by the Lincolnshire member (Pl. 21C). Part of the member is exposed in a roadside quarry one-eighth of a mile southeast of St. Clair Station on the Norfolk and Western Railway.

Geologic Section 5.—Lincolnshire limestone member along Lincolnshire Branch, west of Five Oaks, Tazewell County, Virginia

	Thickness Feet
Lincolnshire limestone member (102 feet)	
7. Limestone, medium grained, dark bluish-gray, cherty; contains *Sowerbyites triseptatus*	28
6. Limestone, brownish-gray, very cherty	16
5. Limestone, dark bluish-gray, very cherty, fine grained	8
4. Limestone, medium grained; contains *Dinorthis atavoides*	5

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[46] Cooper, B. N., and Prouty, C. E., Stratigraphy of the lower Middle Ordovician of Tazewell County, Virginia: Geol. Soc. America Bull., vol. 54, p. 863, 1943.

	Thickness Feet
3. Limestone, medium grained, dark bluish-gray, cherty; contains *Maclurites magnus*	21
2. Limestone, dark bluish-gray, medium grained, compact; has distinctive "worm-eaten" appearance; contains no chert (Pl. 6C)	6
1. Limestone fine to medium grained, bluish-gray, dense; contains nodules of black chert	18

Five Oaks limestone member

Fossils.—Fossils collected from the Lincolnshire limestone include:

- Sponges
    - Eospongia sp.
- Bryozoa
    - Glauconome sp.
    - Monotrypa sp.
    - Nicholsonella sp.
    - Pachydictya robusta Ulrich
- Brachiopods
    - Dinorthis atavoides Willard
    - Rostricellula sp.
    - Sowerbyites [Plectambonites] triseptatus (Willard)
- Gastropods
    - Maclurites magnus Lesueur
- Trilobites
    - Homotelus cf. H. elongatus Raymond

WARD COVE LIMESTONE MEMBER

Name.—The Ward Cove member of the Cliffield formation was named by Cooper and Prouty[47] from exposures along State Highway 91 at the northwest base of Clinch Mountain, near Ward Cove, in western Tazewell County, Virginia. It is well developed in Burkes Garden, in Thompson Valley, and between Rich and Buckhorn mountains, but it is considerably more prominent west of the Burkes Garden quadrangle.

Lithology.—The Ward Cove limestone member is composed of two principal zones, the lower of which is light-gray, medium-

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[47] Op. cit., p. 863.

bedded, coarse-grained limestone. These beds are composed of abraded fragments of crinoids, bryozoans, and brachiopods, which were deposited mainly as shell sands. Some of the layers are highly cross laminated. Nests and streaks of pyrite are the only visible impurities. Locally intercalations of finer grained, bluish-gray cherty limestone occur in the upper 25 feet of the zone. In the Clinch-Bluestone belt cherty limestone is especially abundant, comprising almost half of the total thickness. The average thickness of the coarse-grained limestone is about 60 feet.

Geologic Section 6.—Coarse-grained limestone of the Ward Cove limestone member west of Gratton, Tazewell County, Virginia[48]

	Thickness Feet
Coarse-grained limestone zone (67 feet)	
2. Limestone, very coarse grained, light-gray with pinkish streaks, cross laminated	32
1. Limestone, light bluish-gray mottled with dark-gray, very coarse grained, cross laminated	35
Lincolnshire limestone member	

The upper part of the Ward Cove member is composed of medium-to fine-grained, bluish-gray cherty limestones 75 to 150 feet thick. The upper half of the cherty limestone is very argillaceous in Burkes Garden and Thompson Valley, but not in the belts north of Rich Mountain.

Fossils.—The coarse-grained limestone zone of the Ward Cove limestone member contains an abundance of fossil fragments, but very few specimens can be identified even generically. A composite list of fossils includes the following forms:

- Algae
  - Girvanella sp.
  - Solenopora sp.
- Sponges
  - Eospongia varians Billings
  - Receptaculites sp.
- Bryozoa
  - Chasmatopora sp.
  - Monticulipora sp.

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[48] Section begins at the top of the Lincolnshire member about 100 yards north of the end of Road 646.

- Brachiopods
  - Dinorthis atavoides Willard
  - Oxoplecia cf. O. holstonensis Willard
  - Zygospira sp.
- Cephalopods
  - Gonioceras sp.
- Trilobites
  - Acrolichas minganensis (Billings)
  - Homotelus sp.
  - Illaenus sp.

Fossils are common in the cherty limestones; those identified include:

- Algae
  - Girvanella sp.
- Sponges
  - Nidulites pyriformis Bassler
  - Receptaculites sp.
- Brachiopods
  - Leptellina sp.
  - Lingula sp.
  - Oxoplecia holstonensis Willard
  - Schizambon cuneatus Willard
  - Sowerbyella delicatula (Butts)
  - Sowerbyella negrita (Willard)
  - Strophomena tenuitesta Willard
- Gastropods
  - Eccyliopterus sp.
  - Lophospira perangulata (Hall)
  - Lophospira sp.
  - Phragmolites cf. P. triangularis (Ulrich and Scofield)
- Cephalopods
  - Gonioceras cf. G. anceps Hall
  - Kionoceras sp.
- Trilobites
  - Ampyx sp.
  - Calliops cf. C. gracilens (Raymond)
  - Calliops annulatus (Raymond)
  - Homotelus sp.
  - Hyboaspis sp.
  - Niobe sp.
  - Remopleurides sp.

Geologic Section 7.—Ward Cove limestone member half a mile west of Marys Chapel, Tazewell County, Virginia

	Thickness Feet
Ward Cove limestone member (95± feet)	
5. Limestone, argillaceous, medium grained, contains nodules of black chert; contains *Sowerbyella* and *Dinorthis*	20
4. Limestone, very fine grained, dense, cherty; weathers smoke-gray; contains *Nidulites* in abundance	20
3. Limestone, medium grained, dark bluish-gray	15
2. Limestone, coarse grained, light-gray	20
1. Limestone, medium grained, dark-gray, cherty	15–25
Lincolnshire limestone member	

Northeast of Lincolnshire Branch in Clinch and Bluestone valleys, the cherty limestones of the Ward Cove member become coarser grained and contain fewer fossils. *Nidulites* and *Receptaculites,* which are especially characteristic of the upper two-thirds of the member in other parts of the quadrangle, are rare here.

The Ward Cove member is prominent on the hillside opposite the Tazewell County Farm. *Receptaculites* occur in limestone near the base of the hill; *Nidulites* is abundant in limestones 50 to 80 feet above the *Receptaculites* zone. Coarse-grained limestones and *Nidulites*-bearing beds are well displayed at the west end of Banks Ridge in Burkes Garden.

PEERY LIMESTONE MEMBER

Name.—The Peery limestone member, which constitutes the uppermost division of the Cliffield, was named by the writer and C. E. Prouty[49] from exposures at the south end of the Peery Lime Company's quarry in the east environs of North Tazewell, Tazewell County, Virginia.

Lithology.—The Peery limestone member is composed of two lithologic zones containing similar fossils. The lower is composed of dark bluish-gray to black, fine-grained argillaceous cherty limestone. Where weathered, the beds are coated with a distinctive ash-gray, mealy crust. Few fossils are found in the fresh rock, but

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[49] Op. cit., pp. 863-864.

many are seen in the mealy residue. Bedding is thin and irregular and is accentuated by seams of bituminous, clayey material. The lower zone of the Peery member is also exposed in road cuts along U. S. Route 19 about 100 yards west of Wittens Mills and about 200 yards farther west along the highway. This part of the Peery member averages about 30 feet thick, but it is thin or absent in Burkes Garden.

Thick-bedded, dove-gray calcilutytes comprise the upper part of the member. South of St. Clair school the calcilutyte beds are 140 feet thick, but elsewhere in the Clinch-Bluestone belt the thickness is less than 50 feet. In the roadside quarry along U. S. Route 19 east of Wittens Mills the calcilutytes of the Peery limestone member are about 20 feet thick. Between Rich and Buckhorn mountains the thickness of calcilutytes ranges from a few feet to more than 100 feet. The zone is persistent along the southeast base of Buckhorn Mountain but is thin or absent along the northwest base of Rich Mountain. It is absent in Burkes Garden but well developed in Thompson Valley. West of Thompson School, cross-laminated calcarenytes[50], intercalated in the calcilutyte zone, are composed of small subangular grains of calcilutyte.

Fossils.—The cherty beds in the lower part of the Peery limestone member have an abundance of fossils. From exposures along U. S. Route 19 west of Wittens Mills, many species have been collected from the weathered crust of cherty limestones. Small ostracodes are especially numerous, but most of them have not been described. A composite list of species from the Peery limestone member includes the following:

- Corals
  - Tetradium syringoporoides Ulrich
- Brachiopods
  - Mimella sp.
  - Multicostella sp.
  - Sowerbyella cf. S. negrita (Willard)
  - Sowerbyella sp.
  - Sowerbyites sp.
  - Strophomena "filitexta" (Hall)
  - Strophomena tenuitesta Willard

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[50] Calcarenyte is a variety of limestone formed by the mechanical deposition of sand-size particles of calcium carbonate.

Pelecypods
    Conocardium sp.
    Cyrtodonta sp.
Gastropods
    Bucania emmonsi Ulrich and Scofield
    Eotomaria canalifera Ulrich
    Helicotoma declivis Ulrich
    Helicotoma aff. H. tennesseensis Ulrich and Scofield
    Lophospira aff. L. ampla Ulrich
    Lophospira bicincta (Hall)
    Lophospira perangulata (Hall)
    Lophospira procera Ulrich
    Ophiletina sublaxa depressa Ulrich and Scofield
    Phragmolites cf. P. triangularis Ulrich and Scofield
    Raphistomina sp.
    Trochonema bellulum Ulrich
Cephalopods
    Cyrtoceras sp.
    Gonioceras sp.
    Kionoceras sp.
    Plectoceras bondi (Safford)
Pteropods
    Polylopia [Salterella] billingsi ? (Safford)
Trilobites
    Calliops cf. C. gracilens (Raymond)
    Pseudosphaerexochus sp.
Ostracodes
    Leperditia fabulites pinguis Butts

Most exposures of the cherty beds are not sufficiently weathered for ready extraction of whole fossils, but etched sections of *Lophospira* gastropods are abundant on most exposures. Half a mile southwest of Blue Spring in Burkes Garden, the uppermost cherty beds of the *Lophospira* zone contain large numbers of *Strophomena tenuitesta, Sowerbyella* cf. *S. negrita,* and *Sowerbyites* sp. This association of *Sowerbyites* and *Sowerbyella* in the same beds is unique in the Ordovician rocks of the Burkes Garden quadrangle.

The calcilutyte zone at the top of the Peery member contains large gastropods, many of which are referable to *Lophospira.* The most abundant fossil is *Tetradium syringoporoides;* etched cross sections of this fossil form the familiar "birdseyes" on weathered surfaces. The fine grain and compactness of the calcilutytes makes extraction of fossils almost impossible. The fossils in the calcilutyte zone include:.

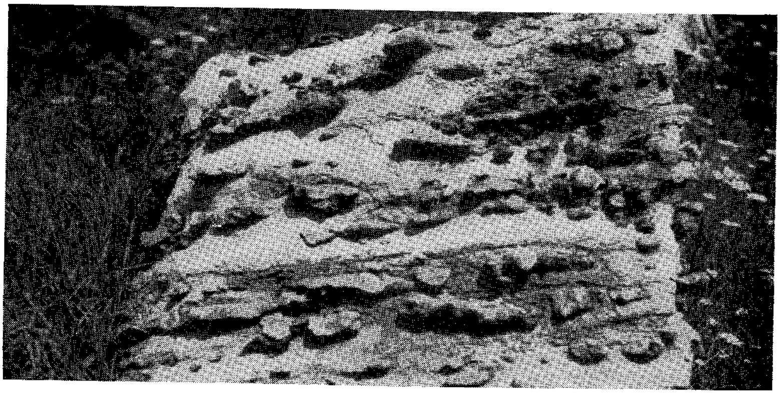
- Sponges
  - Dystactospongia sp.
- Corals
  - Tetradium syringoporoides Ulrich
- Gastropods
  - Lophospira perangulata ? (Hall)
  - Lophospira (several large species)
  - Trochonema ? sp.
- Cephalopods
  - Gonioceras sp.
- Ostracodes
  - Leperditia fabulites (Conrad)

A fine display of large gastropods in Peery calcilutytes occurs in the roadside quarry east of the intersection of U. S. Route 19 and Road 650.

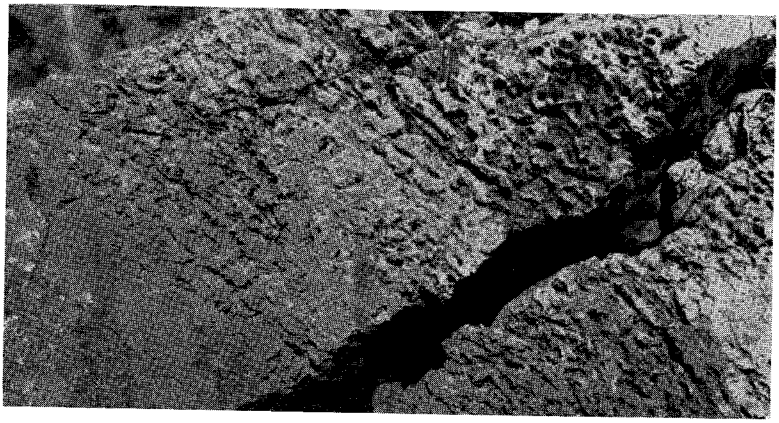
THICKNESS AND FACIES VARIATIONS OF THE CLIFFIELD FORMATION

Strikingly abrupt changes in facies take place in the beds between the lower and upper calcilutyte zones at two places in the quadrangle. Along the southeast base of Buckhorn Mountain, 1½ miles west of Gratton, coarse-grained clastic limestones largely supplant the fine-grained, dark bluish-gray type of limestone which is normally characteristic of the Lincolnshire limestone member, the *Nidulites* beds of the Ward Cove limestone member, and the cherty beds of the Peery limestone member. Less than three quarters of a mile southwest of this locality these beds are normally developed. Between the two localities gradations between dark bluish-gray cherty limestone and light-gray, coarse-grained clastic limestone are evident. North of the end of Road 646, coarse-grained limestones make up nearly all of the thickness of 286 feet between the Five Oaks limestone member and the calcilutyte zone of the Peery limestone member (Pl. 6A). Between the two localities, the coarse clastic limestone facies visibly interfingers with fine-grained cherty limestones, showing that the two are contemporaneous facies. North of Gratton and about 2 miles northeast of the first locality mentioned, nearly all the succession from the top of the Lincolnshire member to the top of the Peery member is dove-gray calcilutyte 540 feet thick. Careful tracing of these beds southwest toward Road 646 shows an interfingering of coarse-grained clastic lime-

A.



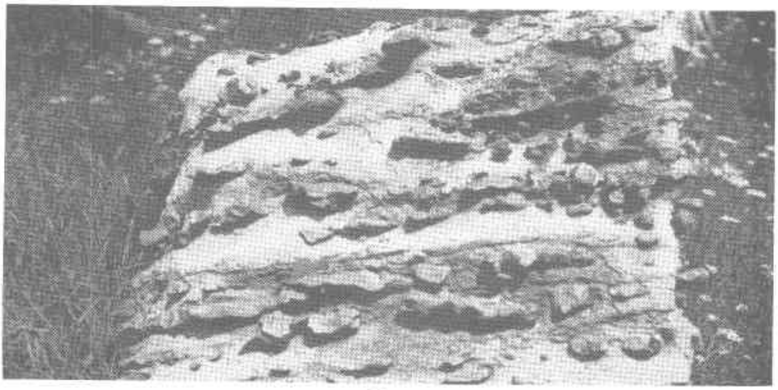
B.



C.

A, Cliffield formation at the southeast base of Buckhorn Mountain; north of Road 646, near Gratton. B, Nodular chert in the Lincolnshire limestone member; near the Tazewell County Farm. C, "Worm-eaten" beds in the Lincolnshire limestone member; in roadside quarry along Lincolnshire Branch, near Five Oaks.

A.



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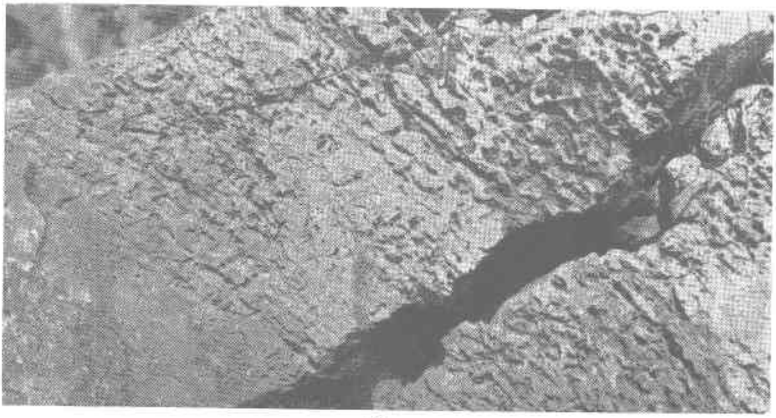
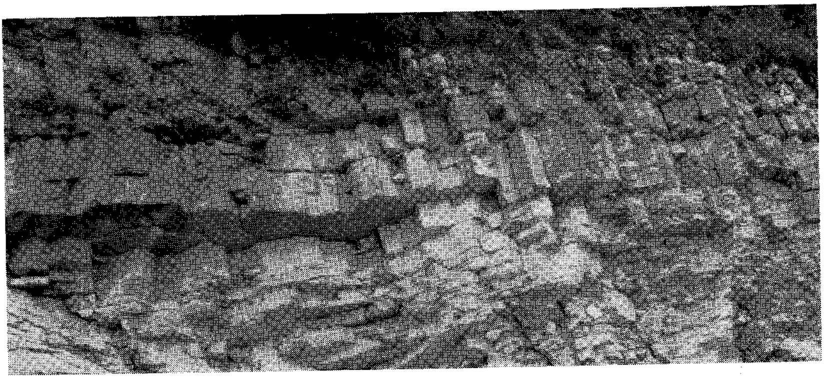
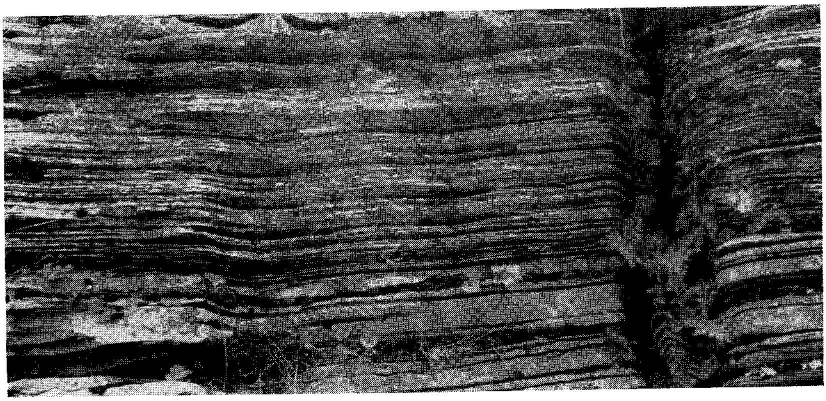


C.

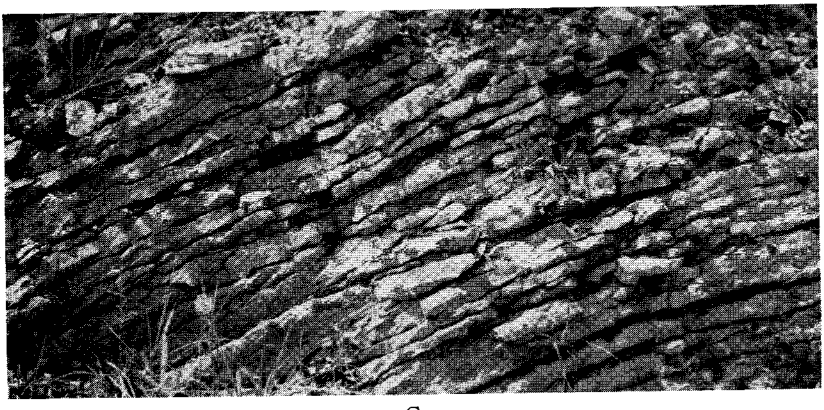
A, Cliffield formation at the southeast base of Buckhorn Mountain; north of Road 646, near Gratton. B, Nodular chert in the Lincolnshire limestone member; near the Tazewell County Farm. C, "Worm-eaten" beds in the Lincolnshire limestone member; in roadside quarry along Lincolnshire Branch, near Five Oaks.



A.

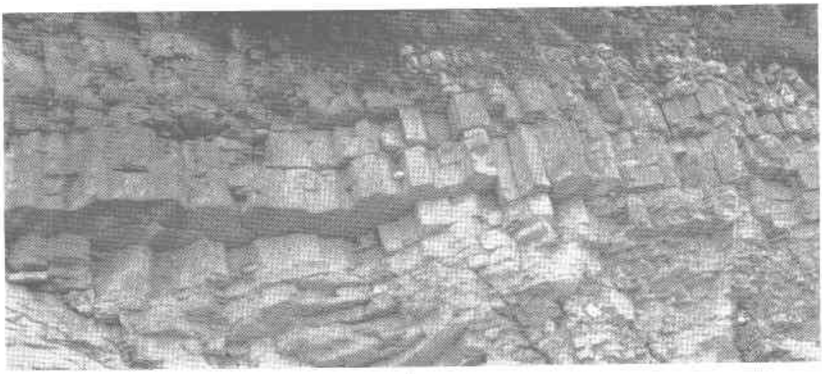


B.

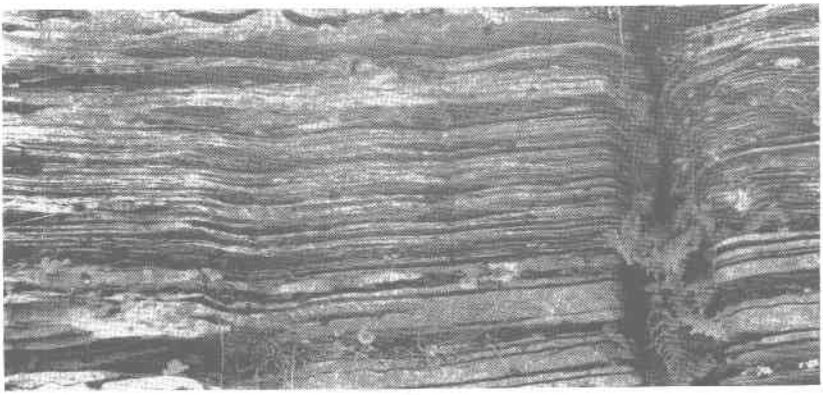


C.

A, Columnar jointing in the basal straticulate beds of the Witten limestone; near Tazewell. B, Straticulate limestone at the base of the Gratton limestone; in Burkes Garden. C, Nodular limestone of the Shannondale member; south of St. Clair Station.



A.



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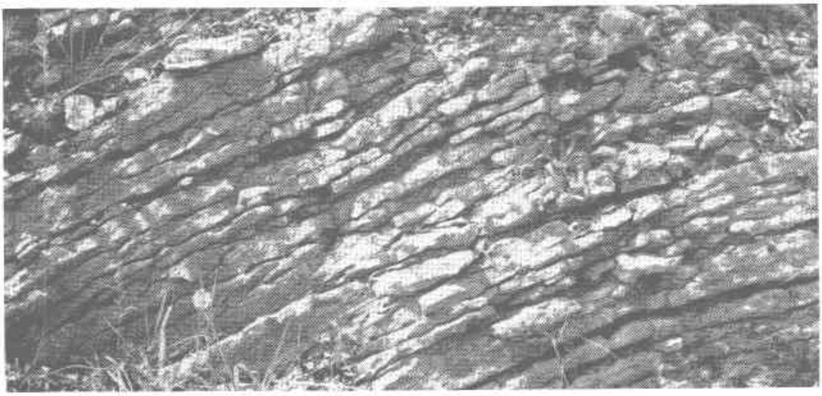

C.

A, Columnar jointing in the basal straticulate beds of the Witten limestone; near Tazewell. B, Straticulate limestone at the base of the Gratton limestone; in Burkes Garden. C, Nodular limestone of the Shannondale member; south of St. Clair Station.

stones with the calcilutytes. Evidently the coarse-grained limestones seen 1½ miles west of Gratton and the calcilutytes north of Gratton are two facies variations resulting from local differences in conditions of sedimentation during Cliffield time.

South of Shannondale in Bluestone Valley all of the zones of the Cliffield formation are typically developed. Along the road leading south from St. Clair Station past St. Clair School, the succession from the top of the Lincolnshire member to the top of the Peery member is 900 feet thick and is composed almost entirely of calcilutyte. In other words, approximately 450 feet of cherty limestone changes northeastward within 3 miles into twice that thickness of calcilutyte. Close study of sections on either side of the St. Clair section and not more than half a mile away from the latter, shows only 450 feet of cherty limestone between the lower and upper calcilutytes of the Cliffield. These remarkable facies variations within exceptionally short distances are also believed to be the result of local differences in environmental conditions of deposition of the Cliffield formation.

The following sections of the Cliffield indicate the range of variation in thickness and facies of the formation in belts northwest of Brushy Mountain:

Geologic Section 8.—Cliffield formation 1 mile north of Gratton, Tazewell County, Virginia

	Thickness Feet
Benbolt limestone	
Cliffield formation (830 feet)	
13. Calcilutyte, dove-gray, thick bedded, with conchoidal fracture; calcite vugs and veins	29
12. Limestone, fine grained, thick bedded, faintly cross laminated; weathered surfaces rough and gritty	44
11. Calcilutyte, light-gray; contains lenses and nests of coarse-grained, clastic-textured limestone	29
10. Covered interval, composed partly of light-gray, coarse-grained saccharoidal limestone	49
9. Calcilutyte, light-gray; abundant secondary calcite	38
8. Calcilutyte, dove-gray; contains many argillaceous partings in the upper part; stylolites abundant	50
7. Calcilutyte, gray, medium bedded; contains considerable secondary calcite in veins and vugs	48

	Thickness Feet
6. Calcilutyte, thick bedded; contains very little insoluble material	50
5. Calcilutyte, argillaceous; abundant stylolites	95
4. Calcilutyte, gray; very little insoluble matter	124
3. Limestone, dark-gray, medium bedded, medium grained, argillaceous	34
2. Limestone, dark-bluish gray, argillaceous; contains nodules of black chert	50
1. Covered interval to base of Cliffield	190
Beekmantown formation	

Geologic Section 9.—Cliffield formation south of Shannondale, Tazewell County, Virginia

	Thickness Feet
Benbolt limestone	
Cliffield formation (470± feet)	
Peery limestone member	
13. Calcilutyte, dove-gray	5–8
12. Limestone, fine to medium grained, cherty; carries *Lophospira* aff. *L. centralis*, *Lophospira bicincta*, and *Helicotoma* sp.	82
Ward Cove limestone member	
11. Limestone, fine grained, smoke-gray, cherty; contains *Oxoplecia*, *Nidulites*, and *Strophomena tenuitesta*	72
10. Limestone, medium grained, dark bluish-gray, cherty; contains *Nidulites*, *Sowerbyella*, and *Receptaculites*	76
Lincolnshire limestone member	
9. Limestone, fine grained, dark bluish-gray, dense; contains *Sowerbyites* and *Dinorthis*	58
8. Limestone, medium-gray, dense; contains black chert; *Sowerbyites* and *Maclurites*	38
Five Oaks limestone member	
7. Calcilutyte, thick bedded, dove-gray	28
6. Calcilutyte, argillaceous, banded	16
Blackford member	
5. Limestone, light-gray, argillaceous, cherty	2
4. Chert, blocky, fossiliferous; *Dinorthis*	40

	Thickness Feet
3. Shale, ash-gray, poorly exposed, cherty at the top	30
2. Covered interval, containing showings of red, silty, mudrock	12
1. Covered interval, apparently composed of dolomite and chert-pebble conglomerate	8
Beekmantown formation	

Geologic Section 10.—Cliffield formation along Road 650, south of St. Clair, Tazewell County, Virginia

	Thickness Feet
Benbolt limestone	
Cliffield formation[51] (1,072 feet)	
21. Calcilutyte, very dark-gray; secondary calcite abundant	45
20. Covered interval, with a few showings of dove-gray calcilutyte	95
19. Limestone, fine grained, dense, dark-bluish to brownish-gray, nodular, cherty	48
18. Calcilutyte, taupe-gray, medium bedded	22
17. Limestone, brownish-gray, dense, slightly cherty	23
16. Calcilutyte, very argillaceous, steel-gray, nodular	30
15. Calcilutyte, partly exposed, light taupe-gray; contains considerable secondary calcite	210
14. Calcilutyte, light taupe-gray, argillaceous, nodular	22
13. Calcilutyte, dark dove-gray	18
12. Calcilutyte, medium-gray; many vugs and stringers of secondary calcite	36
11. Calcilutyte, taupe-gray, laminated	35
10. Calcilutyte, light-gray, thin bedded	33
9. Covered (across U. S. Route 19)	38
8. Calcilutyte, dark dove-gray, sparsely cherty, secondary calcite in vugs and veins	125
7. Calcilutyte, thin bedded, with wavy partings of clay	80
6. Calcilutyte, laminated, taupe-gray, very cherty, weathers blocky	70
5. Limestone, fine grained, neutral-gray, laminated, sparsely cherty	20

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[51] Members of the Cliffield, recognized in most other places in the quadrangle, are not separable in the St. Clair section.

	Thickness Feet
4. Calcilutyte, taupe-gray, cherty with a 5-foot intercalation of brownish-gray limestone in the middle	10
3. Limestone, brownish-gray, fine grained, cherty, dense; exposed in roadside quarry; probably the Lincolnshire limestone member	62
2. Partly covered interval, composed of blocky chert and fine-grained limestone (Five Oaks limestone member)	25
1. Covered interval; few showings of ash-gray shale and red mudrock	25
Beekmantown dolomite	

Geologic Section 11.—Cliffield formation on the northwest slope of Rich Mountain near the Bland-Tazewell county line, Virginia

	Thickness Feet
Benbolt formation	
Cliffield formation (361 feet)	
Peery limestone member	
9. Partly covered interval; a few exposures of dark-gray cherty limestone	32
8. Limestone, dark-brownish gray, fine grained, very cherty; crust weathers ash-gray; *Lophospira*-type gastropods abundant	14
Ward Cove limestone member	
7. Limestone, fine grained, dense, brownish-gray where fresh; weathers smoke-gray, cherty; contains *Sowerbyella, Receptaculites,* and sparse *Nidulites*	105
6. Limestone, coarse grained, faintly cross laminated; contains a few finer grained cherty beds	13
Lincolnshire limestone member	
5. Limestone, brownish-gray, cherty; contains *Maclurites, Dinorthis, Sowerbyites,* and *Homotelus*	46
Five Oaks limestone member	
4. Calcilutyte, mostly covered	15
Blackford member	
3. Chert, bedded; contains intercalations of fine-grained argillaceous limestone	52

	Thickness Feet
2. Shale, ash-gray, cherty in upper part	50
1. Mudrock, maroon-drab, silty; some layers contain chert pebbles	34
Beekmantown dolomite	

Geologic Section 12.—Cliffield formation about half a mile west of Marys Chapel, Tazewell County, Virginia

	Thickness Feet
Benbolt limestone	
Cliffield formation (370 feet)	
Peery limestone member	
12. Limestone, medium-gray, granular, clastic, cross laminated, cherty; contains *Strophomena tenuitesta* and *Sowerbyella* sp.	10
11. Limestone, coarse-grained, gray contains no chert; a few *Strophomena tenuitesta* and *Lophospira*	78
Ward Cove limestone member	
10. Limestone, medium grained, cherty, dark-gray; contains abundance of *Sowerbyella*	20
9. Limestone, very fine grained, cherty, dense; weathers smoke-gray; contains *Nidulites* in abundance	20
8. Limestone, medium grained, dark bluish-gray; contains *Receptaculites*	15
7. Limestone, coarse grained, light-gray	20
6. Limestone, medium grained, dark gray, cherty	15–25
Lincolnshire limestone member	
5. Limestone, fine to medium grained, cherty, nodular; contains *Dinorthis atavoides, Sowerbyites,* and *Maclurites* ? sp.	60
Five Oaks limestone member	
4. Calcilutyte, light-gray to dark dove-gray, medium bedded	44
Blackford member	
3. Chert, bedded; mostly covered	25
2. Shale, ash-gray, mealy, cherty near top	24
1. Mudrock and chert breccia; mostly maroon-drab	34
Beekmantown dolomite	

CLIFFIELD GROUP SOUTHEAST OF CLINCH MOUNTAIN

GENERAL STATEMENT

In the two belts of Ordovician rocks between Walker and Clinch mountains the succession above the Beekmantown and below the Moccasin formation is notably different from that found in the belts northwest of Clinch Mountain (Pls. 5, 8). Red beds and blocky chert of the Blackford member are absent, as is the calcilutyte which forms the top zone of the Peery limestone member of the Cliffield formation. The Lincolnshire limestone member of the Cliffield is much thinner between Walker and Brushy mountains and in places it seems to be absent (Pl. 1). South of Ceres, at the northwest base of Walker Mountain, dark bluish-gray cherty limestones of the Lincolnshire member are overlain by 60 to 80 feet of almost white, coarse-grained, very fossiliferous limestone which contains many species of trilobites and brachiopods. This limestone thickens northeastward and is 220 feet thick in the McNutt quarry (Pl. 21A), southeast of Sharon Springs in Bland County. Detailed study of the coarse-grained limestone at the base of the Ward Cove limestone member of the Cliffield formation northwest of Clinch Mountain led to the discovery of a few fossils which also occur in the coarse-grained limestone exposed in the McNutt quarry. On this basis, and also because of its similar stratigraphic position, the coarse-grained limestone in the McNutt quarry is believed to be the approximate equivalent of the basal division of the Ward Cove limestone member northwest of Clinch Mountain in Tazwell County, Virginia. The coarse-grained fossiliferous beds in the McNutt quarry have been called Holston by Raymond[52], by Willard[53], and by Butts[54]. Above this limestone is 25 to 90 feet of granular, bluish-gray, rusty-weathering limestone containing a very distinctive assemblage of trilobites which so far have not been found northwest of Clinch Mountain. The name Whitesburg limestone has been applied to this formation by Butts[55]. The Whitesburg is overlain by 400 feet of fine-grained black limestone and black fissile shale, which has been referred to the Athens formation by Butts[56]. The Athens near Sharon Springs and Ceres is

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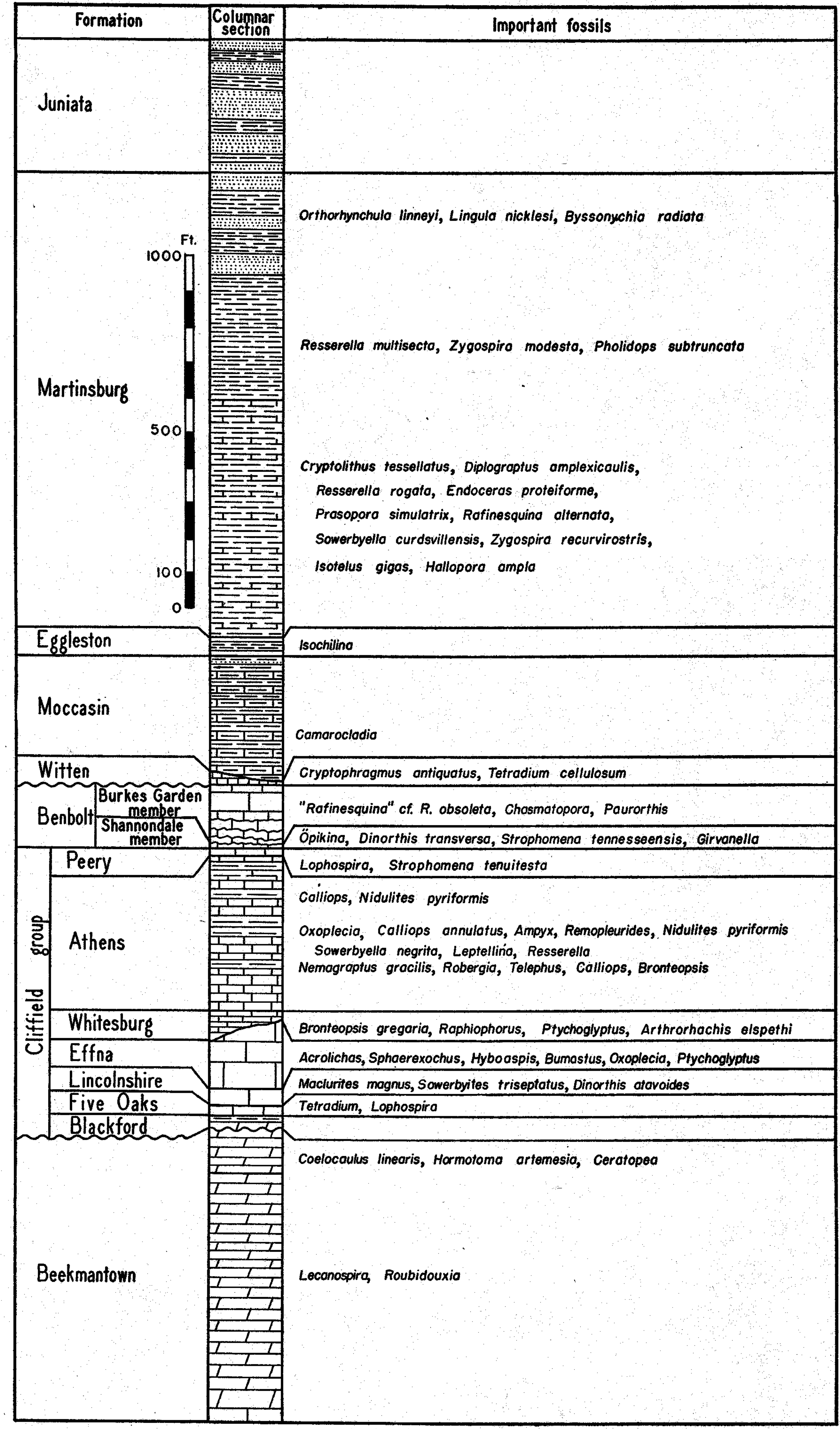
[52] Raymond, P. E., Some trilobites of the lower Middle Ordovician of eastern North America: Harvard Coll. Mus. Comp. Zool. Bull., vol. 67, no. 1, p. 173, 1925.

[53] Willard, Bradford, The brachiopods of the Ottosee and Holston formations of Tennessee and Virginia: Harvard Coll. Mus. Comp. Zool. Bull., vol. 68, no. 6, pp. 255-292, 1928.

[54] Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. 1, pp. 148-154, 1940.

[55] Idem, pp. 154-158.

[56] Idem, pp. 159-170.



Formation		Columnar section	Important fossils
Juniata			
Martinsburg			*Orthorhynchula linneyi, Lingula nicklesi, Byssonychia radiata* *Resserella multisecta, Zygospira modesta, Pholidops subtruncata* *Cryptolithus tessellatus, Diplograptus amplexicaulis, Resserella rogata, Endoceras proteiforme, Prasopora simulatrix, Rafinesquina alternata, Sowerbyella curdsvillensis, Zygospira recurvirostris, Isotelus gigas, Hallopora ampla*
Eggleston			*Isochilina*
Moccasin			*Camarocladia*
Witten			*Cryptophragmus antiquatus, Tetradium cellulosum*
Benbolt	Burkes Garden member		*"Rafinesquina" cf. R. obsoleta, Chasmatopora, Paurorthis*
	Shannondale member		*Öpikina, Dinorthis transversa, Strophomena tennesseensis, Girvanella*
Cliffield group	Peery		*Lophospira, Strophomena tenuitesta*
	Athens		*Calliops, Nidulites pyriformis* *Oxoplecia, Calliops annulatus, Ampyx, Remopleurides, Nidulites pyriformis Sowerbyella negrita, Leptellina, Resserella* *Nemagraptus gracilis, Robergia, Telephus, Calliops, Bronteopsis*
	Whitesburg		*Bronteopsis gregaria, Raphiophorus, Ptychoglyptus, Arthrorhachis elspethi*
	Effna		*Acrolichas, Sphaerexochus, Hyboaspis, Bumastus, Oxoplecia, Ptychoglyptus*
	Lincolnshire		*Maclurites magnus, Sowerbyites triseptatus, Dinorthis atavoides*
	Five Oaks		*Tetradium, Lophospira*
	Blackford		
Beekmantown			*Coelocaulus linearis, Hormotoma artemesia, Ceratopea* *Leconospira, Roubidouxia*

Columnar section of the Ordovician formations southeast of Clinch Mountain, in the Burkes Garden quadrangle, Virginia.

faunally and lithologically similar to the *Nidulites-Sowerbyella* zone of the Ward Cove limestone member of the Cliffield as recognized northwest of Clinch Mountain in Tazewell County[57]. The Athens is overlain by cherty limestones very similar in fauna and lithology to the cherty zone of the Peery limestone member of the Cliffield formation northwest of Clinch Mountain. The Benbolt limestone directly overlies the cherty, *Lophospira*-bearing limestones referred to the Peery.

Since the Athens and Whitesburg are formations overlain and underlain by units equivalent to members of the Cliffield formation in northwestern belts, Blackford, Five Oaks, Lincolnshire, and Peery are used as formation names in the two southeastern belts[58]. Thus the Blackford-Peery sequence between Walker and Brushy mountains is the Cliffield group.

BLACKFORD FORMATION

Name.—Blackford was originally used by Butts[59] as the name of a facies of the so-called Murfreesboro limestone. Cooper and Prouty[60] have shown that the Blackford is not a facies of the Murfreesboro and have redefined the "Blackford facies of the Murfreesboro" as the basal member of the newly recognized Cliffield formation in Tazewell County, Virginia. The Blackford is used herein also as the name of a formation occurring between Clinch and Walker mountains, where it includes beds of the same age as are included in the Blackford member of the Cliffield formation as recognized northwest of Clinch Mountain.

Distribution.—The Blackford formation occurs discontinuously in both belts of Ordovician strata exposed in the valley between Brushy and Walker mountains (Pl. 1). The three best exposures are: near the top of a low hill three-fourths of a mile due north of the town of Ceres; 150 yards south-southwest of the 2,639-foot bench mark a mile south of Ceres; and half a mile north-northeast of the 2,983-foot bench mark on the road from Sharon Springs to the top of Walker Mountain.

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[57] Cooper, B. N., Athens equivalents northwest of Clinch Mountain in southwest Virginia (abstract): Geol. Soc. America Bull., vol. 52, pp. 1892-1893, 1941.

[58] According to G. H. Ashley and others (Classification and nomenclature of rock units: Geol. Soc. America Bull., vol. 44, p. 437, 1933), "the rank of a unit, where circumstances dictate, may be changed without changing its name or its content of rocks. It is thus possible for a member to become a formation, or a formation to become a group; or the process may be reversed."

[59] Op. cit., pp. 120-135.

[60] Cooper, B. N., and Prouty, C. E., Stratigraphy of the lower Middle Ordovician of Tazewell County, Virginia: Geol. Soc. America Bull., vol. 54, pp. 862-863, 1943.

Lithology.—The Blackford formation (Pl. 8) is composed of dolomite-pebble and chert-pebble conglomerate similar to the basal clastics directly overlying the Beekmantown northwest of Clinch Mountain, but lacking the distinctive red color of those beds; and ash-gray, mealy-textured shales identical in character to beds overlying red siltstones of the Blackford member northwest of Clinch Mountain. Locally, bedded chert occurs at the top of the formation. The total thickness of the formation is not known to exceed 60 feet and probably averages less than 25 feet. Somewhat less than half a mile north-northeast of the McNutt quarry, the Blackford formation is composed, in ascending order, of 20 feet of conglomerate; 35 feet of ash-gray, crumbly shale; and 3 to 5 feet of drab-gray shale interbedded with blocky chert. Three-fourths of a mile north of Ceres, the Blackford contains 5 to 9 feet of clastic dolomite with scattered pebbles of pink, detrital chert, 1½ feet of limestone conglomerate, and 4 to 5 feet of gray shale. This succession pinches out 100 yards to the northeast but can be followed southwestward along the strike for about 1½ miles. South-southeast of Ceres, the Blackford formation is composed of a few feet of clastic dolomite containing detrital chert, which is overlain by about 15 feet of ash-gray shale. In many sections the Blackford formation seems to be absent. Sharp irregularities occur at the top of the Beekmantown formation which appears to have been deeply eroded prior to Blackford time. The Blackford sediments apparently were washed off of the "highs" and deposited in the "lows" of the post-Beekmantown erosion surface.

Fossils.—A loose block of weathered chert, found on the outcrop of the Blackford formation northeast of the McNutt quarry, contained specimens of a high-spired gastropod, of *Leperditia* sp., and several small specimens of *Dinorthis holdeni* (Willard). No other fossils were found.

Age and correlation.—The Blackford formation is essentially the same unit as the Blackford member of the Cliffield formation. The geographic extent of the Blackford southeast of Clinch Mountain is as yet unknown. The formation is clearly post-Beekmantown and is believed to be Chazyan.

Stratrigraphic relations.—The marked irregularity of the contact between the Beekmantown and the overlying beds is evidence of erosional unconformity. The local variations in thickness of the

Beekmantown, resulting from trenching of that formation in post-Beekmantown time, are far more pronounced in the area between Walker and Brushy mountains than in the area northwest of Clinch Mountain. North of Ceres the Beekmantown is only 490 feet thick, but one-fourth of a mile northeast along the strike of the beds, it is 910 feet thick. Where the stratigraphic succession is most nearly complete, the Blackford is succeeded by calcilutytes of the Five Oaks limestone and there is no evidence of disconformity. Locally, the Five Oaks and succeeding Lincolnshire limestone are absent and the Blackford is directly overlain by beds identified as Holston by Butts and others. In these places, notably in the vicinity of the McNutt quarry, there is obviously a hiatus between the Blackford and the so-called Holston.

FIVE OAKS LIMESTONE

Name.—The Five Oaks limestone was defined[61] as a member of the Cliffield formation, but it is considered a formation in the area between Brushy and Walker mountains. The same beds have been called the Mosheim, but there are cogent reasons for discontinuing the use of that name in Virginia.[62]

Distribution.—The Five Oaks limestone is not continuous along the strike (Pl. 1). It has been identified only in a dozen localities southeast of Burkes Garden in this quadrangle. The best exposures are three-quarters of a mile north of Ceres and along the northwest base of Walker Mountain southeast of Ceres.

Lithology.—The Five Oaks limestone is composed principally of even-bedded, prevailingly dove-gray calcilutyte (Pl. 8). One or more beds of salmon-pink calcilutyte generally mark the base and in the lower half of the formation buff mealy shales are commonly intercalated in the limestone. The Five Oaks limestone is absent in many places and in others it is so thin as to be easily overlooked. Southeast of Ceres it is only 5 to 8 feet thick; north of Ceres less than 25 feet is present.

Fossils.—Well-preserved fossils are rare. *Tetradium syringoporoides* and several high-spired gastropods, such as occur in the Five Oaks limestone member east of Wittens Mills along U. S. Route 19, were found three quarters of a mile northwest of Ceres.

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[61] Cooper, B. N., and Prouty, C. E., op. cit., p. 863.
[62] Idem, pp. 852-853.

Age and correlation.—The Five Oaks limestone southeast of Clinch Mountain is the Mosheim limestone of Butts[63]; however, it is not definitely known to be the same as the type Mosheim of Tennessee. It is not the same as the Mosheim identified by Butts[64] along Yellow Branch, Lee County, Virginia. As previously shown[65], the so-called Mosheim at Yellow Branch is probably the correlative of the upper zone of the Peery limestone which is present in Tazewell County, Virginia. The stratigraphic position of the Peery is several hundred feet above the horizon of the Five Oaks.

LINCOLNSHIRE LIMESTONE

Name.—The name Lincolnshire was originally proposed[66] for a member of the Cliffield formation, and has been so used in this report in describing the lower Middle Ordovician limestones northwest of Clinch Mountain. In the valley between Brushy and Walker mountains, the Lincolnshire is considered to be a formation that includes the same beds as the Lincolnshire member of the Cliffield formation.

Distribution.—Relatively few exposures of the Lincolnshire are present in this area. In the vicinity of the McNutt quarry the Effna limestone directly succeeds the Blackford formation, and in many other places exposures of the Effna and Blackford are so close together that little or no Lincolnshire appears to be present (Pl. 1). One of the best exposures of the formation occurs about 160 yards south of the 2,639-foot bench mark south of Ceres. One mile north of Ceres, the Lincolnshire is exposed on the north slope of a low hill where it appears to underlie the Five Oaks formation, but this appearance is the result of overturning of the beds.

Lithology.—The Lincolnshire is composed of thin-bedded, nodular-weathering, argillaceous, prevailingly dark bluish-gray, cherty limestones (Pl. 8). The greatest thickness, measured in the section north of Ceres, is 40 feet. South of Ceres the thickness is somewhat less, and only the upper part is fully exposed.

Fossils.—Repeated search for fossils in the Lincolnshire yielded a mere handful of specimens, most of which were *Sowerbyites* or *Dinorthis*

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[63] Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. 1, pp. 135-139, 1940.

[64] Idem, pp. 120-122.

[65] Cooper, B. N., and Prouty, C. E., Stratigraphy of the lower Middle Ordovician of Tazewell County, Virginia: Geol. Soc. America Bull., vol. 54, p. 868, 1943.

[66] Idem, p. 863.

atavoides Willard. A few etched specimens of *Maclurites,* probably *M. magnus* Lesueur, were seen on a loose block of dark-gray limestone, which was presumably derived from a ledge of Lincolnshire on the hill slope to the south.

Age and correlation.—The Lincolnshire limestone is the Lenoir limestone of Butts in the belts southeast of Clinch Mountain. The name Lenoir should not be used in areas considerably removed from the type locality in Tennessee, because the exact age relations of the type Lenoir and of other beds commonly called Lenoir in Tennessee have not yet been established. The Lincolnshire is not the same as the Lenoir identified by Butts in some areas north of Clinch Mountain.[67] It is not equivalent to any part of the Stones River group of Central Tennessee, because the basal Stones River formation, the Murfreesboro, is the correlative of the Peery limestone.

EFFNA LIMESTONE

Definition.—The name Effna limestone is here proposed for the beds overlying the Lincolnshire limestone and underlying the Whitesburg limestone along the northwest base of Walker Mountain. The name is taken from a settlement along State Highway 42 about 2 miles east of Sharon Springs. The type section is exposed in and near McNutt quarry about 1½ miles southeast of Sharon Springs (Pl. 21A).

Butts[68], Raymond[69], and Willard[70] have identified this limestone as Holston though without adequate basis. So little has been published on the fauna of the type Holston that direct correlation on the basis of fossils is impossible. Beds identified by Butts[71] as Holston along the northwest base of Clinch Mountain are a facies of limestone which interfingers with the Blackford, Five Oaks, Lincolnshire, Ward Cove, and Peery members of the Cliffield formation in Russell and Scott counties, Virginia. This belt of so-called Holston continues southwest into Tennessee where it was mapped as lentils of marble in the Chickamauga limestone by Keith[72]. Because Keith's Holston marbles interfinger with beds

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[67] Cooper, B. N., and Prouty, C. E., op. cit., p. 854.

[68] Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. 1, p. 151, 1940.

[69] Raymond, P. E., Some trilobites of the lower Middle Ordovician of eastern North America: Harvard Coll. Mus. Comp. Zool. Bull., vol. 67, no. 1, 180 pp., 1925.

[70] Willard, Bradford, The brachiopods of the Ottosee and Holston formations of Tennessee and Virginia: Harvard Coll. Mus. Comp. Zool. Bull., vol. 68, no. 6, pp. 255-292, 1928.

[71] Op. cit., p. 150.

[72] Keith, Arthur, Description of the Loudoun sheet: U. S. Geol. Survey Geol. Atlas, Loudoun folio (No. 25), map, 1896; Description of the Maynardville quadrangle: U. S. Geol. Survey Geol. Atlas, Maynardville folio (No. 75), map, 1901.

of different ages, the name should not be used to imply time equivalency of any similar appearing beds far away from the Knoxville region in Tennessee.

The name Murat limestone was proposed by H. D. Campbell[73] for a succession of limestones, which is mainly composed of beds of the Holston type, near Lexington, Rockbridge County, Virginia, but the name was later abandoned, though without adequate basis, in favor of Holston[74]. Since only two fossils from Butts' Holston in the McNutt quarry are listed by him[75] from the Holston (Murat) near Lexington, the Effna and Murat are not yet known to be equivalent; hence, Murat can not be used in this report.

Distribution.—The Effna limestone crops out in a northwestward-trending belt along the northwest base of Walker Mountain and is well exposed in McNutt quarry along Road 621, 1½ miles east-southeast of Sharon Springs (Pl. 21A). Another belt of Effna limestone extends southwest from a point three-quarters of a mile north of Ceres and terminates near State Highway 42, where it is cut off by the Ceres fault, a thrust which branches from the Saltville-Bland overthrust (Pl. 1). Nearly all of the Effna limestone is exposed half a mile south of Redoak School. One of the best sections in the quadrangle is 1½ miles south-southeast of Ceres and about a mile east of the 2,545-foot bench mark on the North Fork of Holston River, where the lower and upper contacts are well shown. The Effna limestone rests on the Lincolnshire limestone, which contains *Maclurites magnus* and *Sowerbyites,* and underlies fossiliferous bluish-gray beds of the Whitesburg.

Lithology.—The Effna is mainly a white to light-gray, coarse-grained shell limestone, some beds of which are pinkish like the Holston marble of Tennessee (Pl. 8). The beds in the lower 100 feet of the formation are composed of fragmental shells of brachiopods, colonies of massive and ramose bryozoans, and calcitic casts of trilobites —all of which are knit together by a matrix of coarse-grained calcite surrounding large roundish masses of fine-grained calcite which are apparently of algal origin. Pinkish beds, which are common in the upper half of the formation, are composed almost entirely of the rhombohedral fragments of echinoderms. The beds are almost free of clay and silica. Pyrite occurs as nests and stringers in a 15-foot zone about 70 feet above the base of the formation.

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[73] Campbell, H. D., The Cambro-Ordovician limestones of the middle portion of the Valley of Virginia: Am. Jour. Sci., 4th ser., vol. 20, pp. 445-447, 1905.

[74] Butts, Charles, op. cit., pp. 148-154.

[75] Idem, pp. 152-153.

Geologic Section 13.—Type section of the Effna limestone exposed in and near the McNutt quarry, Sharon Springs, Bland County, Virginia

	Thickness Feet
Whitesburg limestone	
Effna limestone (221 feet)	
10. Covered interval, composed chiefly of light-gray, coarse-grained clastic limestone	46
9. Limestone, light-gray, uneven textured; contains masses of fine-grained algal limestone in a matrix of coarse-grained calcite	6
8. Limestone, bluish-gray, fine grained; vuggy texture, with white calcite rhombs 2 to 6 mm. in diameter	13
7. Limestone, coarsely crystalline, light-gray, with many large trilobites including *Acrolichas prominulus*	8
6. Limestone, medium grained; matrix surrounds fine-grained calcitic masses of algal origin; a few large trilobites, particularly *Bumastus lioderma*	6
5. Limestone, light-gray to white, coarsely crystalline; matrix surrounds fragments of trilobites, brachiopods, and bryozoa	7
4. Limestone, pinkish and greenish-tinted; clastic texture; stylolites abundant	22
3. Limestone, white to light-gray; thick bedded; uneven texture; abundantly fossiliferous	32
2. Limestone, white to light-gray; coarse grained with streaks of pyrite	30
1. Limestone, coarse grained, uneven texture; with abundance of trilobites and bryozoa	51
Lincolnshire limestone	

The maximum thickness of the Effna limestone is in the vicinity of the McNutt quarry. Southwest along the same belt, the thickness decreases to about 60 feet south of Ceres. The thickness in the northern belt is 25 to 75 feet.

Fossils.—The Effna is very fossiliferous; many species have been described by Willard[76] and by Raymond[77] from collections made at the

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[76] Willard, Bradford, The brachiopods of the Ottosee and Holston formations of Tennessee and Virginia: Harvard Coll. Mus. Comp. Zool. Bull., vol. 68, no. 6, pp. 255-292, 1928.

[77] Raymond, P. E., Some trilobites of the lower Middle Ordovician of eastern North America: Harvard Coll. Mus. Comp. Zool Bull., vol. 67, no. 1, 180 pp., 1925.

McNutt quarry. The following composite list includes the fossils listed by Raymond and Willard and those identified by the writer.

- Algae
  - Girvanella sp.
- Corals
  - Billingsaria parva (Billings)
- Bryozoa
  - Chasmatopora sublaxa Ulrich
  - Crepipora sp.
  - Favositella sp.
  - Orbignyella sp.
  - Rhinidictya cf. R. nicholsoni Ulrich
- Brachiopods
  - Acrosaccus panneus Willard
  - Camarella sp.
  - Camarella panderi Billings
  - "Camarotoechia" sp.
  - Christiania sp.
  - Clitambonites holstoni Willard
  - Clitambonites multicostus ? (Hudson)
  - Clitambonites porcia (Billings)
  - Conotreta declivis Willard
  - Crania ? sp.
  - Dinorthis sp.
  - Dinorthis cf. D. pectinella (Emmons)
  - Glyptorthis bellarugosa (Conrad)
  - Lingula lyelli Billings
  - Mimella melonica (Willard)
  - Mimella vulgaris (Raymond)
  - Productorthis agilera (Willard)
  - Oxoplecia sp.
  - Oxoplecia holstonensis Willard
  - Parastrophia rotundiformis Willard
  - Petrocrania ? prona Raymond
  - Ptychoglyptus virginiensis Willard
  - "Rafinesquina" champlainensis Raymond
  - "Rafinesquina" grandistriata Willard
  - "Rafinesquina" cf. R. distans Raymond
  - Schizambon cuneatus Willard
  - Sowerbyella crassus (Willard)

- Trilobites
    - Acrolichas minganensis (Billings)
    - Acrolichas prominulus Raymond
    - Basilicus laeviculus Raymond
    - Bumastus lioderma Raymond
    - Bumastus longiops Raymond
    - Ceraurus hudsoni Raymond
    - Cybeloides sp.
    - Homotelus indentus Raymond
    - Hyboaspis shuleri Raymond
    - Illaenus fieldi Raymond
    - Nileus scrutator Billings
    - Sphaerexochus discrepans Raymond
    - Sphaerexochus parvus Billings
    - Thaleops sp.

Butts[78] lists in addition the following forms from the same locality:

- Brachiopods
    - Dinorthis atavoides Willard
    - Doleroides ? sp.
    - Hallina ? sp.
    - Leptaena sp.
- Pelecypods
    - Clionychia sp.

Despite the supposed equivalency of the McNutt quarry beds to the Murat limestone of Campbell, the number of species known to be common to the two is surprisingly small. From Butts'[79] list of "Holston" fossils obtained from the Murat near Lexington, Virginia, only two, *Clionychia* sp. and *Bumastus lioderma,* have been found in the Effna. The latter form occurs in three stratigraphic zones of Ordovician limestone northwest of Clinch Mountain and therefore has no index value. The genus *Clionychia* is not confined to the Butts' Holston. Raymond[80] lists 8 species of brachiopods from the Holston marble of the Knoxville area: *Paleoglossa belli* (Billings), *Multicostella platys* (Billings), *Pionodema minuscula* Willard, *Sowerbyella negrita* (Willard), *Leptaena ? palustris* Willard, *"Rafinesquina" dupli-*

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[78] Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. 1, pp. 152-153, 1940.

[79] Idem.

[80] Raymond, P. E., The brachiopods of the Lenoir and Athens formations of Tennessee and Virginia: Harvard Coll. Mus. Comp. Zoology Bull., vol. 68, no. 6b, p. 302, 1928.

cistriata Willard, *Ptychoglyptus virginiensis* Willard, and *Camarella panderi* Billings. Only the last two have been reported from the beds in McNutt quarry, and the identification of *Camarella panderi* from McNutt quarry beds is doubtful. *Sowerbyella negrita* occurs in the Athens which is considerably above the Effna; *"Multicostella platys"* has been identified from the Lenoir, Holston, and Rye Cove Ottosee by Butts; *Pionodema minuscula* is characteristic of Butts' Lowville limestone of middle belts of the southern Appalachian Valley; and Raymond[81] lists *"Rafinesquina" duplicistriata* also from the Ottosee south of Fugate Hill, Russell County, Virginia. Raymond[82] lists 5 species of trilobites from the Holston marble of the Knoxville area. Three of these, *Illaenus fieldi, Bumastus longiops,* and *B. lioderma,* occur in the Effna in the McNutt quarry. *Illaenus fieldi* is also listed by Raymond from Athens near Lexington, Virginia, from the Lenoir near Knoxville, Tennessee, and from the Ottosee at Speers Ferry Post Office, Scott County, Virginia. *Bumastus lioderma* is also listed by Raymond from the Lenoir, from the Athens of Bullsgap, Tennessee, and from the Speers Ferry Ottosee. *Bumastus longiops* also occurs in the Whitesburg according to Butts. Thus it is clear that the fossils reported from the Knoxville Holston have been reported from so many formations that their correlative value is doubtful. The asserted faunal similarity of the Knoxville Holston to the McNutt quarry beds and to the Murat limestone of the Lexington, Virginia, area is without adequate basis.

WHITESBURG LIMESTONE

Name.—Ulrich[83] named the Whitesburg limestone from Whitesburg, Hamblen County, Tennessee. Prior to 1930 the Athens formation included the beds now assigned to the Whitesburg.

Distribution.—On the geologic map (Pl. 1), the Whitesburg has been mapped with the Athens and Peery. So far as known the Whitesburg is confined to areas southeast of the Saltville-Bland fault. One belt extends along the southeast base of Brushy Mountain from a point three-fourths of a mile north of Ceres southwestward to State Highway 42 at the southern border of the quadrangle. The Whitesburg of this belt is very poorly exposed and it was seen in only three places; near the northeastern terminus of the belt, along Page Branch, and near the

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[81] Op. cit.

[82] Raymond, P. E., Some trilobites from the lower Middle Ordovician of eastern North America: Harvard Coll. Mus. Comp. Zoology Bull., vol. 67, no. 1, p. 173, 1925.

[83] Ulrich, E. O., Ordovician trilobites of the family Telephidae and concerned stratigraphic correlations: U. S. Nat. Mus. Proc., vol. 76, art. 21, p. 2 (footnote), 1930.

southwestern end of the belt. The second belt of the Whitesburg is along the northwest base of Walker Mountain. Exposures are more numerous there, but none gives a complete section of the formation. The best display of the Whitesburg is south of the McNutt quarry and east of the Walker Mountain road. The lowest beds are well exposed half a mile south of Redoak School and also 1½ miles south-southeast of Ceres.

Lithology.—The Whitesburg is composed of medium-grained, thin-bedded, dark-gray limestones which contain considerable organic matter (Pl. 8). The texture is uneven in many beds, but none of the Whitesburg is as coarse grained as the Effna limestone. Near the top of the formation black argillaceous limestones and black shales, similar to the Athens, form thin intercalations in the granular limestones. The lower part of the Whitesburg weathers nodular, and most exposed surfaces of the formation are stained rusty brown. South of the McNutt quarry the Whitesburg is 100 to 130 feet thick, but it thins to the southwest. South of Ceres only 45 feet is present. In the Brushy Mountain belt the thickness of the Whitesburg probably does not exceed 15 feet.

Geologic Section 14.—Whitesburg limestone south of McNutt quarry, Bland County, Virginia

	Thickness Feet
Athens formation	
Whitesburg limestone (119 feet)	
3. Limestone, dark-gray, uneven textured, argillaceous, weathers rusty brown; contains many blotches and vugs of white calcite; *Homotelus obtusus*	17
2. Limestone, bluish-gray; very fine-grained beds intercalated in granular fossiliferous layers; *Bronteopsis gregaria, Mimella* sp., *Leptaenisca* sp., and ramose bryozoans	57
1. Limestone, dark-gray, thin bedded, weathers nodular to cobbly; contains lenses and thin beds of dark-gray, fine-grained limestone; partings of waxy black clay along bedding surfaces; trilobites, rather abundant, including *Arthrorhachis, Telephus, Bronteopsis, Bumastus,* and *Nileus*	45
Effna limestone	

Fossils.—Fossils, especially trilobites, are common in the Whitesburg. Most of the brachiopods occur in argillaceous layers and are poorly preserved. The following fossils were collected from the Whitesburg exposed south of the McNutt quarry and also south-southeast of Ceres:

- Brachiopods
    - Christiania cf. C. lamellosa Butts
    - Hesperorthis cf. H. disparilis (Conrad)
    - Leptaenisca sp.
    - Mimella sp.
    - Ptychoglyptus virginiensis Willard
    - Schizambon sp.
    - Sowerbyella sp.
- Trilobites
    - Ampyx camurus Raymond
    - Arthrorhachis elspethi Raymond
    - Bumastus cf. B. longiops Raymond
    - Bronteopsis sp.
    - Cryptolithus sp.
    - Homotelus sp.
    - Nileus scrutator Billings
    - Raphiophorus sp.
    - Telephus bicornis Ulrich

Some of the Whitesburg fossils are also found in the Effna limestone and others occur higher in the Athens, but most of the species seem to be confined to the Whitesburg.

ATHENS FORMATION

Name.—Hayes[84] named the Athens from exposures near Athens, McMinn County, Tennessee. Originally the Athens included the Whitesburg. Formerly the name †Liberty Hall limestone was used for the Whitesburg-Athens succession, but was abandoned when it was discovered that the formation was the equivalent of the Athens of Tennessee.

Distribution.—The Athens, like the Whitesburg and Effna, occurs in two belts (Pl. 1). One occurs at the southeast base of Brushy Mountain and the other at the northwest foot of Walker Mountain. In no place in the Burkes Garden quadrangle is the entire thickness

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[84] Hayes, C. W., U. S. Geol. Survey Geol. Atlas, Kingston folio (No. 4), p. 2, 1894.

of the formation exposed. The upper 160 feet is exposed one-fourth of a mile west of Soap Creek north of Ceres, and also near the northeastern end of the Brushy Mountain belt. The lower 150 feet is fairly well exposed south of the McNutt quarry. Most of the middle part of the formation crops out in a creek bed a mile east of Redoak School. Southwestward from this locality to the southern border of the quadrangle the lower part of the Athens is well exposed in a number of places.

Lithology.—The Athens formation consists largely of black fine-grained limestones which are exceedingly dense and which break with a conchoidal fracture (Pl. 8). Some of the limestones of the Brushy Mountain belt are distinctly granular. All of the calcareous layers are argillaceous and separated by thin streaks of bituminous material. The beds average about 4 inches thick; some near the base weather nodular. In the Burkes Garden quadrangle shales constitute only about 20 per cent of the total thickness of the Athens. Leaching and oxidation of the shales result in a striking color change from black to reddish-buff. Soils derived from the Athens are buff and are full of soft mealy chips of leached shale.

In the Walker Mountain belt the thickness of the Athens is about 475 feet, but in the northwestern or Brushy Mountain belt the thickness varies considerably. The deep erosional trench in the top of the Beekmantown north of Ceres was not entirely filled by Blackford, Five Oaks, Lincolnshire, Effna and Whitesburg sediments; hence during early Athens time about 220 feet of limestone accumulated in this depression before Athens sediments were deposited on surrounding areas of the sea floor. By the close of Athens time at least 200 feet more of sediments had been deposited on areas outside the trench and directly upon the Beekmantown. The maximum thickness of 525 feet was measured a short distance west of Soap Creek. Northeast of Soap Creek, the lower half of the Athens impinges against Beekmantown dolomites along a very irregular erosional surface. Near State Highway 42 at the southern border of the quadrangle, the Athens is not more than 350 feet thick, but possibly the middle part of the formation is cut out here by undetected minor faults.

Fossils.—Shale intercalations in the Athens contain graptolites of the *Nemagraptus gracilis* fauna, among which *Nemagraptus gracilis* (Hall), *Dicellograptus sextans* (Hall), *Didymograptus sagittacaulis* Gurley, *Climacograptus bicornis* (Hall), *Glossograptus* sp., and

Dicranograptus ramosus (Hall) are common. Very few graptolites are seen in the limestone layers of the Athens, and no graptolites were found in any of the Athens beds in the Brushy Mountain belt. Limestones in the lower 200 feet of the formation contain trilobites including *Telephus spiniferus* Ulrich, *T. latus* Ulrich, *Robergia* ? sp., *Homotelus* sp., *Raphiophorus* sp., and *Calliops* sp. Nodular limestones about 300 feet above the base contain *Calliops annulatus* (Raymond) in great abundance and in addition *Nileus, Remopleurides, Niobe* sp., *Homotelus laeviurus* Raymond, *Ampyx americanus* Safford and Vogdes, *Corineorthis* ? n. sp., *Orthambonites* n. sp., *Leptellina* n. sp., *Multicostella bursa* (Raymond), *Sowerbyella negrita* (Willard), *Oxoplecia* aff. *O. simulatrix* (Bassler), *Resserella* aff. *R. rogata* (Sardeson), *Schizambon cuneatus* Willard, *Raphistomina* sp., *Hyboaspis* sp., *Receptaculites* sp., *Nidulites pyriformis* Bassler, *Lophospira* sp., and *Echinosphaerites aurantium* (Gyllenhal). The uppermost 100 feet contains *Echinosphaerites aurantium* (Gyllenhal), *Nidulites pyriformis* Bassler, *Calliops annulatus* (Raymond), and *Dionide* cf. D. *holdeni* Raymond in considerable abundance. Fragments of a species of *Cryptolithus* occur in association with *Calliops annulatus* near the top.

PEERY LIMESTONE

Name.—The name Peery limestone member was used by the writer and Prouty[85] for the *Lophospira* beds and the overlying calcilutyte at the top of the Cliffield formation in Tazewell County, Virginia. The type section is in the Peery Lime Company's quarry near North Tazewell. The Peery limestone is thin between Brushy and Walker Mountains and contains no calcilutyte (Pls. 1, 8).

Lithology.—Along the southeast base of Brushy Mountain the Peery limestone is composed of about 18 feet of cherty, *Lophospira*-bearing, bluish-gray limestone which directly overlies the Athens. Along the northwest base of Walker Mountain the Peery is composed of less than 10 feet of cherty limestone, some layers of which are full of gastropods. It may be absent locally south of Ceres where the Athens appears to be directly overlain by beds younger than the Peery.

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[85] Cooper, B. N., and Prouty, C. E., Stratigraphy of the lower Middle Ordovician of Tazewell County, Virginia: Geol. Soc. America Bull., vol. 54, pp. 863-864, 1943.

Fossils.—Few fossils have been collected from the Peery limestone in the Walker Mountain belt. North of Ceres, the following were obtained:

Gastropods
    Helicotoma sp.
    Lophospira perangulata (Hall)
    Lophospira procera Ulrich
    Trochonema bellulum Ulrich
Cephalopods
    Gonioceras sp.
    Plectoceras aff. P. bondi. (Safford)
    Phragmolites sp.
Trilobites
    Calliops cf. C. gracilens (Raymond)

CORRELATION OF THE CLIFFIELD FORMATION AND GROUP

The Blackford as herein used is the same as the "Blackford facies of the Murfreesboro" of Butts[86]. This unit is best developed northwest of Clinch Mountain and is thin or absent southeast of the Saltville-Bland fault.

According to Butts[87], the calcilutyte near the base of the Ordovician limestone succession between Walker and Brushy mountains is the same as the Mosheim of Tennessee. The equivalency remains to be demonstrated. Northwest of Clinch Mountain the Five Oaks limestone member of the Cliffield formation is Butts' Mosheim near Wittens Mills and in most parts of western Tazewell County. However, the calcilutyte zone of the Peery limestone member has been identified by Butts as Mosheim south of St. Clair Station, near Bluefield, Virginia. The name Mosheim should not be used until equivalency with the type Mosheim is successfully established. The Five Oaks limestone is not the same as the Mosheim of Yellow Branch, Lee County, Virginia, where Butts and Ulrich postulate that the Mosheim overlies the Murfreesboro.

The Lincolnshire limestone between Walker and Brushy mountains is Butts' Lenoir of the same area. Northwest of Clinch Mountain, the Lincolnshire has been identified by Butts as the Lenoir in the vicinity of Wittens Mills, but as Murfreesboro south

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[86] Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. 1, pp. 132-133, 1940.

[87] Butts, Charles, Geologic map of the Appalachian Valley of Virginia with explanatory text: Virginia Geol. Survey Bull. 42, map, 1933.

of St. Clair Station. The Lincolnshire is not the Lenoir identified by Butts along Yellow Branch, Lee County, Virginia. Use of the name Lenoir for any beds in Virginia should be held in abeyance at least until the stratigraphic position and fauna of the type Lenoir are better understood.

Coarse-grained limestones in the lower part of the Ward Cove limestone member of the Cliffield are very probably the same as a part or all of the Effna limestone and also probably correspond to the Holston limestone as identified by Butts in the southeastern belts of the southern Appalachian Valley of Virginia. Also, a part of the beds identified as Holston in the northwestern belts is the same as the lower part of the Ward Cove limestone member, but in some places Butts' Holston[88] is younger than any part of the Cliffield formation. The relations of the coarse-grained limestones of the Ward Cove member to the type Holston of Tennessee are unknown. Northeast of Tazewell the same beds which Butts calls Holston in western Tazewell County are classed with the Murfreesboro formation[89]. Possibly beds in the upper part of the coarse-grained limestone of the Ward Cove member are equivalent to all or a part of the Whitesburg limestone, but this is not supported by any known evidence. If there are no Whitesburg equivalents in the coarse-grained limestones of the Ward Cove member, then there is a hiatus between the two zones of the Ward Cove limestone.

The upper part of the Ward Cove limestone, the *Nidulites* zone, is very similar in stratigraphic position, lithology, and fossils to the Athens limestone as developed in the valleys between Walker and Brushy mountains. *Nidulites pyriformis, Receptaculites* sp., *Sowerbyella negrita, Schizambon cuneatus, Lingula* sp., *Lophospira* sp., *Calliops annulatus, Niobe* sp., *Remopleurides* sp., *Hyboaspis* sp., and *Oxoplecia* sp. occur in both the Athens and the *Nidulites* zone of the Ward Cove member as developed northwest of Clinch and Garden mountains. Also *Strophomena tenuitesta* Willard occurs in the topmost beds of the Athens, in the overlying cherty beds of the Peery member (*Lophospira* zone), at the top of the *Nidulites* zone along Plum Creek west of Tazewell, and in the *Lophospira* beds of the overlying Peery member along U. S. Route 19 west of Wittens Mills. The main difference between the *Nidulites* zone of the Ward Cove member and the Athens is the absence of graptolites in the former. Further

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[88] Cooper, B. N., and Prouty, C. E., op. cit., p. 855.

[89] Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. 1, pp. 120-135.

search in the beds northwest of Clinch Mountain may disclose graptolites in the *Nidulites* zone, and the suggested correlation between the Athens and the upper part of the Ward Cove member would then be substantiated. The fact that the *Nemagraptus gracilis* fauna is found in the Normanskill shale of New York is an indication of the equivalency of at least a part of the Normanskill to the Athens formation of the Appalachian Valley.

The fauna of the cherty zone of the Peery member, or formation, is strikingly similar to that of the Murfreesboro limestone of the Central Basin of Tennessee; and the faunal link is so close that there can be little doubt as to their contemporaneity. This similarity of fossils brings to light some serious inconsistencies in the regional stratigraphic nomenclature advocated by Ulrich. According to him, the Murfreesboro underlies the Mosheim along Yellow Branch in Lee County, Virginia, and is therefore older than the Mosheim. In Tazewell County, the Murfreesboro fauna is found only in the *Lophospira* zone of the Peery limestone—300 to 750 feet stratigraphically above the calcilutyte which Butts has identified as the Mosheim. Butts would class the *Lophospira* zone and the *Nidulites* beds near Wittens Mills with the Ottosee formation which is much younger (late Chazyan) than the Murfreesboro of Tennessee, according to Ulrich. The upper calcilutyte of the Cliffield is Butts' Mosheim in the vicinity of Bluefield, Virginia, but is classed with the Ottosee by him in parts of western Tazewell County. The Mosheim at the type locality is probably about the same as the Five Oaks limestone and is therefore older than the Murfreesboro of the Central Basin of Tennessee.

In summary, the Cliffield formation or group is approximately equivalent to Butts' Mosheim-Lenoir-Holston-Whitesburg-Athens succession of the southeastern belts of the Appalachian Valley of Virginia, and to Butts' Murfreesboro, Mosheim, Lenoir, Holston, and lower Ottosee northwest of Clinch Mountain. Correlations of the various parts of the Cliffield with New York formations must await further work.

BENBOLT LIMESTONE

Name.—The Benbolt limestone, named after a historic homestead in the east environs of Tazewell, Virginia, includes all of the limestones between the calcilutyte zone of the Peery limestone and the dove-gray calcilutytes of the Gratton containing *Tetradium* *racemosum* in the exposed section west of the cattle barn at the Tazewell County Farm. The Benbolt was first described by the writer and C. E. Prouty[90].

Distribution.—One belt of the Benbolt extends southwestward along the northwest base of East River Mountain and U. S. Route 19 to Wittens Mills. In the roadside quarry along U. S. Route 19 east of Wittens Mills the Benbolt is only 6 feet thick. In all probability the formation is absent in the vicinity of Five Oaks. Another belt is exposed along Road 650 south and east of St. Clair School. This belt is terminated both on the northeast and southwest by a branch of the St. Clair overthrust. The Benbolt crops out on either side of the valleys between Rich and Buckhorn mountains. Exposures along the base of Buckhorn Mountain extend from Benbolt northeastward to the vicinity of Kinzer Church where the formation ends against a branch of the Narrows overthrust fault. In Burkes Garden the Benbolt crops out over much of the broad valley floor and its two members are mapped separately (Pl. 1). Two belts of the formation in Thompson Valley merge to the northeast. Between Brushy and Walker mountains the Benbolt directly overlies the *Lophospira* zone of the Peery limestone, and its distribution is approximately the same as that of the Athens formation (Pls. 5, 8).

Subdivisions.—The Benbolt is composed of four principal faunal and lithologic zones which are conveniently grouped into two members, the Shannondale (lower) and Burkes Garden limestones.

SHANNONDALE LIMESTONE MEMBER

Name.—The Shannondale limestone member of the Benbolt formation was named from exposures along the northwest base of East River Mountain south of Shannondale on U. S. Route 19[91]. The two zones assigned to this member do not contain the same fossils as are found in the upper zones of the Benbolt formation. Certain lithological differences also make the Shannondale member distinctive.

Lithology.—Dark bluish-gray, medium-bedded, coarse-grained, sparsely cherty limestones occur locally at the base of the Shannondale limestone. In many parts of the quadrangle the coarse-grained

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[90] Cooper, B. N., and Prouty, C. E., op. cit., pp. 868-871.

[91] Idem.

rock at the base of the Shannondale is absent. The zone has its best development in the western part of Burkes Garden near the base of Hall Ridge. In the type section south of Shannondale, the coarse-grained limestone is about 20 feet thick. Near Wittens Mills all of the 6 to 10 feet of the Benbolt are referable to this zone. The zone of coarse-grained rock is also well exposed in Thompson Valley, particularly in the pasture lands 1 mile south of the 2,822-foot bench mark along the Thompson Valley road. So far as known, the coarse-grained limestone of the Shannondale member does not occur in the valleys between Walker and Brushy mountains.

The greater part of the Shannondale member is composed of very argillaceous, dark-gray, nodular-weathering limestones (Pl. 7C). Rapid weathering of the rock frees fossils which litter the outcrop. The northwestern belt contains 65 to 100 feet of nodular limestone between the eastern border of the quadrangle and the divide between Clinch and Bluestone rivers.

Fossils.—The following forms are common in the Shannondale limestone member:

- Algae
  - Girvanella sp.
- Sponges
  - Eospongia cf. E. roemeri Billings
  - Dystactospongia sp.
- Bryozoa
  - Anolotichia cf. A. explanata Coryell
  - Pachydictya sp.
- Brachiopods
  - Camarella cf. C. varians Billings
  - Camarella quadriplicata (Willard)
  - Campylorthis sp.[92]
  - Dinorthis quadriplicata Willard
  - Dinorthis transversa Willard
  - Glyptorthis bellarugosa (Conrad)
  - Mimella melonica (Willard)
  - Mimella superba Butts
  - Öpikina "minnesotensis" (Winchell)
  - Ptychoglyptus sp.
  - Plectorthis cf. P. exfoliata Raymond

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[92] Probably conspecific with "*Multicostella M. aff. platys*" illustrated in Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. 2, pl. 90, figs. 37-48, 1941.

    "Rafinesquina" cf. R. deltoidea (Conrad)
    "Rafinesquina" sp.[93]
    "Rafinesquina" cf. R. pulchella Raymond
    Sowerbyella sp.[94]
    Strophomena tennesseensis[95] Willard
    "Zygospira" cf. Z. acutirostris (Hall)
Gastropods
    Holopea sp.
    Maclurites magnus Lesueur
Trilobites
    Bumastus cf. B. lioderma Raymond
    Calliops cf. C. annulatus (Raymond)
    Homotelus elongatus Raymond
    Illaenus fieldi Raymond
Ostracodes
    Eurychilina cf. E. latimarginata (Raymond)
    Leperditia sp.

Strophomena tennesseensis and *Öpikina "minnesotensis"* are most common and characterize the Shannondale limestone throughout the Burkes Garden quadrangle. Specimens of *Maclurites magnus* from the Shannondale have been compared with *M. magnus* from the Lenoir limestone of the type locality in Tennessee and were found indistinguishable. About 1½ miles southwest of Station Spring in Burkes Garden fossils are especially abundant in the Shannondale member and several fine specimens of *Maclurites magnus* are exposed in the bed of an intermittent stream at the east base of Hall Ridge.

Geologic Section 15.—Type section of Shannondale limestone member, half a mile south of Shannondale, Tazewell County, Virginia

	Thickness Feet
Shannondale limestone member (79 feet)	
2. Limestone, dark-gray, nodular, argillaceous, with *Strophomena tennesseensis, Maclurites magnus, Öpikina "minnesotensis," Camarella* cf. *C. varians, Eospongia* sp., *Mimella* sp., and *Homotelus elongatus*	60

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[93] Compare with species illustrated in Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. 2, pl. 86, figs. 3-4, 1941.
[94] Compare with species illustrated in Butts, Charles, op. cit., pl. 90, figs. 1-8.
[95] Compare with *S. amploides* Butts, op. cit., pl. 87, figs. 7-12.

	Thickness Feet
1. Limestone, coarse grained, light bluish-gray, granular, clastic texture, sparsely cherty, with "*Zygospira*" sp., *Öpikina "minnesotensis,"* and *Camarella* sp.......	19

Cliffield formation

BURKES GARDEN LIMESTONE MEMBER

Name.—The Burkes Garden limestone member was named by Cooper and Prouty[96] from Burkes Garden Creek south of Gose Mills, Tazewell County, Virginia. The type section is near Pounding Mill in western Tazewell County.

Lithology.—Above the nodular argillaceous beds of the Shannondale member is a similar thickness of light-gray, granular, crumbly weathering limestone. It is argillaceous like the nodular beds of the Shannondale and also weathers buff-gray. The calcareous part of the rock consists almost wholly of fragmented fossils, of which the stem plates of crinoids and cystoids are very abundant and conspicuous. They distinguish the nodular limestones of the Shannondale member from the granular beds in the lower part of the Burkes Garden member. Another contrast is the abundance of ramose bryozoans in the lower beds of the Burkes Garden member and their general sparsity in the underlying Shannondale.

The crumbly argillaceous layers are overlain by a variable thickness of coarse-grained, cross-laminated limestone. The lower part is light-gray and very coarse-grained; whereas, the upper beds are dark bluish-gray, medium-grained and cherty. In Burkes Garden along the creek banks west of Fish Spring, numerous layers of pinkish marble are intercalated in the zone of cross-laminated limestone. Similar marble beds are found along the west border of the quadrangle, in Thompson Valley at the southeast base of Rich Mountain. In Burkes Garden the cross-laminated zone is about 75 to 100 feet thick. Northwest of Rich Mountain the zone is thinner and consists largely of dark bluish-gray cherty limestone.

The Burkes Garden member is thin or absent northeast of Gratton and in Clinch and Bluestone valleys. Southeast of the Saltville-Bland fault, the Burkes Garden member is typically developed and coarse-grained, cross-laminated layers are prominent.

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[96] Cooper, B. N., and Prouty, C. E., Stratigraphy of the lower Middle Ordovician of Tazewell County, Virginia: Geol. Soc. America Bull., vol. 54, pp. 869-870, 1943.

The best exposure in the Walker Mountain belt is 1 mile southeast of Sharon Springs. The Burkes Garden member is also fully exposed 1 mile north of Ceres along the southeast base of Brushy Mountain.

Fossils.—Fossils collected from the Burkes Garden limestone member include:

- Algae
  - Girvanella sp.
  - Solenopora compacta (Billings)
- Sponges
  - Eospongia sp.
- Corals
  - Tetradium sp.[97]
- Cystoids
  - Echinosphaerites aurantium (Gyllenhal)
- Crinoids
  - Palaeocrinus cf. P. striatus Billings
- Bryozoa
  - Chasmatopora sp.[98]
  - Graptodictya sp.[99]
  - Phaenopora sp.
  - Rhinidictya sp.
- Brachiopods
  - Dinorthis cf. D. quadriplicata Willard
  - Dinorthis transversa Willard
  - Glyptorthis bellarugosa (Conrad)
  - "Leptaena" aff. L. palustris Willard
  - Mimella superba Butts
  - Campylorthis sp.[100]
  - Öpikina "minnesotensis" (Winchell)
  - Paurorthis sp.
  - Planidorsa sp.
  - Ptychoglyptus sp.
  - "Rafinesquina" cf. R. obsoleta Butts
  - Sowerbyella aff. S. aequistriata Willard
  - Strophomena tennesseensis Willard

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[97] Compare with species illustrated by Butts, op. cit., pl. 88, fig. 1.

[98] Compare with species illustrated by Butts, op. cit., pl. 91, figs. 15-16.

[99] Compare with species illustrated by Butts, op. cit., pl. 91, figs. 17-19.

[100] Compare with *Multicostella aff. M. platys* illustrated by Butts, op. cit., pl. 90, figs. 37-48, 1941.

VARIATION IN THICKNESS

The maximum thickness of the Shannondale member is 125 feet, but outside of Burkes Garden it is generally less than 100 feet. The coarse-grained limestones of this member are only of local occurrence, and in most places the entire thickness is nodular limestone. Near Wittens Mills the Shannondale thins to about 10 feet of coarse limestone; and along Lincolnshire Branch west of Five Oaks it may be absent. The Burkes Garden member is thin or absent in Clear Fork Valley and in the Clinch-Bluestone belt.

STRATIGRAPHIC RELATIONS

The disconformity at the base of the Benbolt is indicated by the local absence of either or both the calcilutyte zone at the top of the Peery limestone member and the coarse-grained part of the Shannondale limestone member. South of Shannondale, both of these zones occur and there is no physical evidence of disconformity. The fact that the calcilutyte at the top of the Cliffield formation is absent in Burkes Garden and in southeastern belts may indicate that the southern half of the quadrangle was uplifted slightly more than the northern half following deposition of the Peery member. This would allow for complete removal of the calcilutyte and a considerable part of the underlying *Lophospira* zone of the Peery before the beginning of Benbolt sedimentation.

Geologic Section 16.—Benbolt limestone at the Tazewell County Farm, Tazewell County, Virginia

	Thickness	
	Ft.	In.
Benbolt limestone (100 feet)		
Burkes Garden limestone member (57 feet)		
7. Limestone, steel-gray, argillaceous, dense faintly cross laminated, cherty	7	6
6. Limestone, coarse grained, light-gray, cross laminated, weathers saccharoidal	10	
5. Limestone, granular, crumbly; contains an abundance of bryozoans and stem-plates of crinoids and cystoids; contains *Girvanella* sp., *Glyptorthis*, *Chasmatopora*, and *Paurorthis*	11	6

	Thickness	
	Ft.	In.
4. Limestone, medium grained, fossiliferous, with bryozoans, particularly *Chasmatopora*, abundant	28	
Shannondale limestone member (43 feet)		
3. Limestone, argillaceous, nodular, weathers buff; contains *Öpikina "minnesotensis"*, *Maclurites magnus*, *Ptychoglyptus* sp., and *Strophomena tennesseensis*	33	5
2. Limestone, blocky, fine to coarse grained, uneven texture; contains *Mimella*, *Maclurites*, and *Lophospira*-type gastropods	3	5
1. Limestone, coarse grained, light-gray; with *Illaenus* sp. and *Strophomena tennesseensis*	6	8
Cliffield formation		

Geologic Section 17.—Benbolt limestone at the east base of Hall Ridge, Burkes Garden, Tazewell County, Virginia

	Thickness	
	Ft.	In.
Benbolt limestone (235± feet)		
Burkes Garden limestone member (90 feet)		
9. Limestone, dark-gray, cherty, granular	20	
8. Limestone, coarse grained, light-gray, cross laminated; *Echinosphaerites aurantium*, *Paleocrinus* cf. *P. striatus*, and an abundance of crinoid and cystoid columnals	43	
7. Limestone, light-gray, argillaceous, weathers buff and crumbly; contains *Chasmatopora* sp., *Dinorthis transversa*, *Dinorthis quadriplicata*, *Paurorthis* sp., and a small *Girvanella*	27	
Shannondale limestone member (125± feet)		
6. Limestone, dark brownish-gray, very fossiliferous, nodular; contains *Maclurites magnus*, *Öpikina "minnesotensis"*, *Mimella* sp., *Eospongia* sp., and *Campylorthis*	50–75	
5. Limestone, fine grained, dense, cherty, dark bluish gray; *Strophomena tennesseensis*	24	
4. Limestone, medium grained, bluish; with *Maclurites*	4	6

	Thickness	
	Ft.	In.
3. Covered interval, nodules of *Öpikina*-bearing limestone in soil	22	5
2. Limestone, nodular, argillaceous	5	
1. Limestone, nodular, argillaceous, grades down into granular black limestone; contains large *Maclurites* about 6 inches in diameter	15	9

Base not exposed

Geologic Section 18.—Benbolt limestone a mile north of Ceres, Bland County, Virginia

	Thickness Feet
Moccasin formation	
Benbolt limestone (102 feet)	
Burkes Garden limestone member (80 feet)	
5. Limestone, dark bluish-gray, cherty, few fossils	7
4. Limestone, coarse grained, medium- to light-gray; contains *Solenopora compacta,* a massive bryozoan, *Girvanella* sp., and numerous columnals of crinoids and cystoids	18
3. Limestone, very coarse grained, bluish-gray, cross laminated, weathers crumbly	27
2. Limestone, very argillaceous, weathers bright-buff; contains *Chasmatopora* sp., *"Rafinesquina"* cf. *R. obsoleta, Dinorthis quadriplicata,* and *Paurorthis* sp.	28
Shannondale limestone member (22 feet)	
1. Limestone, argillaceous, nodular, dark-gray; contains *Öpikina "minnesotensis", Strophomena tennesseensis,* and a small *Maclurites*	22
Cliffield formation (*Lophospira* zone of the Peery limestone member)	

AGE AND CORRELATION

The Benbolt corresponds to Butts' Ottosee limestone of certain areas in southwestern Virginia, notably Rye Cove and the Speers Ferry—Gate City area in Scott County. Beds identified as Lenoir limestone by Butts at St. Clair, Tazewell County, and along Yellow Branch, Lee County, Virginia, are apparently the same as the Benbolt. The Benbolt is also tentatively correlated with the Pierce and Ridley formations of the Central Basin of Tennessee. The type Lenoir of Tennessee is much older than the Benbolt and its equivalents. The New York equivalents of the Benbolt have not yet been established.

GRATTON LIMESTONE

Name.—The Gratton limestone was named by Cooper and Prouty[101] from Gratton, Tazewell County, Virginia. The type locality is at the Tazewell County Farm, south of Benbolt.

Distribution.—The Gratton limestone is present only in the Ordovician belts northwest of Clinch Mountain, and it has no equivalents in the Ordovician limestones exposed in the valley between Walker and Brushy mountains (Pls. 1, 5).

Lithology.—Two distinctive zones of Gratton limestone are present in Burkes Garden and other belts north of the Saltville-Bland fault. The lower zone is composed of slightly argillaceous, straticulate calcilutyte. The laminated structure (Pl. 7B) is accentuated by weathering. Many bedding surfaces are mud-cracked, and reworking of the desiccated laminae has produced intraformational sliver breccias. The lower beds contain nodules of white chert in Burkes Garden and in Clear Fork Valley. The best exposures of the straticulate beds are 2½ miles east of Gratton, about 250 feet south of a quarry in the Lincolnshire limestone; along the northwest base of East River Mountain south of Shannondale swimming pool; and half a mile south of the 3,194-foot bench mark in the eastern part of Burkes Garden. In all three localities the cherty beds at the base are well exposed. The average thickness of these beds is 15 feet but in Burkes Garden it is 30 feet thick.

The upper zone of the Gratton is medium- to thick-bedded, dove-gray calcilutyte containing locally intercalations of dark bluish-gray, granular, cherty limestone. Weathered surfaces of the fine-grained beds are dotted with "birdseyes" of white calcite which have replaced corallites of *Tetradium* corals. Bedding surfaces are commonly stylolitic, and some are mud cracked. Intraformational breccia and conglomerate are prominent in Burkes Garden and in Thompson Valley. The average thickness of the calcilutyte zone is about 60 feet. The zone is well exposed in the following places: along U. S. Route 19 east of Wittens Mills and west of

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[101] Op. cit., pp. 872-873.

Benbolt; south of Shannondale; north of Gratton; along the northwest slope of Rich Mountain near the Bland-Tazewell County line; 1 mile south of the 2,822-foot bench mark in Thompson Valley; and west of the cattle barn at the Tazewell County Farm.

Fossils.—Few of the fossils in the Gratton limestone can be freed from the rock and the number identified is small. The following were collected from the type section west of the Tazewell County Farm:

- Sponges
    - Cryptophragmus antiquatus Raymond (rare)
- Hydroids
    - Stromatocerium rugosum Hall (rare)
- Corals
    - Tetradium cellulosum (Hall)
    - Tetradium columnare ? (Hall)
    - Tetradium racemosum Raymond (common)
- Gastropods
    - Eotomaria sp.
    - Omospira cf. O. laticincta Ulrich
    - Subulites sp.
- Cephalopods
    - Orthoceras sp. (common)
- Trilobites
    - Bathyurus sp.
    - Calyptaulax sp.
- Ostracodes
    - Isochilina sp.
    - Leperditella sp.
    - Primitiella constricta Ulrich
    - Primitiella sp.

Geologic Section 19.—Type section of the Gratton limestone at the Tazewell County Farm near Benbolt, Tazewell County, Virginia

	Thickness Ft.	In.
Gratton limestone (48 feet)		
6. Calcilutyte, brownish-gray, weathers bluish-gray....	8	
5. Calcilutyte, golden-gray; contains *Tetradium cellulosum* and *Tetradium racemosum*	4	

	Thickness	
	Ft.	In.
4. Calcilutyte, thin bedded, nodular weathering, somewhat argillaceous; *Tetradium racemosum* abundant	5	
3. Calcilutyte, bluish-gray; stylolites along bedding surfaces; contains *Eotomaria* and *Subulites*, as well as numerous *Tetradium*	20	4
2. Calcilutyte, taupe-gray, weathers smoke-gray	1	3
1. Calcilutyte, argillaceous, laminated; clayey laminae weather buff	9	5
Benbolt limestone		

Geologic Section 20.—Gratton limestone 2½ miles northeast of Gratton, along Rich Mountain, Tazewell County, Virginia

	Thickness	
	Ft.	In.
Gratton limestone (113 feet)		
4. Limestone, steel-gray, finely granular, weathers fluted	27	
3. Calcilutyte, light bluish-gray; beds average 6 inches thick; contains *Isochilina* and *Calyptaulax*	58	
2. Calcilutyte, finely laminated; clayey layers weather buff and limestone laminae weather gray; few fossils other than *Tetradium*	14	
1. Limestone, fine grained, dense, partly straticulate; contains numerous flattened nodules of white chert; one 4-inch bed of white chert about 1 foot below top	14	
Benbolt limestone.		

Correlation.—The fauna of the Gratton is somewhat similar to that of the Lowville ("Birdseye") limestone of New York State, but this similarity is equalled by that between the Gratton and New York Pamelia. Possibly the Gratton is not equivalent to either. The Gratton comprises a part of the Lowville-Moccasin of Butts in the eastern part of Tazewell County, but west of the town of Tazewell Butts puts the Gratton in the Ottosee.

Stratigraphic relations.—In the west part of Burkes Garden and in the valley of the South Fork of Clinch River west of Marys Chapel, the Gratton limestone is overlain in ascending order by the Wardell, Bowen, and Witten formations. Elsewhere the Gratton is directly succeeded by the Witten. Although a hiatus exists between the Gratton and Witten, their contact shows no evidence of disconformity. The Gratton seems to be conformable with the underlying Benbolt where the Burkes Garden limestone member is present. In parts of Clear Fork Valley and in Bluestone Valley a disconformity occurs between the Gratton and the underlying Shannondale limestone.

WARDELL FORMATION

Name.—The Wardell formation was named by Cooper and Prouty[102] from exposures on the southeast slope of Paint Lick Mountain, south of Claypool Hill, Tazewell County, Virginia.

Distribution.—The Wardell formation occurs in Thompson Valley, in the western part of Burkes Garden, and in the valley of the South Fork of Clinch River west of Marys Chapel. In Tazewell County, Virginia, the Wardell forms a wedge which overlaps the Gratton limestone to the northeast (Pls. 1, 5). Like the Gratton, it appears to be absent in the valley between Walker and Brushy mountains.

Lithology.—The Wardell formation is composed of four principal zones, each of which is unusually distinctive. The lowest beds are coarse-grained, coquina limestones containing an abundance of corals and hydroids. The second zone, which is the most distinctive, is composed of very argillaceous, nodular-weathering, fossiliferous limestones. Nodular beds are overlain locally by lenses of coarse-grained, pinkish limestone similar to the Holston marble of Tennessee. This zone occurs only in Thompson Valley. The top or fourth division is composed of calcareous shale which weathers bright buff. In Thompson Valley, the Wardell is 75 to 95 feet thick; west of Marys Chapel, 35 feet; and in Burkes Garden about 60 feet thick. One of the best exposures of the Wardell in southwestern Virginia is along State Highway 16 on the northwest side of Thompson Valley, about 3 miles west of the Burkes Garden quadrangle. Essentially the same succession extends northeastward to Burkes Garden.

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[102] Op. cit., pp. 873-875.

Geologic Section 21.—Wardell formation along State Highway 16, about 3½ miles southwest of Tazewell, Tazewell County, Virginia

	Thickness	
	Ft.	In.
Wardell formation (95 feet)		
9. Shale, smoky-gray, calcareous; weathers buff and very platy; middle part contains thin lenses of coarse-grained limestone	47	4
8. Limestone, coarse grained, nodular; contains large ostracodes and an abundance of cystoid columnals and bryozoans	2	
7. Limestone, medium to coarse grained, dark-gray, very granular; bryozoans abundant	6	
6. Limestone, coarse-grained; resembles the Holston marble of Tennessee; lenticularly bedded; 6 inches of buff shale near base; crinoid and cystoid stem-plates abundant	12	
5. Limestone, medium grained, uneven textured, argillaceous; contains large *Isochilina armata* ? and a few *Girvanella* sp.	2	
4. Limestone, cross laminated, coarse grained, bluish-gray; clastic texture	1	2
3. Limestone, very nodular, thin bedded, argillaceous, buff weathering; contains *Rostricellula* cf. *R. plena, Receptaculites biconstrictus, Batostoma sevieri, Escharopora* sp., *Rhinidictya* sp., *Pachydictya* sp., and *Scenellopora* sp.	10	8
2. Limestone, coarse grained; contains abundance of cystoid stem-plates	1	3
1. Limestone, medium grained, uneven textured; argillaceous stringers and pits; contains *Batostoma sevieri, Cleiocrinus* sp., *Stromatocerium rugosum, Foerstephyllum halli, Lichenaria carterensis, Girvanella* sp., *Solenopora compacta,* and a compressed *Receptaculites*	13	4
Gratton limestone		

Geologic Section 22.—Wardell formation at the east base of Hall Ridge in Burkes Garden, Tazewell County, Virginia

	Thickness Feet
Wardell formation (62 feet)	
3. Shale, buff, platy; contains numerous bryozoans	1
2. Limestone, nodular, argillaceous; contains large *Isochilina, Receptaculites, Girvanella,* and *Rostricellula* sp.	15
1. Limestone, coarse grained, somewhat argillaceous, very fossiliferous; contains *Foerstephyllum halli, Lichenaria carterensis, Stromatocerium rugosum, Escharopora* sp., *Girvanella* sp., and *Batostoma sevieri*	46
Gratton limestone	

Geologic Section 23.—Wardell formation half a mile west of Marys Chapel, Tazewell County, Virginia

	Thickness Feet
Wardell formation (35 feet)	
3. Shale, buff, platy; bryozoans abundant	15
2. Limestone, nodular, fine grained	12
1. Limestone, coarse grained, clastic texture; contains *Foerstephyllum*	8
Gratton limestone	

Fossils.—The Wardell is one of the most fossiliferous formations in the Burkes Garden quadrangle. The common forms include:

- Algae
  - Girvanella sp.
  - Solenopora compacta (Billings)
- Sponges
  - Dystactospongia sp.
  - Receptaculites biconstrictus Ulrich
  - Receptaculites sp.
- Hydroids
  - Stromatocerium rugosum Hall

Corals
    Foerstephyllum halli (Nicholson)
    Fletcheria sp.
    Lichenaria carterensis (Safford)
Cystoids
    Caryocystites sp.
    Cheirocrinus angulatus Wood
Crinoids
    Carabocrinus sp.
    Cleiocrinus tessellatus (Troost)
    Diabolocrinus sp.
Bryozoa
    Batostoma sevieri Bassler
    Escharopora cf. E. subrecta Ulrich
    Hemiphragma sp.
    Pachydictya robusta Ulrich
    Rhinidictya sp.
    Scenellopora radiata Ulrich
Brachiopods
    Glyptorthis sp.
    Hesperorthis cf. H. tricenaria (Conrad)
    Mimella globosa (Willard)
    Pionodema ? subaequata circularis (Winchell)
    Rostricellula cf. R. plena (Hall)
    Strophomena cf. S. emaciata Winchell and Schuchert
    Strophomena incurvata (Shepard)
Pelecypods
    Vanuxemia cf. V. crassa Ulrich
Trilobites
    Calliops callicephalus (Hall)
    Illaenus conradi Billings
Ostracodes
    Isochilina armata (Walcott)

Stratigraphic relations.—There is no physical evidence of a break between the Wardell formation and underlying Gratton limestone. An unconformity between the Wardell and overlying Bowen formation is indicated by the absence of the brown sandstone which overlies the buff shales of the Wardell in western Tazewell County. In Burkes Garden, the Wardell is unconformably overlain by the Witten limestone. The

Wardell overlaps the Gratton and is overlapped by the Bowen and Witten formations.

Correlation.—The Wardell includes some of the beds which Butts considers characteristic of the Ottosee in southwestern Virginia. Locally, he has regarded the Gratton as a part of the Lowville and has mapped the Wardell with the Moccasin formation. Correlatives of the Wardell in other states are not yet known.

BOWEN FORMATION

Name.—The Bowen formation was named by Cooper and Prouty[103] from Bowen Cove in western Tazewell County, Virginia.

Distribution.—In the Burkes Garden quadrangle, the Bowen formation occurs only in Thompson Valley and in the valley of the South Fork of Clinch River west of Marys Chapel (Pl. 1). It is thin or absent along the northwest base of Walker Mountain and is absent along the southeast base of Brushy Mountain northwest of Ceres.

Lithology.—In western Tazewell County the Bowen formation is composed of brown-weathering sandstone and an overlying zone of red, straticulate mudrock (Pl. 5). Both zones extend southwest along Clinch Mountain into Scott County, Virginia, but they thin to the northeast. The sandstone pinches out about 8 miles northeast of the Russell-Tazewell county line. The mudrock zone extends farther northeast but pinches out near Marys Chapel, Five Oaks, and the east end of Thompson Valley.

Most of the Bowen in the Burkes Garden quadrangle is maroon-drab mudrock but dove-gray and apple-green argillaceous calcilutytes are locally prominent. The upper 3 to 5 feet is mud cracked and columnar jointed. Half a mile west of Marys Chapel, the Bowen is about 30 feet thick; along Lincolnshire Branch about 2 feet thick; and in Thompson Valley less than 40 feet thick.

Fossils.—The only fossil which has been found in the Bowen is *Tetradium fibratum* Safford. Slabs of red mudrock containing this coral were found along the southeast slope of Rich Mountain near the western border of the quadrangle and also near Marys Chapel.

Stratigraphic relations.—An unconformity between the Bowen and the underlying Wardell formations is indicated by the absence of brown sandstone which underlies the red mudrock tongue in western

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[103] Op. cit., pp. 876-877.

Tazewell County. The upper contact is conformable. Columnar joints in the lower part of the overlying Witten limestone persist downward into the topmost beds of the Bowen mudrock. Evidently the Bowen was consolidated during the short interval of desiccation in early Witten time, when the columnar joints were produced.

Correlation.—The Bowen is the basal part of the Lowville-Moccasin formation of Butts[104] in middle belts of the southern Appalachian Valley in Virginia. It was not considered a part of the Moccasin by Campbell[105] (Pl. 9). It extends southwest at least as far as the Tennessee-Virginia line. Whether the Bowen is present northeast of Tazewell County is not yet known.

WITTEN LIMESTONE

Name.—The Witten limestone was named by Cooper and Prouty[106] from Witten Valley, Tazewell County, Virginia. The type section is along State Highway 16 about 3½ miles southwest of Tazewell.

Distribution.—The Witten is found directly below the Moccasin red beds in all the Ordovician belts northwest of the Saltville-Bland fault. It is absent along the southeast base of Brushy Mountain, but seems to be represented by a few feet of beds along the northwest slope of Walker Mountain (Pls. 1, 5, 8).

Lithology.—The Witten limestone is composed of four faunal and lithologic zones with an aggregate thickness of 100 to 125 feet. The lowest beds are taupe-gray, argillaceous, straticulate calcilutyte 10 to 25 feet thick. Columnar joints in the laminated beds cause the zone to weather into pillars. One of the finest exposures of this zone is one-fourth of a mile west of the intersection of Roads 631 and 632 near North Tazewell (Pl. 7A). It is exposed on the northwest slope of East River Mountain south of Shannondale swimming pool and also a few yards south of U. S. Route 19 about 1¼ miles east of Wittens Mills.

The straticulate beds grade upward into medium-bedded, light dove-gray calcilutytes 20 to 35 feet thick. Weathered surfaces are covered with "birdseyes" of *Tetradium* corals. The Witten calcilutytes are considerably more argillaceous than those of the Gratton and

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[104] Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. 1, pp. 179-191, 1940.

[105] Cooper, B. N. and Prouty, C. E., Stratigraphy of the lower Middle Ordovician of Tazewell County, Virginia: Geol. Soc. America Bull., vol. 54, p. 877, 1943.

[106] Idem, pp. 877-879.

Cliffield formations and are easily distinguished by their buff-weathering surfaces.

Light-gray, coarse-grained limestones compose the third zone of the Witten and comprise the most fossiliferous beds in the formation. Most of the beds are crowded with fragmented fossils. Generally the base is somewhat shaly, and from these layers whole fossils are readily extracted. Over 100 measurements of this zone in Tazewell County show that the thickness is from 15 to 25 feet and averages 18 feet. The upper contact is gradational, and coarse-grained beds are thinly intercalated throughout the overlying zone of the Witten.

The top division, comprising the most distinctive zone of the Ordovician of southwestern Virginia, is composed of fine-grained, even-bedded, golden-gray to dark dove-gray limestones. Weathered surfaces are generally much lighter than the fresh rock. Ribbon-like beds of coarse-grained limestone form thin intercalations but make up less than 15 per cent of the total thickness which is 50 to 75 feet. The beds are full of clayey casts of sponges and fucoids and, where weathered, have a "worm-eaten" appearance. The finest display of "worm-eaten" beds is about 1 mile west-southwest of Station Spring in Burkes Garden. The fucoid beds characteristically weather into slabs 1 to 3 inches thick.

The Walker Mountain belt of the Witten contains about 40 feet of impure calcilutytes and thin intercalations of coarse-grained, *Cryptophragmus*-bearing limestone.

Fossils.—The four zones of the Witten are fossiliferous, but the coarse-grained beds contain the greatest variety of fossils. The following list includes only the more common forms:

- Fucoids
    - Buthotrephis cf. B. inosculata Bassler
    - Phytopsis tubulosa ? Hall
- Sponges
    - Camarocladia cf. C. gracilis Bassler
    - Camarocladia cf. C. implicatum Bassler
    - Cryptophragmus antiquatus Raymond
    - Dystactospongia minor Ulrich and Everett
- Hydroids
    - Dermatostroma sp.

- Corals
  - Tetradium cellulosum (Hall)
  - Tetradium clarki ? Okulitch
  - Tetradium fibratum Safford
  - Tetradium racemosum Raymond
- Bryozoa
  - Escharopora sp.
  - Graptodictya sp.
  - Phyllodictya frondosa Ulrich
  - Rhinidictya nicholsoni Ulrich
- Brachiopods
  - Doleroides sp.
  - Hesperorthis cf. H. tricenaria (Conrad)
  - Pionodema minuscula Willard
  - Sowerbyella cf. S. lebanonensis Bassler
  - Strophomena incurvata (Shepard)
  - Zygospira cf. Z. recurvirostris (Hall)
- Gastropods
  - Helicotoma cf. H. verticalis Ulrich
  - Helicotoma cf. H. granosa Ulrich
  - Liospira sp.
  - Maclurites bigsbyi (Hall)
  - Omospira cf. O. laticincta Ulrich
  - Subulites regularis Ulrich and Scofield
  - Trochonema umbilicatum (Hall)
- Cephalopods
  - Cameroceras multicameratum (Emmons)
- Trilobites
  - Illaenus sp.
  - Calliops callicephalus (Hall)
  - Calytaulax confluens (Foerste)
- Ostracodes
  - Isochilina armata (Walcott)
  - Krausella arcuata Ulrich
  - Leperditella sulcata (Ulrich)

Geologic Section 24.—Witten limestone 1½ miles northeast of Thompson School, Thompson Valley, Tazewell County, Virginia

	Thickness Feet
Moccasin formation	
Witten limestone (86 feet)	
3. Limestone, lilac-gray to dark dove-gray, flaggy, fine grained; *Camarocladia* abundant; contains a few thin intercalations of coarse-grained limestone	55
2. Limestone, thin and wavy bedded, coarse grained, fossiliferous; contains *Zygospira* cf. *Z. recurvirostris, Sowerbyella* sp., *Cryptophragmus antiquatus,* and *Rhinidictya nicholsoni*	15
1. Calcilutyte, medium bedded in upper part, straticulate near the base; *Tetradium racemosum* abundant	16
Bowen formation	

Geologic Section 25.—Witten limestone 1 mile south of Shannondale, Tazewell County, Virginia

	Thickness Feet
Moccasin formation	
Witten limestone (121 feet)	
4. Limestone, golden-gray to dove-gray, fine grained, dense, flaggy; contains *Camarocladia* and *Buthotrephis*	66
3. Limestone, coarse grained, thin bedded, fossiliferous; *Cryptophragmus antiquatus, Isochilina armata, Zygospira recurvirostris,* and bryozoans	15
2. Calcilutyte, medium bedded, argillaceous, buff-gray; contains *Tetradium cellulosum* and *Tetradium columnare*	17
1. Calcilutyte, straticulate, mud cracked, weathers in short pillars; *Calyptaulax* sp.	23
Gratton limestone	

Geologic Section 26.—Witten limestone 1½ miles east of Cove Creek, Tazewell County, Virginia

	Thickness Feet
Moccasin formation	
Witten limestone (115 feet)	
4. Limestone, dove-gray, fine grained, slabby; contains *Camarocladia* cf. *C. gracilis* and *Isochilina* sp.	47
3. Limestone, coarse grained, thin bedded, dark-gray; contains *Cryptophragmus antiquatus, Zygospira recurvirostris, Strophomena incurvata, Sowerbyella* cf. *S. lebanonensis, Helicotoma* cf. *H. granosa,* and *Rhinidictya nicholsoni*	15
2. Calcilutyte, argillaceous, medium bedded, golden-gray; weathered surfaces covered with "birdseyes" of *Tetradium* corals	43
1. Calcilutyte, argillaceous, platy, mud cracked	10
Gratton limestone	

Stratigraphic relations.—Where the Witten is underlain by the Bowen mudrock, the lower contact is transitional. In Bluestone and Clear Fork valleys and in parts of Burkes Garden and Clinch Valley, an unconformity between the Gratton and Witten is indicated by the absence of the Wardell and Bowen formations. Throughout the Ordovician belts northwest of the Saltville-Bland fault, the Witten and Moccasin are apparently conformable.

Correlation.—The Witten limestone bears faunal similarity to the Lebanon and Tyrone formations of the Central Basin of Tennessee, the Lowville and Pamelia of New York and Ontario, and to part of the Camp Nelson limestone of Kentucky. However, its exact equivalents have not yet been established. The Witten corresponds to the Lowville limestone of the Lowville-Moccasin formation of Butts in middle belts of the Appalachian Valley in Virginia southwest of Tazewell.

MOCCASIN FORMATION

Name.—Campbell[107] named the Moccasin formation from Moccasin Creek, near Moccasin Gap, Scott County, Virginia. A study of

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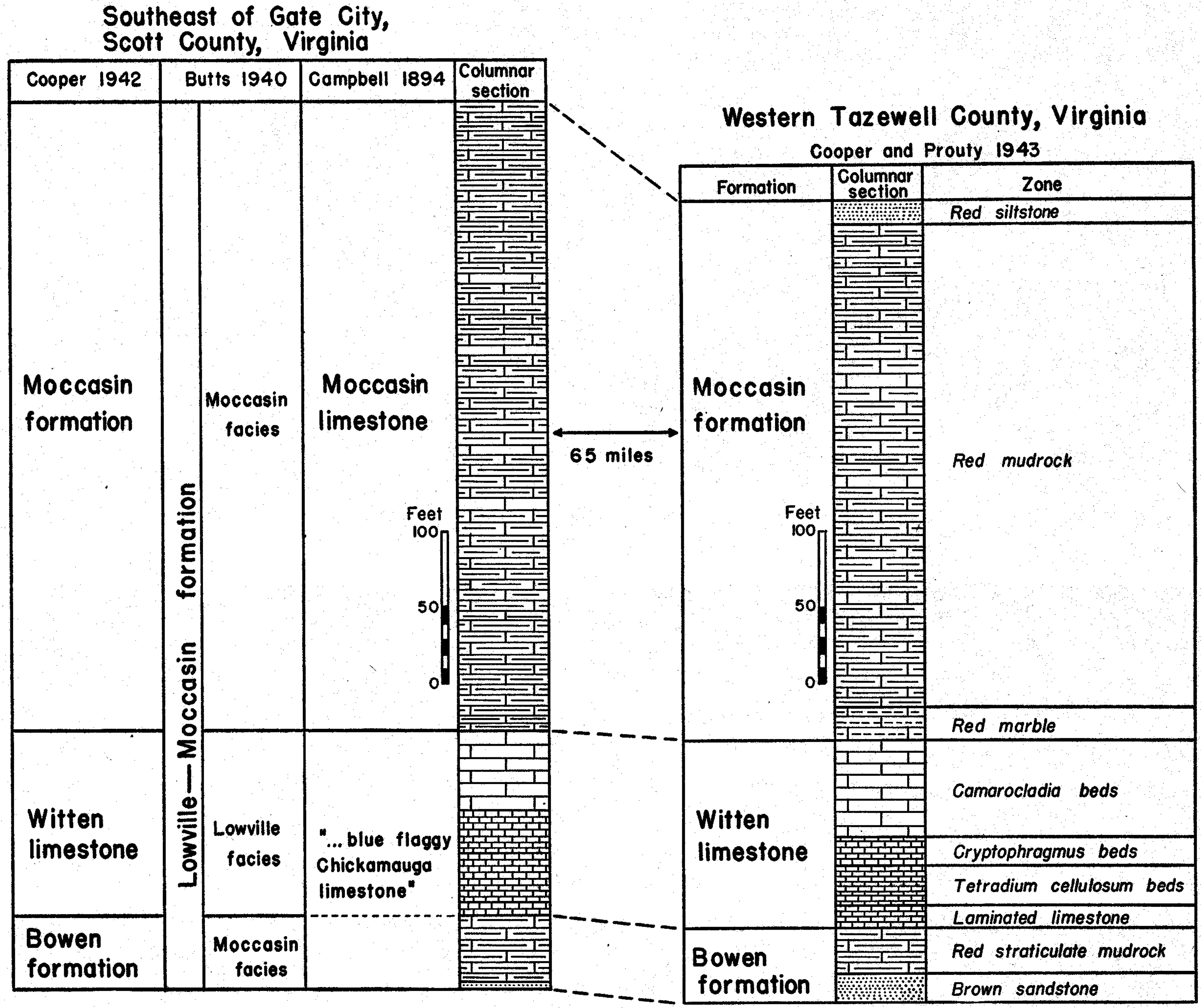
[107] Campbell, M. R., U. S. Geol. Survey Geol. Atlas, Estillville folio (No. 12), p. 2, 1894.



Comparative sections of the Moccasin formation and related beds in southwestern Virginia.

the type section of the Moccasin by the writer[108] shows that the Moccasin formation as defined by Campbell includes only the thick succession of red mudrock above the *Camarocladia* zone of the Witten limestone and does not include the lithologically similar Bowen mudrocks or the intervening limestones of the Witten. The Witten limestones are considered by Butts[109] to represent the Lowville limestone of New York. He also regards the Bowen formation as the initial phase of the Moccasin and concludes that the limestones between the two red zones represent an intercalation of Lowville limestone within the Moccasin. He believes that the stratigraphic relations of the so-called Lowville and the Moccasin indicate that the two are equivalent, and has given the name Lowville-Moccasin to mixtures of limestone and mudrock facies. Cooper and Prouty[110] have suggested that this name should be discarded for the following reasons: the beds given the name Lowville in southwestern Virginia are not known to be equivalent to the New York Lowville; and the limestones which have been called Lowville together with the underlying beds of the Moccasin type of lithology were excluded by Campbell from the type Moccasin (Pl. 9).

The original usage of the name Moccasin is followed by the writer. The formation as thus used includes the relatively thick succession of predominantly red beds overlying the Witten limestone.

Distribution.—The Moccasin is present in all of the belts of Ordovician limestone in the Burkes Garden quadrangle (Pl. 1).

Lithology.—Three zones are readily distinguishable in the Moccasin (Pls. 5, 8). The lowest zone, which is especially well developed northwest of Clinch Mountain, includes the transitional beds between the *Camarocladia*-bearing limestones of the Witten and the main part of the Moccasin which is very argillaceous. This zone has been called the red marble zone of the Moccasin formation[111]. Rocks in this zone take a high polish and are suitable for interior decorative stone. The beds are predominantly red but are mottled with bluish-gray and apple-green. The average thickness of this zone is about 40 feet. The middle zone of the Moccasin is composed of maroon-drab, brick-red, buff-gray, and olive-drab mudrock and siltstone, red waxy shale and metabentonite, bluish-gray calcilutyte, and drab-gray argillaceous limestone. The thickness of this zone is 250 to 435 feet (Pl. 11B).

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[108] Cooper, B. N., Moccasin formation in southwestern Virginia (abstract): Geol. Soc. America Bull., vol. 53, pp. 1799-1800, 1942.

[109] Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. 1, pp. 179-191, 1940.

[110] Cooper, B. N., and Prouty, C. E., Stratigraphy of the lower Middle Ordovician of Tazewell County, Virginia: Geol. Soc. America Bull., vol. 54, p. 877, 1943.

[111] Idem, pp. 879-880.

Throughout the Burkes Garden quadrangle, the Moccasin formation has at its top 15 to 30 feet of black-weathering argillaceous siltstone. Where fresh these beds are dark maroon-drab to olive-drab, like many other beds of the Moccasin, but the mealy texture of this third zone is distinctive.

Probably the best section of the Moccasin in southwestern Virginia is along State Highway 16 about 3½ miles southwest of Tazewell. Essentially the same succession is present in Burkes Garden and in Clinch, Bluestone, and Clear Fork valleys.

Geologic Section 27.—Moccasin formation along State Highway 16, 3 miles southwest of Tazewell, Tazewell County, Virginia

	Thickness	
	Ft.	In.
Eggleston formation		
Moccasin formation (368 feet)		
29. Mudrock and siltstone, red and green	22	
28. Mudrock, red and green, silty	5	
27. Mudrock and siltstone, maroon-drab mottled with green, calcareous	9	
26. Shale, red bentonitic		1
25. Mudrock, maroon-drab, shows fracture cleavage	4	6
24. Shale, bentonitic, dark-maroon		1
23. Mudrock, pale-green, mottled with red	9	
22. Shale, bentonitic, red and green		3
21. Mudrock, maroon-drab	5	6
20. Shale, brick-red to dark-maroon		1
19. Mudrock, maroon-drab, with mud-cracked bedding surfaces	15	
18. Shale, bentonitic, waxy, dark-maroon		6
17. Mudrock, maroon-drab and greenish-gray, mottled	25	
16. Shale, maroon-drab, waxy, bentonitic		2
15. Mudrock, brick-red, slightly calcareous	8	
14. Shale, maroon-drab, waxy, bentonitic		2
13. Mudrock, reddish-brown, calcareous, silty	28	
12. Shale, red and green, mottled, waxy; in sheared zone	1	2

	Thickness	
	Ft.	In.
11. Mudrock, maroon-drab, with intercalations of light-gray, argillaceous limestone	70	6
10. Limestone, greenish-gray and maroon-drab, very fine grained	4	6
9. Limestone, greenish-gray and maroon-drab, mottled, laminated and platy, very argillaceous	7	
8. Calcilutyte, dove-gray to greenish-gray, with thin seams of bentonitic shale	2	
7. Mudrock, bluish-gray, calcareous	1	9
6. Calcilutyte, dove-gray, with abundant calcite veins and vugs. Small fault terminates this bed near top of road cut	4	6
5. Mudrock, brick-red, shaly; contains a few thin seams of mottled red and green calcareous mudrock	17	6
4. Calcilutyte, light-gray to greenish-gray, with seams of yellow clay	16	6
3. Mudrock, maroon-drab, silty, mealy, noncalcareous; contains thin lenses of greenish-gray limestone	51	
2. Mudrock, maroon-drab, calcareous	8	
1. Limestone, argillaceous, brick-red and greenish-gray, variegated	51	
Witten limestone		

Locally, along the southeast base of Buckhorn Mountain, in Clear Fork Valley the Moccasin is composed mainly of olive-drab beds.

Geologic Section 28.—Moccasin formation, half a mile northwest of Kinzer Church, Tazewell County, Virginia

	Thickness Feet
Eggleston formation	
Moccasin formation (434 feet)	
8. Siltstone, olive-drab and maroon-drab, weathers nearly black	22

	Thickness Feet
7. Mudrock, partly calcareous, maroon-drab and olive-drab	28
6. Mudrock, calcareous, lumpy, all maroon-drab	36
5. Mudrock, olive-drab; contains a few intercalations of drab-gray limestone, some with gastropods	33
4. Mudrock, olive-drab; contains many intercalations of argillaceous dove-gray calcilutyte; no red beds	178
3. Mudrock, maroon-drab, lumpy, silty	25
2. Mudrock, calcareous, maroon and olive-drab; contains few intercalations of dove-gray calcilutyte	80
1. Limestone and mudrock, variegated red and green; contains only a few beds of "marble"	32
Witten limestone	

Geologic Section 29.—Moccasin formation along Road 625 from Ceres to Rural Retreat, Bland County, Virginia

	Thickness Feet
Eggleston formation	
Moccasin formation (421 feet)	
17. Mudrock, shaly, purplish-red, with a few thin streaks of metabentonite	14
16. Siltstone and mudrock, purplish-red, mealy	10
15. Mudrock and siltstone, cuneiform joined, purplish-red, micaceous; contains a few intercalations of buff siltstone	20
14. Mudrock, silty, mottled, greenish-gray and red; blocky jointing	44
13. Mudrock, brick-red and greenish gray, mottled; contains a few thin seams of waxy bentonitic clay	38
12. Covered interval, mostly maroon-drab mudrock	69
11. Mudrock, maroon-drab, silty, lumpy; with 1-inch partings of buff clay near the top	21
10. Siltstone, dark dull-red; weathers shaly	11
9. Mudrock, maroon-drab, silty	2

	Thickness Feet
8. Mudrock, maroon-drab, with intercalations of greenish-gray lumpy mudrock; a few thin intercalations of sandy siltstone near the middle	18
7. Mudrock, maroon-drab, soft, mealy	18
6. Limestone, brick-red, argillaceous, blocky; contains tubes of *Camarocladia*	1
5. Calcilutyte, argillaceous, mottled red and green; contains *Camarocladia* tubes	3
4. Limestone breccia; coarse-grained matrix of calcite; surrounding slivers of red mudrock and rounded masses of fine-grained limestone	3
3. Limestone breccia; fine-grained varicolored matrix surrounding rounded masses of *Solenopora compacta* and slivers of red limestone and mudrock	3
2. Limestone, coarse-grained, pinkish with numerous *Solenopora*	3
1. Mudrock and limestone, mottled red and green, very fine grained; bedding accentuated by silty partings; many layers are mud cracked	143

Witten limestone

The Moccasin formation along the southeast base of Brushy Mountain is much thinner than in any of the other belts, the average of three measurements being 95 feet. About three-fourths of a mile north of Ceres it is 110 feet thick and is sufficiently well exposed to show that faults have not affected the formation. Evidently, less Moccasin was deposited there than elsewhere in the quadrangle.

Fossils.—A sponge, similar to *Camarocladia gracilis* Bassler, occurs in many of the limy beds of the Moccasin northwest of the Saltville-Bland fault. In a few places northwest of Clinch Mountain, *Tetradium fibratum* occurs in some of the intercalated dove-gray limestones. A few *Solenopora* are found in some of the limestones intercalated in the Moccasin along the northwest base of Walker Mountain.

Correlation.—It is possible that the Moccasin is lower Trenton[112], but the correlation has not yet been fully substantiated. However, the

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[112] Cooper, B. N., and Prouty, C. E., op. cit., pp. 880-881.

Moccasin as defined by Campbell definitely overlies the limestone which Butts has called Lowville[113]. So far as is now known, the Moccasin seems to be younger than the Pamelia (basal Black River) and older than the Hull limestone (Trenton).

Stratigraphic relations.—Northwest of the Saltville-Bland fault, the upper and lower contacts of the Moccasin appear to be conformable. Along Walker and Brushy mountains a hiatus between the Moccasin and underlying Benbolt is indicated by the absence of the Gratton limestone, Wardell and Bowen formations, and locally the Witten limestone. In the same belts, the Moccasin is conformably overlain by the Eggleston formation.

EGGLESTON FORMATION

Name.—The Eggleston formation was named by Mathews[114] from exposures near Eggleston and near Narrows, Giles County, Virginia. As used here by the writer, the Eggleston includes the strata above the Moccasin formation and below the lowest beds containing *Sowerbyella curdsvillensis, Resserella rogata,* which are considered to be indexes of the lower Martinsburg. The Eggleston, as here used, includes the greater part of the "cuneiform group" of Rosenkrans[115].

Distribution.—The Eggleston formation occurs above the Moccasin in all the Ordovician belts in the quadrangle (Pls. 1, 5, 8). It crops out at the ends of spurs along Rich, Buckhorn, East River, Clinch, Brushy, Garden, and Walker mountains.

Lithology.—The red beds of the Moccasin are succeeded by 30 to 115 feet of dark-gray calcareous mudrocks, medium-gray argillaceous limestone, dark-brown siltstones, wavy bands of rusty-brown fossiliferous chert, apricot-buff metabentonites, and greenish-gray, cuneiform-jointed, silicified mudrocks. A fine section of the Eggleston which is exposed along State Highway 16 about 3 miles southwest of Tazewell and about 3 miles beyond the western border of the Burkes Garden quadrangle is typical of the beds in that area.

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[113] Cooper, B. N., Moccasin formation in southwestern Virginia (abstract): Geol. Soc. America Bull., vol. 53, pp. 1799-1800, 1942.

[114] Matthews, A. A. L., Marble prospects in Giles County, Virginia: Virginia Geol. Survey Bull. 40, p. 11 (footnote), 1934.

[115] Rosenkrans, R. R., Stratigraphy of Ordovician bentonite beds in southwestern Virginia: Virginia Geol. Survey Bull. 46-I, pp. 87-101, 1936.

Geologic Section 30.—Eggleston formation along State Highway 16, about 3 miles southwest of Tazewell, Tazewell County, Virginia

	Thickness	
	Ft.	In.
Martinsburg formation		
Eggleston formation (51 feet)		
12. Shale, greenish-gray; interbedded with calcareous siltstone	3	6
11. Shale, apricot-buff, bentonitic; with many thin seams of metabentonite 1/32 to 1½ in. thick	4	4
10. Limestone, partly silicified, cuneiform jointed, bluish-gray	7	
9. Limestone, thin bedded, drab-gray to dark-brown argillaceous, cobbly; has calcite vugs, some of which replace fossils; contains a few ostracodes including *Eurychilina subradiata, Leperditella sulcata,* and a large species of *Isochilina*	12	2
8. Shale, greenish-gray, bentonitic; with 1½ inches of maroon-drab shale in the middle		7
7. Mudrock, greenish-gray, calcareous, even-bedded; weathers nodular to cobbly; topmost beds are cuneiform jointed	8	
6. Limestone, cuneiform jointed, silicified, greenish-gray, very fine grained; contains thin partings of brown and green shales	5	2
5. Clay, buff, bentonitic, arkosic	1	
4. Metabentonite, blocky, buff		3
3. Clay, bentonitic, maroon-drab	2	2
2. Limestone, silicified, cuneiform jointed, greenish-gray to dark-gray; contains *Achatella transsectus* (Raymond) and large *Isochilina* sp.	2	2
1. Mudrock, drab-gray, nodular weathering, calcareous; contains many calcite vugs; *Escharopora subrecta* in shales at the top	4	8
Moccasin formation		

Where fully exposed the Eggleston shows two thick zones of metabentonite, one about 10 feet above the siltstones at the top of the Moccasin and the other near the Eggleston-Martinsburg contact. Many thinner layers of altered volcanic ash are also present, and locally one or more of these beds may appear to be as thick as the others. During Appalachian folding, the plastic bentonites and associated beds were crumpled and sheared. Some layers were squeezed out locally and thickened elsewhere. Local variations in thickness of the metabentonites is well shown along State Highway 61 less than one-fourth of a mile north of Benbolt.

The most characteristic feature of the Eggleston is the cuneiform jointing developed in silicified beds adjacent to the metabentonites (Pl. 11A). During chemical alteration of the volcanic ash considerable silica was released, which impregnated the contiguous mudrocks. The silicified beds are very brittle. They presumably yielded to stresses by complex shearing.

In Burkes Garden, 40 to 50 feet of drab-gray calcareous mudrock underlies the lowest cuneiform-jointed bed and overlies the highest siltstone of the Moccasin. These are similar to limestones intercalated in the upper part of the Eggleston; hence, they are included in the Eggleston.

Rosenkrans[116] regards the Eggleston as a facies of the Moccasin formation, but classified a part of the Eggleston beds of the writer with the Martinsburg. According to Rosenkrans the Moccasin-Eggleston boundary of Mathews varies from place to place. At least in Tazewell County, Virginia, the top of the Moccasin is sharply defined by a siltstone zone which can be identified in nearly all exposures; the Moccasin-Eggleston boundary is, therefore, at the same stratigraphic horizon. The upper part of the cuneiform-jointed zone does overlie fossiliferous layers containing species typical of the lower Martinsburg formation. The Eggleston formation is a valid formation, if defined so as to include only the beds which overlie the Moccasin siltstone and underlie the lowest beds carrying Martinsburg fossils.

At the time of Rosenkrans' field studies the cuneiform beds were fully exposed in new road cuts along State Highway 78 ascending the northwest slope of Rich Mountain. His description of this section[117] includes the full thickness of the Eggleston formation as defined in this report.

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[116] Rosenkrans, R. R., op. cit., pp. 100-101.

[117] Idem, pp. 107-108.

Geologic Section 31.—Eggleston formation along State Highway 78 south of Gratton, Tazewell County, Virginia[118]

		Thickness	
		Ft.	In.
Martinsburg formation			
Eggleston formation (44± feet)			
26.	Bentonite, distinct orange; thickness varies because of local squeezing		2–11
25.	Shale, bluish-green	1	10
24.	Shale, blocky, arenaceous		2½
23.	Shale, dark-gray		5
22.	Limestone, argillaceous, blocky	2	
21.	Limestone, drab, argillaceous; typical cuneiform jointing	2	4
20.	Shale, green		2
19.	Bentonite, squeezed		2–4
18.	Limestone, blocky; cuneiform jointing		7
17.	Bentonite		¾
16.	Limestone, blocky; cuneiform jointing	2	
15.	Shale, bluish-gray	1	6
14.	Shale, greenish, hackly	1	
13.	Bentonite	1	11
12.	Chert bed with ripple marks; wave length of ripples is 25 inches		4
11.	Shale, blocky, green, calcareous	2	
10.	Bentonite		2
9.	Shale, green, blocky		6
8.	Shale, calcareous	1	
7.	Limestone, gray, shaly		3
6.	Shale	1	
5.	Limestone, greenish-drab, argillaceous; a mudrock	17	
4.	Bentonite		11
3.	Limestone, a massive, blocky bed capped by 2 inches or more of chert; upper surface of chert is very smooth, white, and ripple marked	1	

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[118] Zones 12 to 26 inclusive were classified by Rosenkrans with the Martinsburg, and zones 1 to 11 inclusive were a part of his Moccasin. The detailed description is taken directly from Rosenkrans, but the classification of the beds is based upon the definition of the Eggleston formation as given in this report.

	Thickness	
	Ft.	In.
2. Shale	3	
1. Covered interval[119]	2	
Moccasin formation		

Geologic Section 32.—Eggleston formation along State Highway 61, one-fourth of a mile north of Benbolt, Tazewell County, Virginia

	Thickness	
	Ft.	In.
Martinsburg formation		
Eggleston formation (58± feet)		
11. Mudrock, dark-gray, silicified, cuneiform jointed; weathers dull buff	6	
10. Metabentonite, flaky mixed with silt; weathers buff		9
9. Mudrock, silty, silicified, dark-gray; with conspicuous cuneiform jointing	5	
8. Shale, buff; with streaks of soft unctuous metabentonite	1	9
7. Limestone, greenish-gray, very argillaceous	22	6
6. Shale, greenish-gray, calcareous; contains cystoid plates on under surface of bed	2	3
5. Mudrock, greenish-gray, calcareous	2	
4. Limestone, argillaceous; with streaks of buff shale	2	2
3. Shale, greenish-gray, calcareous; weathers buff; thin silicified zone near base	7	
2. Metabentonite, weathers buff, silty	3	
1. Mudrock, locally silicified near zone 2; greenish-gray, with calcite vugs and stringers; contains few *Rhinidictya* and large *Isochilina*	5	9
Moccasin formation		

Fossils.—The only common fossil in the Eggleston is a large species of *Isochilina*.[120] Other fossils found in the formation are:

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[119] Thickness determined by the writer.

[120] Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. 2, Pl. 94, Figs. 24-25, 1941.

- Bryozoa
    - Escharopora subrecta (Ulrich)
    - Hallopora multitabulata (Ulrich)
    - Rhinidictya cf. R. neglecta Ulrich
- Trilobites
    - Achatella transsectus (Raymond)
- Ostracodes
    - Eurychilina subradiata Ulrich
    - Leperditella sulcata (Ulrich)

Stratigraphic relations.—The Eggleston appears to be conformable with the overlying Martinsburg in all belts. The 40 to 50 feet of drab-gray limestone at the base of the Eggleston in the western part of Burkes Garden appears to be absent elsewhere.

Correlation.—According to Mathews[121], the fossils of the Eggleston are Black River. Most, if not all, of the fossils collected from the formation by the writer occur also in the upper part of the Decorah shale of the Upper Mississippi Valley, which is Trenton.

MIDDLE AND UPPER ORDOVICIAN SERIES

MARTINSBURG FORMATION

Name.—The Martinsburg formation was named by Geiger and Keith[122] from exposures at Martinsburg, West Virginia. According to Wilmarth[123], the Federal Geological Survey includes in the Martinsburg 300 feet of shaly limestone which was originally included in the Chambersburg limestone. Beds included in the Martinsburg formation would normally be grouped into several formations, were it not for the fact that it is almost impossible to map the Trenton-Eden and Eden-Maysville boundaries. The Martinsburg is almost invariably so poorly exposed and so complexly folded (Pl. 10) and faulted that delineation of the Trenton, Eden, and Maysville units is impracticable. The Martinsburg is therefore a convenient mapping unit rather than a faunal and lithologic unit.

Distribution.—The Martinsburg underlies the greater part of the grassy slopes of East River, Buckhorn, Rich, Clinch, Garden,

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[121] Mathews, A. A. L., Marble prospects in Giles county, Virginia: Virginia Geol. Survey Bull. 40, p. 11 (footnote), 1934.

[122] Geiger, H. R., and Keith, Arthur, The structure of the Blue Ridge near Harpers Ferry, Maryland-West Virginia: Geol. Soc. America Bull., vol. 2, pp. 156-163, 1891.

[123] Wilmarth, M. G., Lexicon of geologic names of the United States: U. S. Geol. Survey Bull. 896, pt. 2, p. 1313, 1938.

Brushy, and Walker mountains (Pl. 1). Parts of the formation are well exposed in road cuts, but none of these sections is complete. The best exposure is along Road 614 on the northwest slope of Rich Mountain, where about 1,300 feet of beds is exposed. Other good exposures are along State Highway 78 south of Gratton, along Road 623 on the northwest slope of Garden Mountain, and along Road 621 on the northwest slope of Walker Mountain. The best exposure of the lower Martinsburg is at the intersection of State Highway 61 and U. S. Route 19, near Burkes Garden Station on the Norfolk and Western Railway (Pl. 10). The middle and upper parts are exposed along the old wagon road through Walker Gap on Garden Mountain. The upper division is well exposed in the pasture fields at the head of Thompson Valley, below Hutchinson Rock.

Lithology.—The Martinsburg formation is roughly divisible into three parts in the section exposed along Road 614. The lowest, or Trenton, division is composed of light-gray, medium-grained, shell limestones which are very dense and hard. Dark-gray shales, some of which are highly calcareous, occur as intercalations in the limestones and constitute about 25 per cent of the total thickness of this division. The limestone beds vary from a fraction of an inch to 15 inches in thickness (Pls. 10, 12A). Many of the thinner beds are wavy and discontinuous. One of the most conspicuous and characteristic features of the Trenton division is the abundance of calcite veins and vugs, some of which are several inches wide. All of the rock is argillaceous and weathers to soft clay, so that fresh limestone is rarely exposed. The general character of the Trenton is well shown along Road 623 on the slopes of Garden Mountain (Pl. 12A). A distinctive feature of the lowest 50 feet of beds is the occurrence of thin, wavy beds of brown chert which are full of external molds of characteristic fossils. The chert beds occur in the "cuneiform beds"[124], the upper part of which is in the Martinsburg. Metabentonites occur in the lowest 50 to 75 feet of the Martinsburg, but none is as thick as those of the underlying Eggleston. In the lowermost 15 feet, three zones of buff metabentonite and cuneiform-jointed, silicified mudrock are generally found. The thickness of the Trenton, as determined by measurements made by the writer, below Crabtree Gap, on Garden Mountain south of

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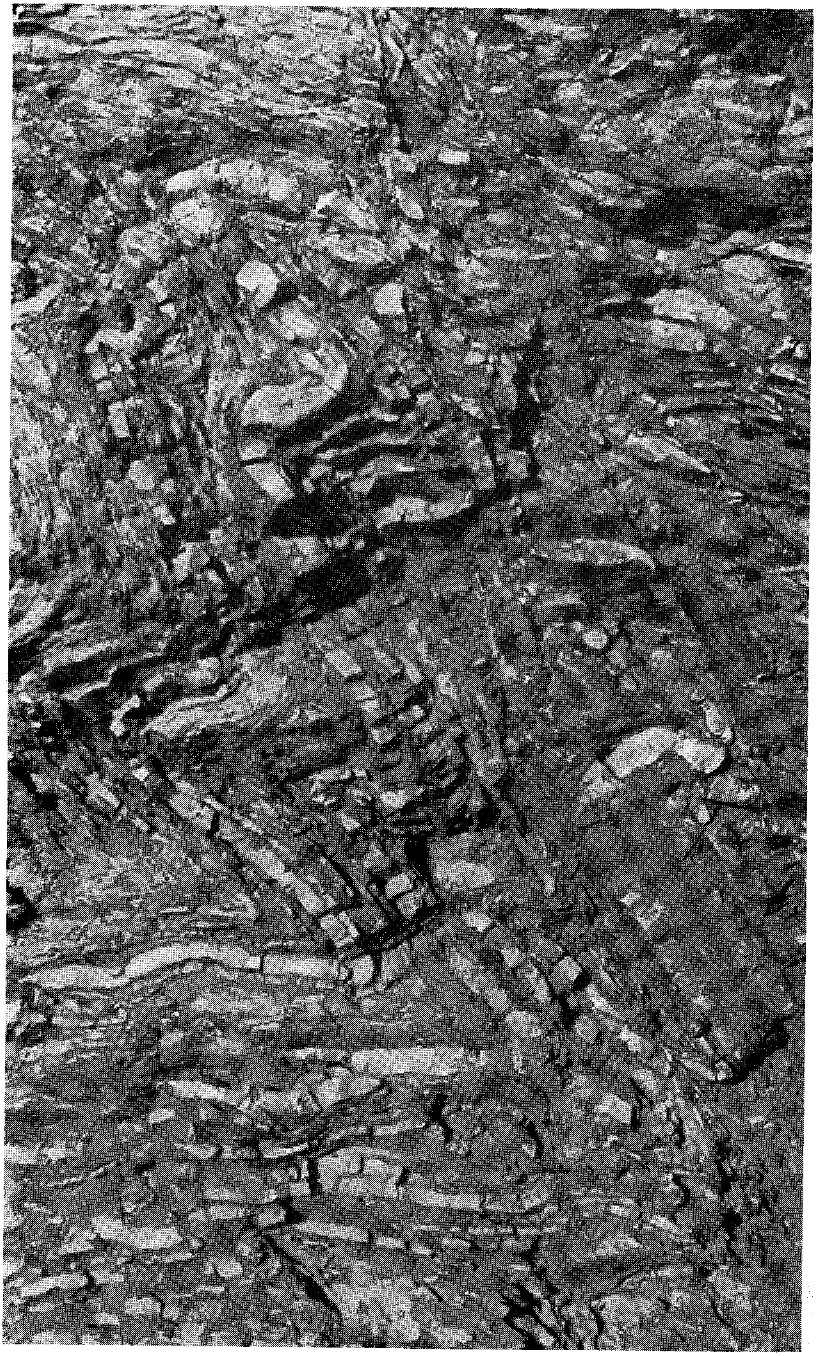
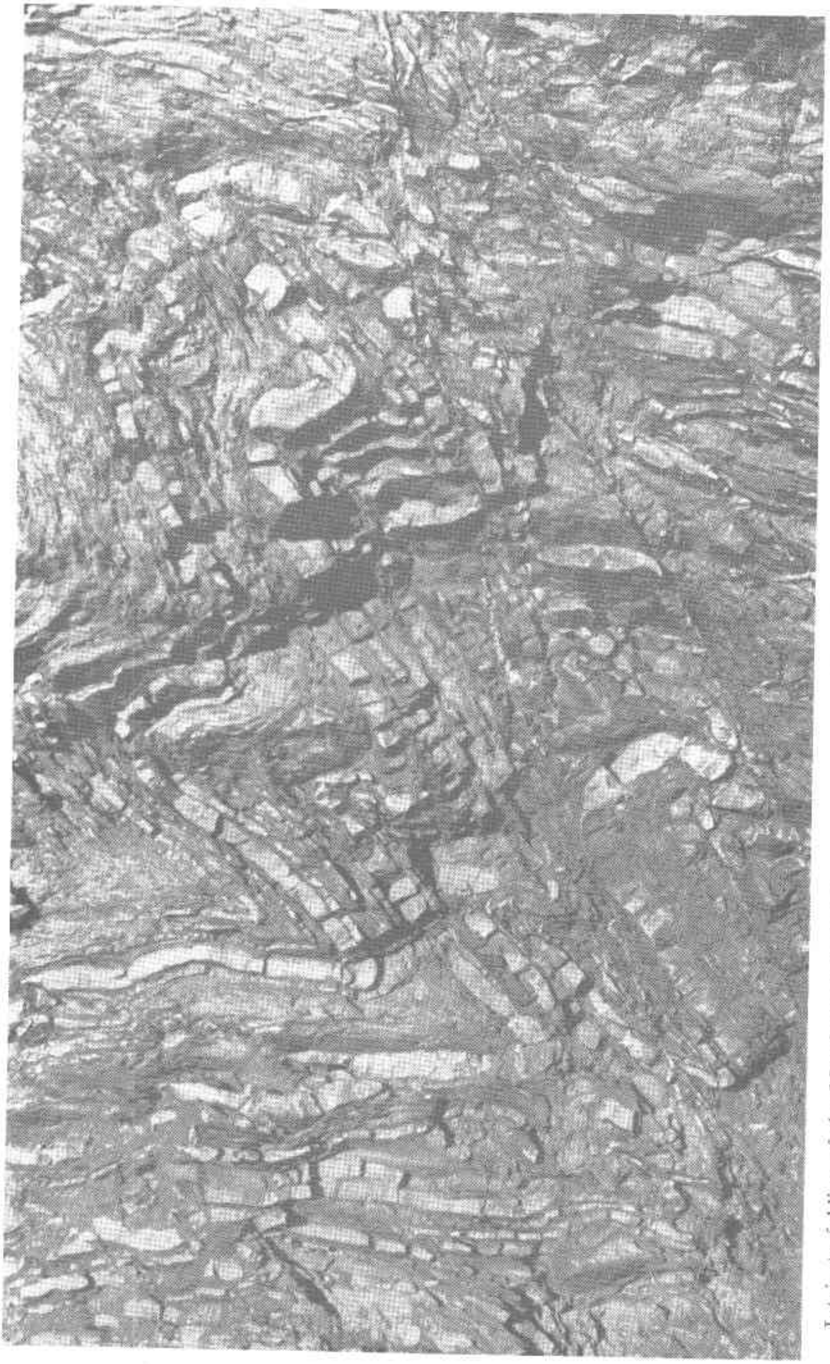
[124] Cooper, B. N., and Prouty, C. E., Stratigraphy of the lower Middle Ordovician of Tazewell County, Virginia: Geol. Soc. America Bull., vol. 54, pp. 846-847, 1943.

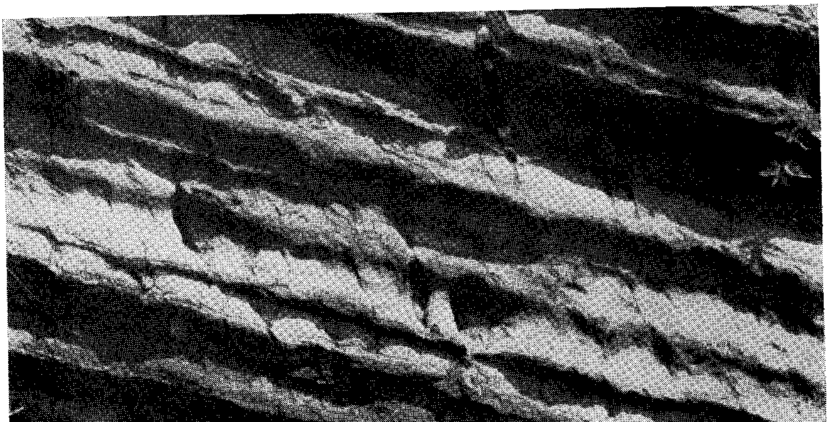


Intricate folding of the Martinsburg beds; at the intersection of U. S. Route 19 and State Highway 61, near Tazewell, Virginia.



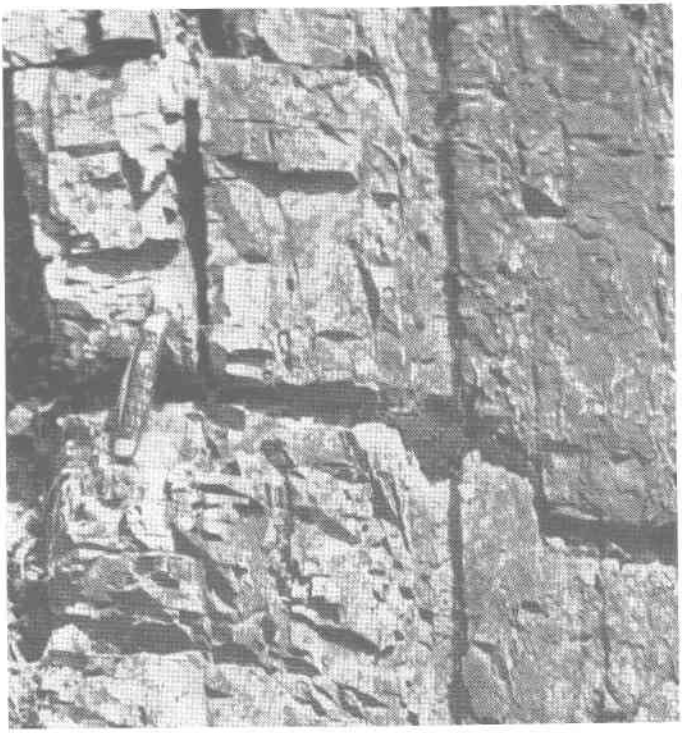
Intricate folding of the Martinsburg beds; at the intersection of U. S. Route 19 and State Highway 61, near Tazewell, Virginia.

A.

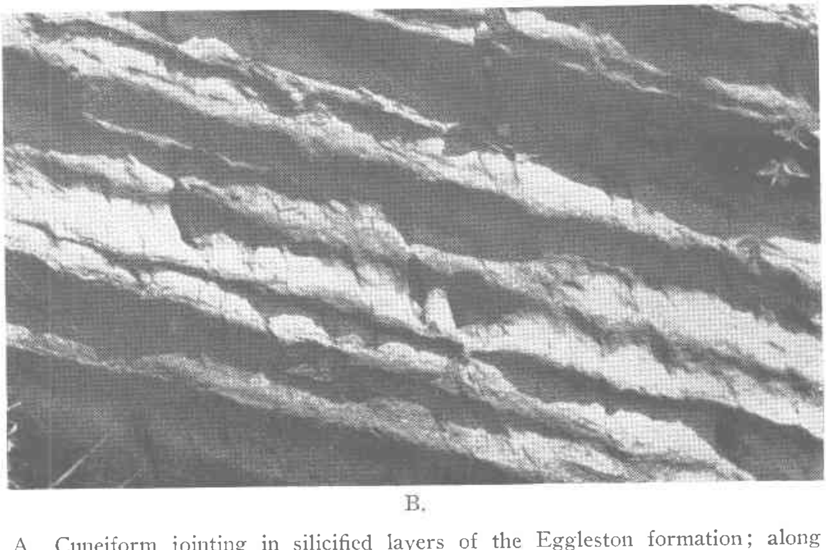


B.

A, Cuneiform jointing in silicified layers of the Eggleston formation; along State Highway 61 near Benbolt. B, Moccasin mudrock, showing alternation of limy and clayey layers; near Tazewell.



A.



B.

A, Cuneiform jointing in silicified layers of the Eggleston formation; along State Highway 61 near Benbolt. B, Moccasin mudrock, showing alternation of limy and clayey layers; near Tazewell.

Burkes Garden, and on Rich Mountain, is about 650 feet. The Trenton beds are about 750 feet thick on Walker Mountain where shale forms a greater part of the division than in any other belt of the Martinsburg.

The Eden division of the Martinsburg is composed of olive-drab and drab-gray fissile shales and slabby argillaceous limestones. The olive-drab beds are silty and micaceous, and most of them are noncalcareous. Very few good exposures of the Eden are found in the Burkes Garden quadrangle. About 250 feet of Eden beds is exposed on Garden Mountain, along the Medley Valley-Walker Gap road, but the contacts are concealed. Thickness determinations of the Eden along State Highway 78 and below Crabtree Gap on Rich Mountain were 400 and 460 feet, respectively. The Eden on East River Mountain is somewhat thicker, possibly as thick as 500 feet. Limestones constitute about 20 per cent of the Eden in all belts north of Clinch and Garden mountains. On Walker Mountain the greater part of the Eden is siltstone with almost no limestone.

The Maysville, or uppermost division is 250 to 350 feet thick and, except for the uppermost 50 to 75 feet, closely resembles the Eden division. The separation of the upper Eden and lower Maysville is made wholly on the basis of fossils. The topmost 50 to 75 feet of the Maysville consists of soft, mealy, reddish and greenish siltstones, many of which weather in distinctive spheroidal patterns (Pls. 12B, C). This part of the Maysville contains many fossils not found in the lower part. *Orthorhynchula linneyi* James is particularly characteristic in a zone which everywhere marks the top of the Martinsburg. This zone is 70 feet thick in Crabtree Gap, 60 feet thick on Garden Mountain and in Mill Gap, and 80 feet thick on East River Mountain. In each of these localities, concretionary beds, like those shown in Plates 12B and C, are prominent. The Maysville is transitional with the overlying Juniata which can be distinguished by its even-bedded, blocky sandstones and lack of fossils.

Below Dial Rock and from there west to Tazewell, the Martinsburg makes a broad belt of well-rounded grassy hills 50 to 150 feet high. The soil derived from the Martinsburg is very fertile and supports a thick cover of bluegrass; hence most of the area underlain by the Martinsburg has been cleared for pasture land. Locally, slopes as steep as 50 degrees are grazed without gullying or loss of sod. The lower limit of the timbered areas on the ridges corresponds closely to the Juniata-Martinsburg contact.

Fossils.—Each of the three divisions of the Martinsburg contains characteristic fossils (Pls. 5, 8). Collections from the Trenton contain the following species:

- Graptolites
  - Diplograptus amplexicaulis (Hall)
- Bryozoa
  - Escharopora sp.
  - Eridotrypa sp.
  - Hallopora ampla (Ulrich)
  - Mesotrypa discoidea Ulrich
  - Prasopora simulatrix Ulrich
  - Prasopora orientalis Ulrich
  - Rhinidictya mutabilis (Ulrich)
  - Rhinidictya neglecta Ulrich
- Brachiopods
  - Hebertella sinuata Hall and Clarke
  - Plectorthis plicatella (Hall)
  - Rafinesquina alternata (Emmons)
  - Rafinesquina cf. R. deltoidea (Conrad)
  - Resserella rogata (Sardeson)
  - Resserella sp.
  - Resserella fertilis (Bassler)
  - Rhynchotrema cf. R. increbescens (Hall)
  - Sowerbyella curdsvillensis (Foerste)
  - Sowerbyella rugosa (Meek)
  - Sowerbyella "sericea" (Sowerby)
  - Zygospira recurvirostris (Hall)
- Gastropods
  - Sinuites cancellatus (Hall)
- Cephalopods
  - Endoceras proteiforme elongatum Hall
  - Spiroceras bilineatum (Hall)
- Trilobites
  - Calliops callicephalus (Hall)
  - Calyptaulax eboraceous (Clarke)
  - Cryptolithus tessellatus Green

- Ostracodes
  - Bythocypris cf. B. cylindrica (Hall)
  - Eurychilina subradiata Ulrich

Well-preserved graptolites occur along the bedding surfaces of several thin layers of limestone in the exposure at the intersection of State Highway 61 and U. S. Route 19, about 15 feet south of the federal highway sign (Pl. 10).

Fossils collected from the Eden division, exposed along the road from Medley Valley to Walker Gap on Garden Mountain, include the following:

- Bryozoa
  - Amplexopora sp.
  - Bythopora gracilis (Nicholson)
  - Hallopora sp.
- Brachiopods
  - Pholidops cincinnatiensis Hall
  - Rafinesquina fracta (Meek)
  - Resserella multisecta (Meek)
  - Sowerbyella cf. S. rugosa (Meek)
  - Zygospira modesta Hall
- Trilobites
  - Calyptaulax sp.

The Maysville contains two rather distinct faunas. The lower is confined to the drab-gray siltstones and shales below the *Orthorhynchula* zone. The following are locally abundant:

- Bryozoa
  - Hallopora sp.
- Brachiopods
  - Hebertella sinuata Hall and Clarke
  - Pholidops subtruncata (Hall)
  - Zygospira kentuckiensis James
- Pelecypods
  - Pterinea sp.
- Gastropods
  - Tetranota sp.

Red and green siltstones in the upper part of the Maysville, which constitute the *Orthorhynchula* zone, contain:

- Bryozoa
  - Dekayella sp.
  - Escharopora sp.
- Brachiopods
  - Hebertella sinuata Hall and Clarke
  - Lingula nicklesi Bassler
  - Orthorhynchula linneyi James
  - Plectorthis fissicosta (Hall)
  - Rafinesquina nasuta (Conrad)
  - Zygospira sp.
- Pelecypods
  - Byssonychia praecursa Ulrich
  - Byssonychia radiata (Hall)
  - Byssonychia vera Ulrich
  - Ctenodonta sp.
  - Modiodesma modiolare (Conrad)
  - Modiolopsis milleri Ulrich
  - Orthodesma contractum (Hall)
  - Pterinea demissa (Conrad)
  - Rhytimya compressa Ulrich
- Gastropods
  - Cyclonema sp.
  - Cyrtolites ornatus Conrad
  - Liospira cf. L. vitruvia (Billings)
- Cephalopods
  - Orthoceras sp.

This fauna is found along State Highway 78 near the crest of Rich Mountain; along the road northwest of Crabtree Gap; on the northwest slope of East River Mountain along Road 662; on the southeast slope of Buckhorn Mountain north of Kinzer Church; and along the trail from Burkes Garden to Thompson Valley, below Hutchinson Rock. The upper layers of the *Orthorhynchula* zone carry great numbers of *Lingula nicklesi,* a distinctive brachiopod with a black phosphatic shell.

Age and correlation.—Resserella rogata and *Sowerbyella curdsvillensis,* which occur in the basal layers of the Martinsburg, also occur in the Curdsville limestone in Central Tennessee. Since the Curdsville corresponds to the Hull limestone of the Trenton group of New York, the Martinsburg probably does not include the equivalents of the basal Trenton, Rockland limestone, of New York. The upper part of the Trenton in Tennessee, Kentucky, and New York contains faunas which are not known to be represented in the Trenton division of the Martinsburg of the Burkes Garden area. The highest Trenton faunule in this area is that of the lower Cobourg; and therefore the upper Cobourg, Collingwood, and Gloucester of the New York Trenton probably are not represented in the Martinsburg of the Burkes Garden quadrangle. However, there is no physical evidence of a hiatus between the Trenton and the Eden divisions. All, or nearly all, of the Eden appears to be represented, but the variety of fossils is not as great in the Burkes Garden area as it is in Kentucky. The Maysville division of the Martinsburg is early Maysville. *Orthorhynchula linneyi* occurs at two distinct horizons in Kentucky, but only the lower one (Fairview) is present in the Burkes Garden quadrangle.

Stratigraphic relations.—So far as known, in this area the Martinsburg is conformable with the underlying Eggleston and also with the overlying Juniata formation.

JUNIATA FORMATION

Name.—Darton[125] named the Juniata formation from exposures along the Juniata River in Pennsylvania. As now used by the United States Geological Survey, the Juniata is restricted to beds above the Oswego sandstone and below the Clinch, or Tuscarora, sandstone.

Distribution.—The Juniata crops out in several belts along East River, Buckhorn, Rich, Clinch, Garden, and Walker mountains (Pls. 1, 13A). Along the slopes of Buckhorn and Brushy mountains faults have broken the continuity of the Juniata belts. The Juniata also crops out on the various spurs at the western ends of East River and Buckhorn mountains. The Juniata is exposed in a number of inliers on the southeast slope of East River Mountain, and also on the southeast slopes of Clinch Mountain below Beartown.

Lithology.—The Juniata formation is composed of dark-maroon, mealy shales, lumpy silty mudrocks, and hard blocky beds of quartz sandstone (Pls. 5, 8, 13A). Shales and mudrocks make up about three-fifths of the total thickness. The uppermost 100 feet contains several

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[125] Darton, N. H., U. S. Geol. Survey Geol. Atlas, Piedmont folio (No. 28), p. 2, 1896.

5-foot zones of light-gray flaggy sandstone. Both the red mudrocks and red sandstones contain light-green streaks and blotches formed by localized reduction of ferric oxides. These mottled beds are especially common in the lower 150 feet of the formation. That none of the Juniata sandstones are very resistant is attested by the fact that few of the sandstone boulders which litter the slopes of the various ridges are derived from the Juniata. Soil formed from the disintegration and decomposition of the formation is dark-red. Where the woodlands have been cleared from the Juniata terrane, gullying is deep and rapid.

On East River Mountain the Juniata is about 400 feet thick; along Road 662 it is 415 feet thick. Below Dial Rock it is not more than 385 feet thick. On Buckhorn Mountain the average thickness is 360 feet. The best exposed section of the Juniata, along State Highway 78 south of Burkes Garden, is 435 feet thick. On Walker Mountain, where not more than 350 feet of Juniata is present, siltstones and mudrocks comprise about 80 per cent of the total thickness.

The Juniata bears considerable resemblance to the Rose Hill formation (Silurian). In faulted areas where the normal succession of the strata is lacking, considerable difficulty was found in identifying and distinguishing the two formations. Butts[126], for example, identified the red shales and mudrocks exposed along State Highway 85, south of Bluefield, Virginia, as part of the Juniata. In this locality, the strata are overturned just north of the St. Clair fault, the trace of which runs along the highway. The red beds "overlie" a white sandstone which Butts identified as the Clinch. As a result of very detailed study the problem of identification of the red beds was solved by the discovery that the Juniata red beds are almost invariably lighter colored than those of the Rose Hill. The Rose Hill contains intercalations of olive-drab, buff, and brown shales which are practically absent in the Juniata. Also, the Rose Hill invariably contains thin beds of fossiliferous hematite which are unknown in the Juniata. Furthermore, the Juniata contains finely laminated and cross-laminated sandstones which are absent in the Clinton. Upon this evidence, the Juniata appears to be absent along State Highway 85 in the south environs of Bluefield, Virginia. Northwest of Marys Chapel on the slopes of Buckhorn Mountain, the red beds which crop out southeast of the crest of the ridge were identified by Campbell[127] as Juniata. In this locality the evidence in favor of the identification of the red beds as Rose Hill is

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[126] Butts, Charles, Geologic map of the Appalachian Valley of Virginia with explanatory text: Virginia Geol. Survey Bull. 42, map, 1933.

[127] Campbell, M. R., U. S. Geol. Survey Geol. Atlas, Pocahontas folio (No. 26), geologic map, 1896.

more convincing than it is near Bluefield. Not only are the red beds darker, but beds of fossiliferous hematite, olive-drab shales with Rose Hill ostracodes, and conspicuous zones of brown shale occur within the belt mapped by Campbell as Juniata. Northeast of Gratton some of the beds which Campbell earlier identified as Juniata are now known to be Clinton because of typical fossils in some of the included shales.

The best exposures of the Juniata are along Road 662 on the northwest slope of East River Mountain; along Road 623 over Garden Mountains (Pl. 13A); and on Rich Mountain south of Gratton, on State Highway 78. Other good, but less accessible, exposures of the Juniata occur below Dial Rock and Hutchinson Rock, at the west end of Buckhorn Mountain, and in Low Gap in Garden Mountain.

Age and correlation.—No fossils occur in the Juniata in the Burkes Garden quadrangle. The age of the formation has been determined by Butts[128] on the basis of observable facies changes from red beds to limestones (Sequatchie) containing Richmond fossils. The Juniata has a stratigraphic position similar to that of the Queenston shale of the Niagara gorge in New York.

Stratigraphic relations.—In spite of the apparent conformity of the Maysville and Juniata formations, a hiatus may exist between them. In the northern Appalachian region, the Oswego sandstone intervenes between the Juniata and Maysville. The upper contact of the Juniata is lithologically transitional and, so far as known, conformable with the Clinch sandstone.

SILURIAN SYSTEM

LOWER SILURIAN SERIES

CLINCH SANDSTONE

Name.—Safford[129] originally proposed the name Clinch Mountain sandstone for gray and red sandstones exposed along Clinch Mountain in Hancock and Hawkins counties, Tennessee. Keith[130] later restricted the name Clinch to the massive white sandstone which composes the upper part of the formation defined by Safford. As now used, the term Clinch applies to the white sandstone above the Juniata and below the Clinton. In Virginia north of James River, the same beds are known as the Tuscarora sandstone.

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[128] Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. 1, pp. 221-229, 1940.

[129] Safford, J. M., A geological reconnaissance of the State of Tennessee: Nashville, 1st. Bien. Rept., p. 157, 1856.

[130] Keith, Arthur, U. S. Geol. Survey Geol. Atlas, Knoxville folio (No. 16), p. 2, 1895.

Distribution.—The Clinch crops out in a number of belts on East River and Buckhorn mountains and forms the top of Havens Spur, Dial Rock, and Short Ridge (Pls. 1 and 18C). Another belt extends southwestward along the crest of Rich Mountain across the quadrangle. Another belt crops out on the southeast side of Rich Mountain north of Thompson Valley. East of Low Gap, this belt upholds Garden Mountain which rims Burkes Garden (Pl. 13B). Hutchinson Rock (Pl. 18A) is a large massive outlier of Clinch near the end of the dividing spur between Burkes Garden and Thompson Valley. The Clinch makes bold cliffs along the east face of Beartown (Pl. 19A) and also along the south slopes of Beartown descending to Roaring Fork. A faulted belt of the Clinch upholds parts of Brushy Mountain northwest of Ceres. The Clinch also forms the crest of Walker Mountain.

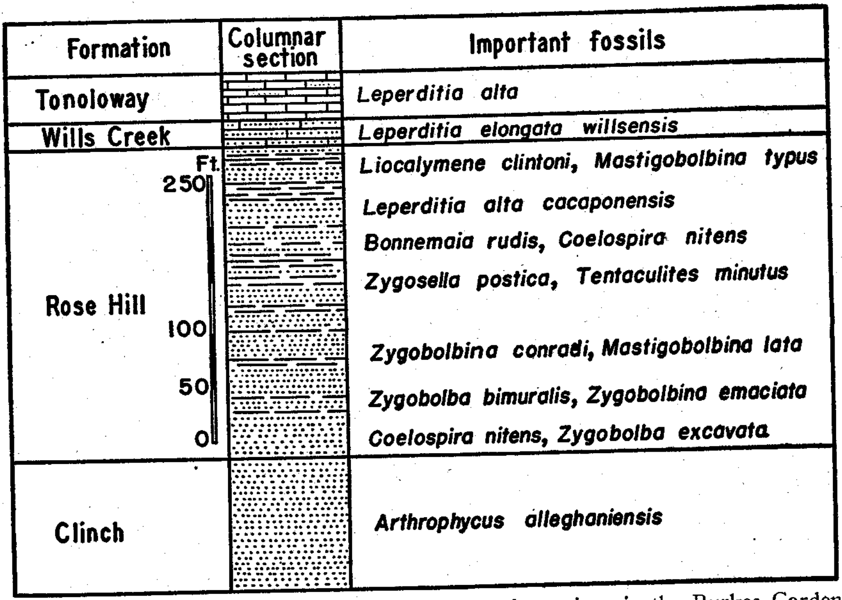
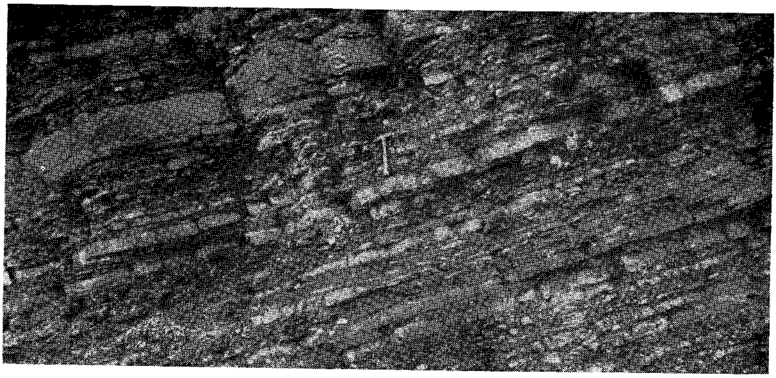


FIGURE 4.—Columnar section of the Silurian formations in the Burkes Garden quadrangle, Virginia.

Lithology.—The Clinch consists of coarse-grained quartzitic sandstones and quartz-pebble conglomerates (Fig. 4). Most of the sandstones are white to light-buff and contain little ferruginous or argillaceous material. The sand grains and quartz pebbles are firmly cemented by interstitial quartz. Cross lamination of many beds is indicated by reddish laminae of iron-stained sands. Maroon and buff



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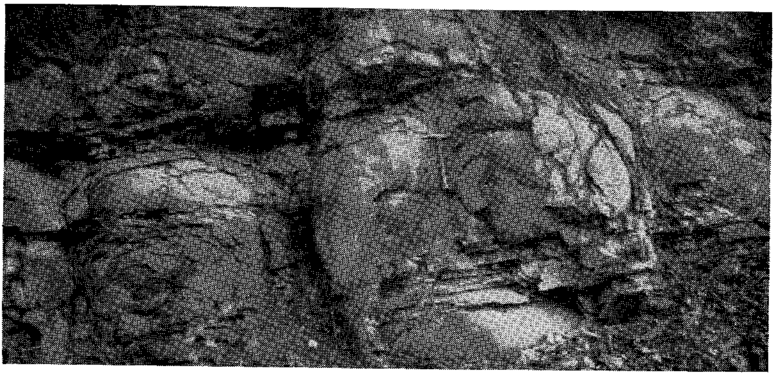

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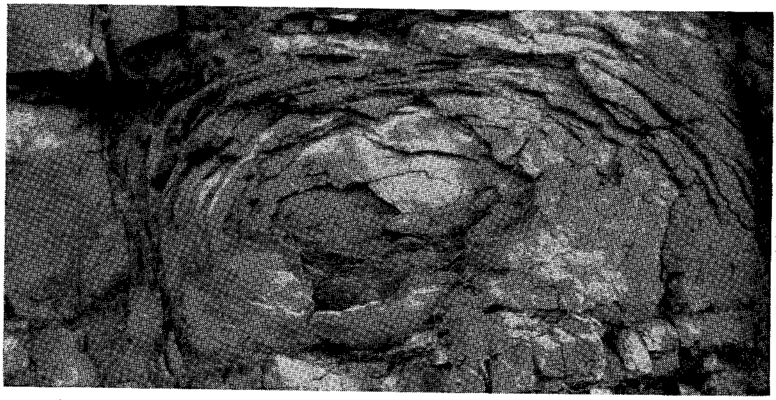
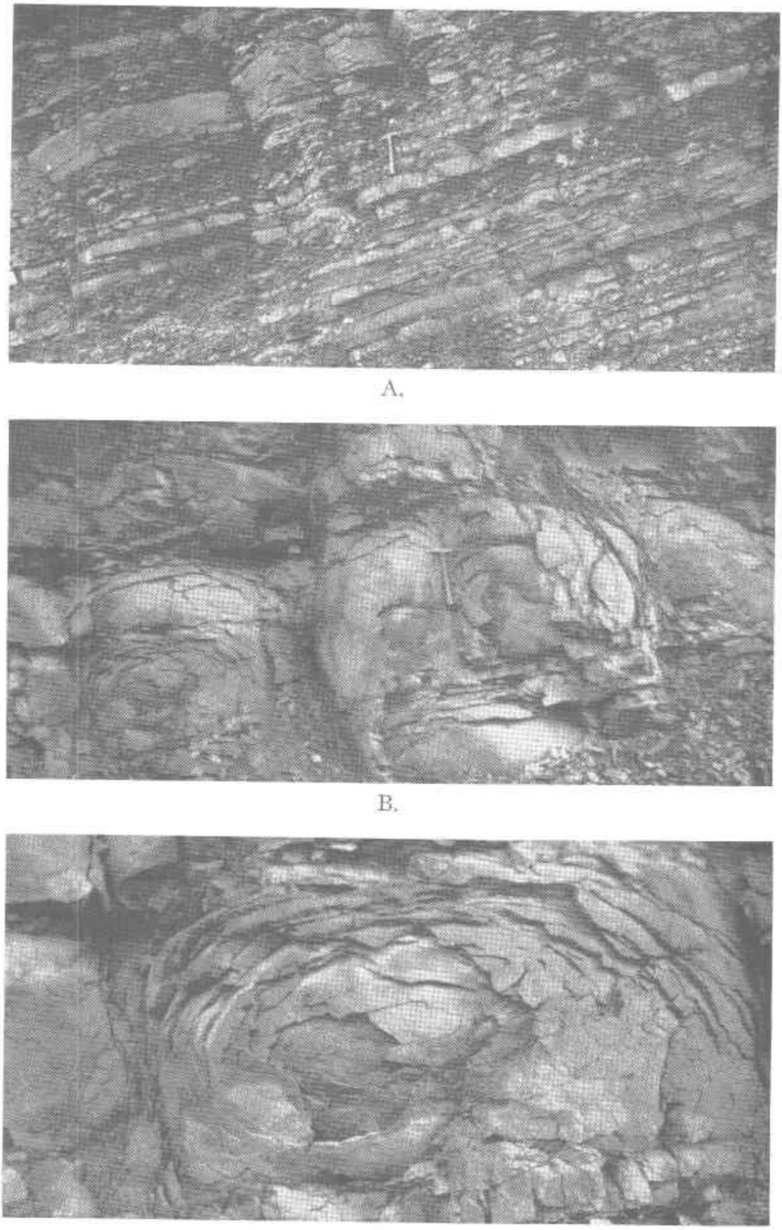
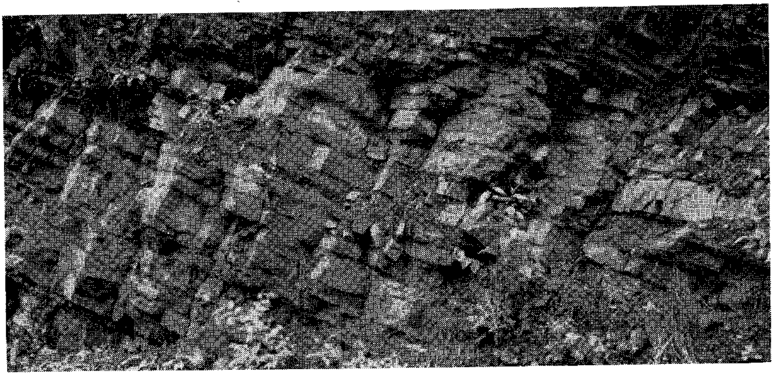


C.

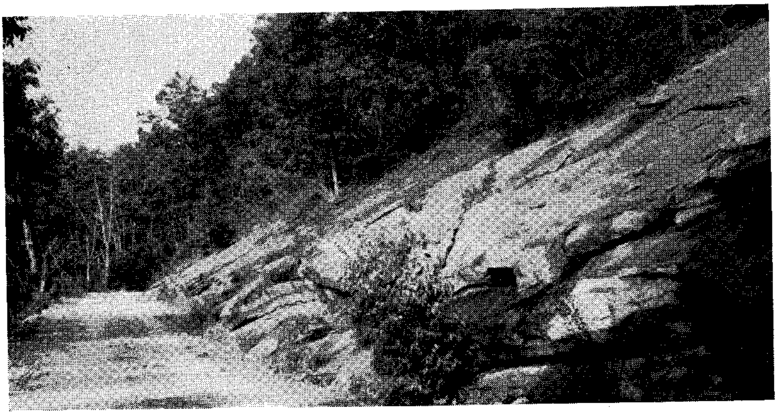
A, Interbedded shales and limestones of the Trenton division of the Martinsburg formation; along Road 623, south of Burkes Garden. B, Concretionary zone near the top of the Maysville division of the Martinsburg formation; along Road 623. C, Near view of concretionary zone shown above.



A, Interbedded shales and limestones of the Trenton division of the Martinsburg formation; along Road 623, south of Burkes Garden. B, Concretionary zone near the top of the Maysville division of the Martinsburg formation; along Road 623. C, Near view of concretionary zone shown above.



A.



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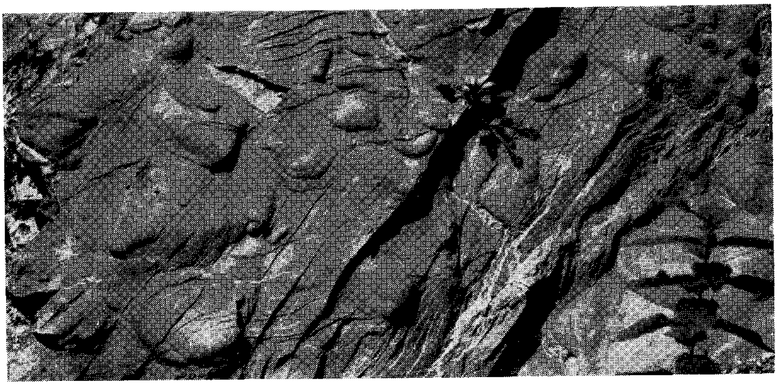
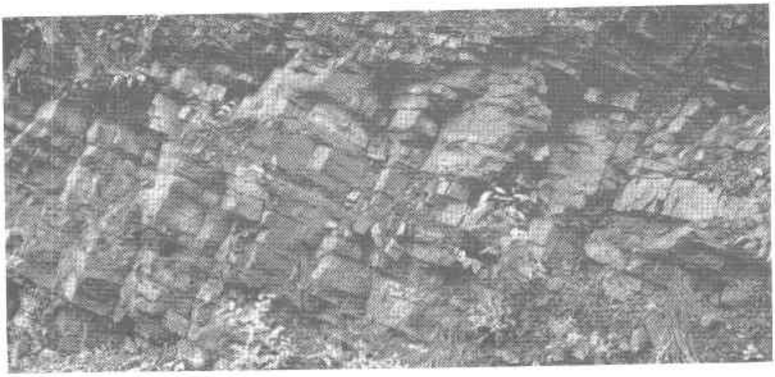


C.

A, Blocky sandstones and intercalated shales in the Juniata formation; along, Road 623, on Garden Mountain. B, Dip slope of Clinch sandstone; along Road 623, on the southeast slope of Garden Mountain. C, Current markings in Brallier shale; along State Highway 85, south of Bluefield, Virginia.



A.

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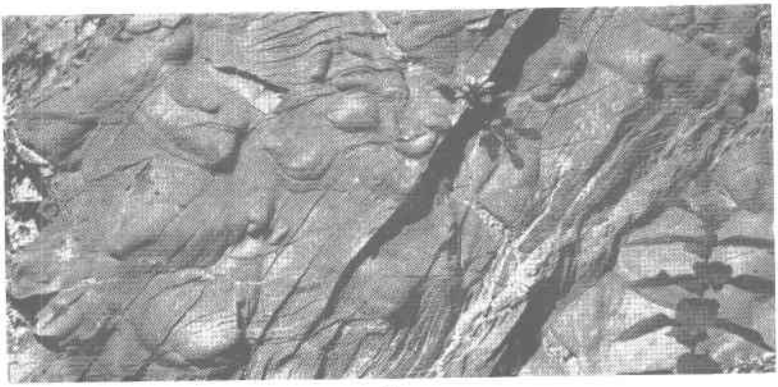

C.

A, Blocky sandstones and intercalated shales in the Juniata formation; along, Road 623, on Garden Mountain. B, Dip slope of Clinch sandstone; along Road 623, on the southeast slope of Garden Mountain. C, Current markings in Brallier shale; along State Highway 85, south of Bluefield, Virginia.

shales, which occur as thin wavy intercalations between the resistant sandstone beds, are more numerous in the upper part of the formation. The quartz pebbles are characteristically egg-shaped and range in size from one-fourth of an inch to 1½ inches. Basal beds are almost invariably conglomeratic. On many ridges the lowest bed of the Clinch forms an overchanging cliff, and the under side of this bed generally contains many large pebbles.

Clinch sandstones are ridge-makers of the first magnitude. The durability of the rock is not only attested by the high ridges which it upholds, but also by the float blocks which litter the sides of the ridges (Pls. 17A, B, and C). Nearly every one of these blocks is as firm and hard as the parent mass which crops out on the ridge crests. The dip slopes below the outcropping face of the Clinch weather by granular disintegration of the sandstone. Descending waters dissolve some of the interstitial quartz and make the rock saccharoidal, but even this weathered material is resistant. Most of the surface water seeps into the sand to become ground water. In the absence of surface runoff, the dip slopes (Pl. 13B) are not eroded rapidly.

The thickness of the Clinch ranges from 100 to 175 feet. In Mill Gap, where the Clinch is fully exposed, the formation is 124 feet thick. At Dial Rock (Pl. 18C) and on the south face of Short Ridge it is 165 feet thick. The section exposed on the crest of East River Mountain along Road 662 has a thickness of 127 feet. Rough measurements made along the temporary plank road to the lumbering camp on Beartown show that the Clinch is 120 to 150 feet thick on Clinch Mountain. The thickness of the formation on Walker Mountain is about 100 feet.

Dial Rock is one of the best exposures of the Clinch sandstone in the southern Appalachian region. The manner in which the Clinch is normally eroded is well shown in that locality. As erosion removes the less resistant Juniata beds from beneath the Clinch, large joint-blocks of the Clinch creep away from the parent mass and move down the mountain slopes. During prolonged rains, erosion of the Juniata is rapid, and large masses of Clinch sandstone are thus undermined in a short time. A 1,700-ton block, which broke off the face of Dial Rock in 1918 and crashed down the mountain side for one-fourth of a mile, can be seen near the edge of the forest below Dial Rock. On the dip slopes of the ridges the Clinch forms an effective "armor-plate" through which few of the resequent streams have been able to cut.

Fossils.—Only two kinds of fossils were found in the Clinch, and both are worm markings. *Arthrophycus alleghaniensis* occurs on the under side of many sandstone beds. The worms apparently burrowed in the muds between the sands. Temporary withdrawal of the sea caused the muds to dry prior to the deposition of the sands which filled the anastomosing burrows. Other burrows consist of vertical tubes which are referred to *Scolithus*. Some beds of the Clinch are composed of isolated columns of white sand enclosed in pinkish sand. The fact that some of the columns are annulated, like *Arthrophycus,* suggests an organic origin.

Age and correlation.—The Clinch is areally continuous with the Tuscarora sandstone of the northern Appalachian region. Both formations are considered by Butts and Ulrich to be equivalent to the Albion (Medina) sandstone of New York and to the Brassfield limestone of the Ohio Valley.

Stratigraphic relations.—The contact between the Juniata and Clinch is somewhat irregular, but probably does not signify any appreciable interruption in deposition between the two formations. Relations between the Clinch and the overlying Rose Hill are less certain, and it is possible that there is a disconformity between the two.

NIAGARAN SERIES

ROSE HILL FORMATION

Name.—The Rose Hill formation was named by C. K. Swartz[131] and has been used to denote the pre-Rochester, post-Tuscarora (Clinch) succession of Maryland. Butts[132] and also Ulrich applied the name Clinton to the same general succession in other parts of southwestern Virginia. According to them the Clinton includes the Rochester shale. The Keefer sandstone, a member of Butts' Clinton and supposed to be of Rochester age, is not present in the Burkes Garden quadrangle. The white sandstone, formerly called Keefer in this area, is a part of the Rose Hill. The name Rose Hill is used here to emphasize the fact that the Clinton of this area contains no Keefer or Rochester beds.

Distribution.—The Rose Hill formation crops out in several belts in the rugged area between East River and Buckhorn mountains,

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[131] Swartz, C. K., and others, Geologic relations and geographic distribution of the Silurian strata of Maryland: Maryland Geol. Survey, Silurian, pp. 27-28, 1923.

[132] Op. cit., pp. 237-250.

along the northwest slope of East River Mountain south of Springville, and on Buckhorn Mountain from Benbolt northeastward to the vicinity of Kinzer Church (Pl. 1). The upper half of the formation is exposed along State Highway 85 south of Bluefield, Virginia. Much of the dip slopes of East River, Buckhorn, Rich, Garden, Clinch, and Walker mountains are underlain by the Rose Hill. The resistant beds at the top of the formation form the conspicuous "flat-irons" near the base of these mountains. The "flat-irons" comprising the dissected dip slope southeast of Beartown are made by the Rose Hill red beds. Another belt of Rose Hill crops out on Brushy Mountain between branches of the Saltville-Bland overthrust. The upper part of the dip slope of Walker Mountain is underlain by the Rose Hill and all the "flat-irons" which are conspicuous from U. S. Route 52 are made by the upper part of the formation.

Lithology.—The Rose Hill is composed of dark reddish-black, flaggy sandstones, soft reddish and purplish silty mudrocks, olive-drab fissile shale, mealy buff shales, brown siltstones, beds of fossiliferous hematite, and white sandstones (Fig. 4). Except in road cuts the shales are rarely seen. The flaggy dark-red sandstones are very resistant; hence slabby blocks of ferruginous sandstone litter the outcrop in such abundance as to obscure all but the highest beds of the formation, which are equally resistant. The lower 150 feet of the Rose Hill consists of dark-red sandstones interbedded with varicolored shales and siltstones. Iron oxides in the dark-red flaggy sandstones compose 5 to 20 per cent of the rock.

One of the characteristic features of the Rose Hill is the fossiliferous hematite which occurs in thin beds in the lower 150 feet of the formation. These beds are composed of white fragments of fossils inclosed in a matrix of compact hematite. Exposures of the hematite are seldom seen, except in road cuts, but float blocks of the "ore" are abundant along the slopes of the various ridges. From the abundance of fossils in the hematite beds it would seem that the layers were once limestone. Possibly the iron was concentrated in the limy beds by meteoric waters. None of the hematite beds are over 2 feet thick, and most of them are less than 6 inches thick.

The uppermost 50 to 75 feet of the Rose Hill consists of light-gray to white sandstones which are very similar to the Clinch. In parts of the quadrangle the two can be distinguished only by their stratigraphic position. Butts[133] identified the white sandstone along State Highway 85 south of Bluefield, Virginia, as the Clinch, but the writer considers it to be the white sandstone near, but below, the top of the Rose Hill. The thickness of this sandstone (50 feet) is more in accord with the thickness of the white sandstone near the top of the Rose Hill than with the thickness of the Clinch. The Clinch is generally a coarse-grained sandstone, whereas the white sandstone of the Rose Hill is generally fine grained. A notable feature of the white sandstone south of Bluefield is its fine texture.

The thickness of the Rose Hill on East River Mountain is about 310 feet, but elsewhere the formation is less than 300 feet thick. The lithologic details of the Rose Hill are shown in the following section:

Geologic Section 33.—Rose Hill formation along State Highway 78 in Mill Gap, Burkes Garden, Tazewell County, Virginia

	Thickness	
	Ft.	In.
Rose Hill formation (288 feet)		
9. Shale, buff, fissile, fossiliferous; contains *Chonetes novascoticus, Liocalymene, Plethobolbina,* and *Mastigobolbina*	27	
8. Sandstone, light-gray, fine grained, thick bedded; with *Leperditia alta cacaponensis*	19	6
7. Sandstone, dark-purplish, medium grained, blocky; interbedded with light-gray, fine-grained sandstone; contains *Bonnemaia*	15	9
6. Sandstone, light-gray to pinkish, medium to thin bedded, cross laminated	17	
5. Sandstone, white, cross laminated, fine grained, very hard; contains few partings of purplish shale	15	6
4. Sandstone and shale; sandstone is medium bedded, blocky, dark-maroon, highly ferruginous; shales are olive-drab, buff, and purplish; purplish shales contain *Buthotrephis gracilis intermedia;* buff shales carry *Zygobolbina conradi*	21	

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[133] Butts, Charles, Geologic map of the Appalachian Valley of Virginia with explanatory text: Virginia Geol. Survey Bull. 42, map, 1933.

	Thickness	
	Ft.	In.
3. Sandstone, dark-maroon, purplish-red; interbedded with nodular siltstones which carry *Zygobolba* sp. 55 feet above the base, and *Mastigobolbina lata* 80 feet above the base	127	
2. Sandstone, gray, thinly laminated; resembles the Clinch	32	
1. Sandstone, dark-red, blocky to flaggy; with *Coelospira nitens*	14	
Clinch sandstone		

One of the most extensive displays of the Rose Hill is at the south end of Big Ridge, a spur of East River Mountain. The white sandstones which occur near the top of the formation "pave" the dip slope, but are turned up on end at the base of the mountain along the old wagon road from Cove Creek to Laurel Creek.

Fossils.—The Rose Hill contains a number of characteristic ostracodes and a few other fossils. Several collections were made from exposures along the trail from Kinzer Church to Mudley Branch of Cove Creek. The beds below the white sandstones near the top of the Rose Hill contain the following forms:

- Fucoids
  - Buthotrephis gracilis intermedia Hall
- Brachiopods
  - Coelospira nitens (Vanuxem)
  - Whitfieldella cf. W. marylandica Prouty
- Pelecypods
  - Clidophorus sp.
- Pteropods
  - Tentaculites minutus Hall
- Trilobites
  - Liocalymene sp.
- Ostracodes
  - Bonnemaia pulchella Ulrich and Bassler
  - Bonnemaia rudis Ulrich and Bassler
  - Mastigobolbina lata Hall
  - Mastigobolbina modesta Ulrich and Bassler
  - Mastigobolbina typus Ulrich and Bassler

Mastigobolbina typicalis Ulrich and Bassler
Zygobolba sp.
Zygobolba anticostiensis? Ulrich and Bassler
Zygobolba arcta Ulrich and Bassler
Zygobolba bimuralis Ulrich and Bassler
Zygobolba excavata Ulrich and Bassler
Zygobolbina conradi Ulrich and Bassler
Zygobolbina emaciata Ulrich and Bassler
Zygosella limula Ulrich and Bassler
Zygosella postica Ulrich and Bassler
Zygosella sp.

The above list is a composite of 5 or possibly 6 faunules of the Rose Hill. The lowest beds of the Clinton carry *Coelospira, Zygobolba anticostiensis,* and *Zygobolbina excavata.* This faunule is succeeded by beds carrying *Zygobolba bimuralis, Plethobolbina* sp., *Clidophorus* sp., *Zygobolbina emaciata,* and *Zygosella* sp. The *Zygobolba anticostiensis* and *Zygobolbina emaciata* zones are generally confined to the lowermost 50 feet of the formation, but the thickness of each of these zones varies considerably from place to place. The next faunule is found in buff siltstones intercalated in dark-red flaggy sandstones and constitutes the most fossiliferous zone of the formation. It is characterized by *Mastigobolbina lata* and *Zygobolbina conradi,* both of which occur in great abundance. Shaly beds somewhat higher above the *Mastigobolbina lata* faunule contain *Zygosella postica* and *Tentaculites* cf. *T. minutus.* Buff siltstones a few feet beneath the heavy bed of white sandstone near the top of the Rose Hill yield several species of *Bonnemaia* and other poorly preserved ostracodes. The white sandstone zone near the top of the Rose Hill contains *Leperditia alta cacaponensis* Ulrich and Bassler, a species of *Eridoconcha,* and *Bythocypris.* Buff shales in the topmost 30 feet of the Rose Hill and above the white sandstone, identified by Butts as Clinch, exposed along State Highway 85 south of Bluefield, Virginia, yielded *Chonetes novascoticus* Hall, *Tentaculites* sp., *Plethobolbina typicalis, Mastigobolbina* sp., *Camarotoechia neglecta* (Hall), and *Liocalymene clintoni* (Vanuxem). On Walker Mountain, East River Mountain, and Chestnut Spur of Garden Mountain, the white sandstones near the top of the Rose Hill show *Scolithus keeferi* Prouty.

Age and correlation.—The Rose Hill beds of the Burkes Garden quadrangle are thought to be lower and middle Niagaran and to correspond roughly to part of the Clinton succession exposed at Clinton, New York. By means of fossils, a much closer correlation is established with the Rose Hill of Maryland. In that State, the Clinton is composed of nine faunules, six of which are probably represented in the Clinton of the Burkes Garden area. The *Drepanellina clarki* zone, which correlates with the Rochester shale of New York State was not identified in the Burkes Garden area; neither were the *Zygobolba erecta* and *Zygobolba decora* zones. The white sandstones in the upper part of the Clinton of southwest Virginia have been correlated with the Keefer sandstone member of the Rochester formation of Maryland. In the Burkes Garden quadrangle, the upper white sandstone which would be called Keefer by some geologists is overlain by buff shales carrying *Plethobolbina typicalis* and *Chonetes novascoticus.* These fossils occur below the type Keefer in Maryland. Therefore, the writer believes that the so-called Keefer sandstone of southwestern Virginia is older than the true Keefer and occupies a stratigraphic position between the *Bonnemaia rudis* and *Mastigobolbina typus* zones of the Rose Hill formation. There is no evidence to indicate that the Rochester, as developed in Maryland and parts of northern Virginia,[134] is present in the Burkes Garden quadrangle. The Rose Hill is equivalent to a part of the Rockwood formation of Tennessee and to parts of the Red Mountain formation of Alabama.

CAYUGAN SERIES

WILLS CREEK SANDSTONE

Name.—Uhler[135] named the Wills Creek sandstone from Wills Creek, near Cumberland, Maryland.

Distribution.—The Wills Creek has been certainly identified in many places in the quadrangle north of Brushy Mountain, but to the south of that ridge the Rose Hill seems to be directly overlain by Devonian beds (Pl. 1). Because of the thinness of the formation, it is generally exposed only along roads and streams. Three exceptionally good exposures were found: along Road 625 on the southeast slope of Garden Mountain; along the north bank of Wolf Creek about 100 yards east of Hemppatch Branch; and along the gorge of Cove Creek, about 1 mile north of Cove Creek School, which is the best exposure.

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[134] Butts, Charles, op. cit., pp. 245-247, 1940.

[135] Uhler, P. R., The Niagara period and its associates near Cumberland, Maryland: Maryland Acad. Sci. Trans., new ser., vol. 2, pp. 19-26, 1905.

Lithology.—Nearly all of the Wills Creek beds are fine- to medium-grained buff sandstone (Fig. 4). Locally along Cove Creek and in the valley of Wolf Creek, the Wills Creek sandstone contains several beds of calcareous sandstone and a few partings of calcareous shale, but elsewhere the formation appears to be noncalcareous. The maximum thickness is about 25 feet, but it is not more than 10 feet south of Walker Gap. Possibly the formation is absent locally along the southeast slope of Garden Mountain.

Fossils.—*Leperditia elongata willsensis* Ulrich and Bassler and *Dizygopleura halli* (Jones) were collected from shaly layers exposed along Wolf Creek near the mouth of Hemppatch Branch. The same fossils were found on surfaces of sandstone blocks along the road one mile north of Cove Creek School.

Correlation.—According to Butts[136], the Wills Creek of Virginia is the same unit known by that name in Maryland, but the thin correlatives of the formation in southwest Virginia may represent only a part of the Wills Creek beds of the type locality. Butts correlates the Wills Creek with the Camillus shale of New York.

Stratigraphic relations.—In the northern part of the Appalachian Valley of Virginia[137] the Rose Hill is overlain in ascending stratigraphic order by the Keefer sandstone, Rochester shale or limestone, the McKenzie limestone, Bloomsburg formation, and the Wills Creek which is composed of limestone, shale, and sandstone. Since the Wills Creek rests directly upon the Rose Hill in the Burkes Garden quadrangle, disconformity between them is indicated by the absence of several hundred feet of beds. The upper contact of the Wills Creek is probably conformable.

TONOLOWAY LIMESTONE

Name.—The Tonoloway limestone was named by Ulrich[138], though without definition, from Tonoloway Ridge west of Hancock, Maryland.

Distribution.—The Tonoloway has the same distribution as the Wills Creek formation, but is somewhat better exposed. Excellent exposures of the formation occur along Wolf Creek east of the mouth of Hemppatch Branch; along the old wagon road descending

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[136] Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. 1, pp. 260-261, 1940.

[137] Butts, Charles, op. cit., pp. 243-257.

[138] Ulrich, E. O., Revision of the Paleozoic systems: Geol. Soc. America Bull., vol. 22, Pl. 23, 1911.

the south side of Garden Mountain, south of Walker Gap; and along Road 662 about 1 mile north of Cove Creek School (Pl. 1). The sticky, laminated, residual clays of the Tonoloway were seen in scores of places along the slopes of the ridges northwest of Brushy Mountain, but no Tonoloway beds were found southeast of Brushy Mountain.

Lithology.—The Tonoloway is predominantly a limestone but contains minor proportions of calcareous shale and a few beds of calcareous, saccharoidal sandstone (Fig. 4). The most characteristic beds of the formation are straticulate and argillaceous. On Garden Mountain south of Walker Gap the limestones are thick bedded and are pure enough to be burned for lime. In the valley of Wolf Creek and along Cove Creek, the Tonoloway contains argillaceous limestones which weather into vivid shades of red and yellow. Some of these layers have been leached of their original calcium carbonate, and the remaining clay has been impregnated with secondary calcite.

In most places the Tonoloway is represented only by sticky, laminated clay which has been prospected locally for manganese. Where fully exposed the Tonoloway limestone is 45 to 50 feet thick. The residual clays are somewhat thinner, averaging about 25 feet thick.

Geologic Section 34.—Wills Creek and Tonoloway formations along Wolf Creek near Hemppatch Branch, Bland County, Virginia

	Thickness	
	Ft.	In.
Rocky Gap sandstone		
Tonoloway limestone (44 feet)		
6. Limestone, argillaceous, ribbon banded, dark blood-red to brownish-gray	3	
5. Limestone, very coarse grained, dark-gray, argillaceous; weathers mealy	1	
4. Limestone, light-brown, very silty and argillaceous; leached and cavernous; impregnated with secondary white calcite; weathers carmine-red to orpiment-yellow	14	1
3. Limestone, thoroughly weathered, mealy, silty; very evenly bedded; weathered surfaces are carmine-red to orpiment-yellow	2	4

	Thickness	
	Ft.	In.
2. Limestone, blocky to platy, very silty and argillaceous; vugs and veins of white calcite; weathered surfaces are blood-red to burnt-sienna; the fresh rock is light bluish-gray........	24	
Wills Creek sandstone (20 feet)		
1. Sandstone, shaly, buff; some beds are casehardened with secondary quartz..................................	20	
Rose Hill formation		

Geologic Section 35.—Wills Creek and Tonoloway along Road 662, a mile north of Cove Creek School, Tazewell County, Virginia

	Thickness	
	Ft.	In.
Rocky Gap sandstone		
Tonoloway limestone (49 feet)		
14. Limestone, drab-gray, ribbon banded, fine grained, argillaceous; weathers salmon-pink..	5	
13. Shale, bluish-gray, calcareous, platy; contains *Leperditia* alta (Jones)..	3	6
12. Limestone, dark bluish-gray, platy to blocky, argillaceous	2	8
11. Calcilutyte, dove-gray to salmon-pink, very dense; weathers blocky..	5	
10. Limestone, dark-gray, coarse grained, sandy; weathers saccharoidal	7	6
9. Limestone, light-gray, mealy; covered with a crust of ash-gray clay..	3	6
8. Quartz sandstone, dark bluish-gray, medium grained, calcareous..	3	2
7. Limestone, light-gray mottled with pink; mealy, fine grained, cherty..	2	4
6. Calcilutyte, light-gray, dense; thoroughly fractured		9
5. Shale, platy, ash-gray, with salmon-pink to blood-red blotches; partings of ash-gray limestone	5	10

	Thickness	
	Ft.	In.
4. Limestone, straticulate, drab-gray; weathers mealy and cavernous; weathers to carmine-red and orpiment-yellow	3	8
3. Limestone, dull buff, argillaceous, very porous and spongy textured; vuggy calcite abundant	1	3
2. Limestone, platy, mealy, calcareous, buff; vugs of secondary calcite	4	8
Wills Creek sandstone (25± feet)		
1. Shale and sandstone, buff, calcareous where fresh; base not exposed	25±	
Rose Hill formation		

Fossils.—Ostracodes are very abundant upon the bedding surfaces of the thin, platy, argillaceous limestones. *Leperditia alta* (Jones) is the most common species; few of the other species are well enough preserved to be identified. Bluish-gray limestones exposed along the wagon road below Walker Gap contain *Camarotoechia tonolowayensis* Swartz.

Correlation.—Butts[139] considers that the beds carrying *Leperditia alta* corresponds to the Tonoloway of Maryland, but points out that the same fossil is reported from the Wills Creek of Maryland. The Tonoloway corresponds to part of the Hancock limestone of Lee and Wise counties, Virginia, and with the †Sneedville limestone of Tennessee.

Stratigraphic relations.—The Tonoloway appears to be conformable with the Wills Creek, but the contact with overlying beds is an unconformity of considerable magnitude. In the northeastern part of the quadrangle, the Tonoloway is overlain by the New Scotland formation (Devonian), but farther south the Tonoloway is directly overlain by the Rocky Gap sandstone which is younger than the New Scotland. No representatives of the Keyser formation or of the Lower Devonian Coeymans limestone have been identified by the writer in the Burkes Garden quadrangle.

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[139] Op. cit., p. 263.

DEVONIAN SYSTEM

ULSTERIAN SERIES

"NEW SCOTLAND" FORMATION

Name.—Clarke and Schuchert[140] named the New Scotland formation from the town of the same name in Albany County, New York. In this report the name is used provisionally for a succession of sandstone, limestone and chert found only in the belt of Devonian north of the St. Clair fault. The formation has been identified in only one locality in the quadrangle, namely, along State Highway 85 north of the Saunders farm. No claim is made that the beds here termed "New Scotland" are precise equivalents of the New York formation, but that they are approximately equivalent is indicated by their general lithology and fossils.

Distribution.—The "New Scotland" beds have been traced from the Bluefield, Virginia, ball park (formerly a fairgrounds and airport) southwestward into the Burkes Garden quadrangle, but they appear to thin north of Dills Spring (Pl. 1). The writer was unable to trace them as far southwest as the adjacent belts of Rocky Gap sandstone and Cayugan limestones are known to extend.

Lithology.—The character of the "New Scotland" is shown in exposures immediately south of the old sand pit at the south entrance to the Bluefield, Virginia, ball park (Pl. 14).

Geologic Section 36.—"New Scotland" formation at the south entrance to the ball park, Bluefield, Tazewell County, Virginia

	Thickness	
	Ft.	In.
Rocky Gap sandstone		
"New Scotland" formation (83+ feet)		
8. Limestone, gray, partly oolitic, clastic texture; contains *Delthyris perlamellosus* (Hall), *Meristella* sp., *Schuchertella woolworthana* (Hall), and *Aechmina*	5	
7. Chert, spongy, deeply weathered, wavy bedded; contains *Spirifer macropleurus* (Conrad), *Rhipidomella.* sp., and crinoid stems	44	

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[140] Clarke, J. M., and Schuchert, Charles, The nomenclature of the New York Series of geologic formations; Science, new ser., vol. 10, pp. 874-878, 1899.

	Thickness	
	Ft.	In.
6. Limestone, very coarse grained; clastic texture, medium-gray; contains partings of shale and *Meristella symmetrica* Schuchert	4	
5. Covered	5	
4. Limestone, medium to fine grained, argillaceous; ribbon bedded	4	
3. Covered	8	6
2. Limestone, dark bluish-gray, medium grained, conglomeratic	5	3
1. Sandstone (Healing Springs sandstone), light buff, quartzitic; deeply weathered at the base	7	6
Tonoloway limestone		

Southwest of the above section the formation is marked only by a sparse residuum of porous chert.

Fossils.—The fossils listed above are the only ones obtained by the writer. Neither the basal sandstone nor the immediately overlying limestone (zones 2 and 4) has yielded fossils. One specimen of *Aechmina,* resembling very closely a form that occurs in the Haragan shale of Oklahoma, was found in the oolitic limestone about 3½ feet below the top of the formation. The specimens of *Meristella symmetrica,* which occur in zone 6, are silicified interiors of the ventral valve and occur only in the outer, weathered crust of the beds. A local resident showed the writer a well-preserved cephalon of *Synphoroides pleuroptyx* (Green), said to have been collected from the section described above.

Age and correlation.—The "New Scotland" locally developed near the Bluefield ball park is rather similar to the beds called the New Scotland in Bath, Highland, and Alleghany counties, Virginia, by Butts[141].

Identity of the "New Scotland".—Considerable confusion seems to exist with regard to the section exposed south of the old quarry at the entrance to the Bluefield ball park. Reger[142] measured a thickness of 235 feet of Helderberg limestone at the same locality. According to him the cherty Helderberg is overlain by 130 feet of Oriskany sandstone

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[141] Op. cit., pp. 276-279.

[142] Reger, D. B., Mercer, Monroe, and Summers counties, West Virginia: West Virginia Geol. Survey, County Reports, p. 195, 1926.

and is underlain by 540 feet of Clinton beds. He made no mention of the sandstone (zone 1) or of the underlying Cayugan formations. Butts[143] identified 133 feet of highly fossiliferous limestone as the "New Scotland limestone." Woodward[144] assigned the upper 4 to 5 feet of the "New Scotland"—zone 8 in geologic section 36—to the overlying sandstone formation which he called the "Becraft limestone" and identified the underlying weathered, cherty beds as "Healing Springs sandstone?" Subsequently, he[145] identified the sandstone at the base of the "New Scotland"—zone 1 in geologic section 36—as the Clifton Forge member of the Keyser formation. The identity of this sandstone is uncertain, but all the available evidence seems to favor its assignment to the "New Scotland". It is here identified with the Healing Springs sandstone member of the "New Scotland" because of the similarity in its stratigraphic position and lithology to the Healing Springs sandstone member in Alleghany County, Virginia. So far as known, the Keyser is absent in southwestern Virginia.

ROCKY GAP SANDSTONE

Name.—F. M. Swartz[146] named the Rocky Gap sandstone from Rocky Gap, Bland County, Virginia. Butts[147] has used the name Becraft for this sandstone throughout southwestern Virginia, but this use should be abandoned. The sandstone contains a number of fossils suggestive of the lower Oriskany, which are not found in the type Becraft of New York. The Oriskany elements in the fauna occur in the Shriver chert of West Virginia and Maryland, which has been considered the lower division of the Oriskany of those areas. G. A. Cooper[148] believes that the sandstone is sufficiently different in facies and fauna from the typical Becraft limestone of New York to warrant use of the name which Swartz has proposed.

Distribution.—The Rocky Gap sandstone is well exposed in the area northwest of Brushy Mountain (Pl. 1). The best section is at the south entrance to the ball park at Bluefield, Virginia, a short distance beyond the northeastern limits of the Burkes Garden quad-

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[143] Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. 1, p. 283, 1940.

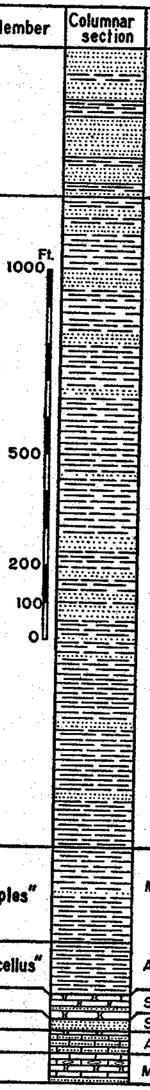
[144] Woodward, H. P., Limestones from Cambrian to Devonian, *in* McCue, J. B., and others, Limestones at West Virginia: West Virginia Geol. Survey, vol. 12, p. 125, 1939.

[145] Woodward, H. P., Silurian system of West Virginia: West Virginia Geol. Survey, vol. 14, p. 246, 1941.

[146] Swartz, F. M., The Helderberg group from central Pennsylvania to southwestern Virginia: Pennsylvania Acad. Sci. Proc., vol. 3, p. 80, 1929.

[147] Op. cit., pp. 282-291.

[148] Cooper, G. A., personal communication, Dec. 16, 1942.



Formation	Member	Columnar section	Important fossils
"Chemung"			*Cyrtospirifer disjunctus, Schizodus chemungensis, Chonetes scitulus, Productella lachrymosa, Orthothetes chemungensis, Cypricardella bellistriata, Leiorhynchus mesacostale*
Brallier			*Pteridichnites biseriatus, Spirifer mesistrialis, Productella, Palaeoneilo, Nuculites*
Millboro	"Naples"		*Manticoceras patersoni, Probeloceras lutheri, Pterochaenia fragilis, Buchiola retrostriata, Trachydomia praecursor*
	"Marcellus"		*Actinopteria muricata, Chonetes lepidus, Schizobolus concentricus*
Huntersville			*Schuchertella pandora, Spirifer duodenarius, Chonetes acutiradiatus*
Ridgeley			*Spirifer arenosus*
Rocky Gap			*Aspidocrinus caroli, Spirifer concinnus, Camarotoechia praespeciosa*
"New Scotland"			*Meristella symmetrica, Delthyris perlamellosus, Aechmina*

Columnar section of the Devonian formations in the Burkes Garden quadrangle, Virginia.

rangle. From this point the sandstone extends southwestward for about 2½ miles in a wooded ridge about 100 feet high. Midway between the road leading north to Bluefield from Dills Spring and St. Clair School, the Rocky Gap passes under the overthrust Ordovician limestones of the St. Clair fault block.

On the southeast slopes of East River Mountain the sandstone is exposed in six places along the Cove Creek road, and farther south, toward State Highway 61, the formation is exposed in three places. It forms a conspicuous bluff about 75 feet high near the junction of the forks of Cove Creek. One of the belts of the sandstone along Cove Creek extends northeast beyond the Bland-Tazewell county line and is fully exposed along the CCC road from Cove Creek to Rocky Gap. Two belts of the Rocky Gap are present in Wolf Creek Valley. Good exposures of the northwestern belt occur about 100 yards east of the mouth of Hemppatch Branch, along State Highway 78 on the southeast slopes of Rich Mountain, and in an old roadside quarry at the north end of Mill Gap. Another belt extends along the northwest bases of Garden Mountain, Chestnut Ridge, and Clinch Mountain, and is exposed along Road 623; along the old wagon road south of Walker Gap; and along the "four-foot" road which angles down the southeast slope of Clinch Mountain, west of Beartown. Possibly 5 to 10 feet of the sandstone exposed on the southeast slopes of Walker Mountain is referable to the Rocky Gap, but these beds may be Ridgeley (Oriskany).

Lithology.—Where fully exposed the Rocky Gap consists predominantly of coarse-grained, saccharoidal sandstone, but mealy, arenaceous chert is conspicuous in the uppermost 10 feet of the formation (Pl. 14). The fresh Rocky Gap is a hard steel-gray sandstone cemented with calcium carbonate. Generally the cement has been leached out of the exposed beds, leaving a loose aggregate of sand. Iron oxide and manganese stains are commonly seen on the weathered exposures. Bedding laminations are characteristic of the Rocky Gap.

The average thickness of the Rocky Gap is about 60 feet, but locally on East River Mountain the formation is 75 to 85 feet thick.

Fossils.—The Rocky Gap is fossiliferous, but well preserved specimens are rather rare. The most characteristic fossil is *Aspidocrinus caroli* Swartz. Both *Spirifer angularis* and *Spirifer concinnus* are found in association with the cuplike impressions of calyces of *Aspido-*

crinus. So far as known, the most fossiliferous locality of the Rocky Gap is at the south entrance to the ball park at Bluefield, Virginia, where the following section is exposed:

Geologic Section 37.—Huntersville, Ridgeley, and Rocky Gap formations at the ball park, Bluefield, Tazewell County, Virginia

	Thickness	
	Ft.	In.
Huntersville chert (18+ feet)		
17. Chert, irregularly bedded; gray, stained brown by iron oxide; contains *Orbiculoidea* sp. and a large, flat-ribbed *Spirifer;* thickness undetermined.		
16. Shale and siltstone; siliceous, glauconitic; dark-green to greenish-gray	8	
15. Chert, medium-gray to rusty-brown, interbedded with sandstone; contains *Stropheodonta* and *Spirifer*	5	
14. Shale, greenish gray, siliceous; suggestions of *Leiorhynchus*	1	
13. Limestone, coarse grained, light-gray; composed almost wholly of fragmented fossils; grades laterally along the bedding into chert		6
12. Chert, thin bedded, light-gray; interbedded with greenish-gray, siliceous shale	1	6
11. Chert, thin bedded, slightly glauconitic and sandy; interbedded with gray shale	1	9
Ridgeley sandstone (3 feet 9 inches)		
10. Chert, arenaceous, rusty brown; interbedded with thin, friable sandstone; contains *Rhipidomella assimilis* and *Spirifer arenosus*	1	6
9. Chert, white, stained with iron oxide		6
8. Sandstone, fine-grained, soft, mealy; contains *Spirifer arenosus* and *Atrypa reticularis*	1	9
Rocky Gap sandstone (57 feet)		
7. Chert, fossiliferous, stained brown by iron oxide; contains *Spirifer angularis* and *Plethorhyncha praespeciosa*	2	4

	Thickness	
	Ft.	In.
6. Clay, reddish-brown, unctuous; contains an abundance of chertified fossils which include *Meristella lentiformis, Spirifer angularis,* and *Stenochisma formosa*	1	4
5. Sandstone, deeply weathered, saccharoidal; few fossils near the top	13	
4. Sandstone, laminated, calcareous, firmly cemented	8	
3. Sandstone, thoroughly weathered, rusty-brown saccharoidal	8	
2. Sandstone, laminated, steel-gray; hard	5	6
1. Sandstone, rusty-brown, friable; carries *Spirifer concinnus, Leptaena rhomboidalis,* and impressions of *Aspidocrinus*	18	9

"New Scotland" limestone

The exposures of zones 6 to 11, inclusive, are such that loose fossils collected on the surface are apt to be a mixed assemblage obtained from as many zones. Careful collections were made of all loose fossils and these were kept separate from other collections obtained from the bedrock. Almost all of the loose fossils were found also in the clay and chert of zones 6 and 7. The following list of species includes the forms obtained below the top of zone 7 and above the "New Scotland" limestone:

Corals
    Striatopora sp.
    Favosites cf. F. conicus Hall
Crinoids
    Aspidocrinus caroli Swartz
Brachiopods
    Artypa reticularis (Linné)
    Cyrtina rostrata (Hall)
    Leptaena rhomboidalis (Wilckens)
    Leptocoelia fimbriata Hall
    Leptocoelia flabellites (Conrad)
    Meristella cf. M. arcuata (Hall)
    Meristella lentiformis Clarke
    Nucleospira elegans Hall
    Plethorhyncha sp.
    Plethorhyncha praespeciosa (Schuchert)

Rensselaeria aff. R. suessana immatura Schuchert
Rhipidomella assimilis (Hall)
Rhynchotreta cumberlandicum Rowe
Spirifer cyclopterus Hall
Spirifer angularis Schuchert
Spirifer intermedius Hall
Spirifer tribuarius Schuchert
Stropheodonta planulata (Hall)
Uncinulus cf. U. velicatus (Hall)
Whitfieldella sp.

Gastropods

Platyceras cf. P. subfalcatum Ohern

Members of the above fauna, which occur also in the Shriver cherts, are the species *Cyrtina rostrata, Atrypa reticularis, Meristella lentiformis, Rensselaeria aff. R. suessana immatura,* and *Spirifer tribuarius.* Several of the species of *Spirifer* occur in the lower part of the Ridgeley sandstone of Maryland. Prior to the work of F. M. Swartz[149] both the Ridgeley and Shriver were thought to be of Oriskany age. The Shriver and Ridgeley species in the Rocky Gap fauna occur in association with other forms common in the Becraft of New York.

Age and correlation.—Mainly from the writer's study of the section described above, he regards the Rocky Gap as the equivalent of the Shriver chert and the so-called Becraft limestone of northern Virginia. The Rocky Gap appears to correspond to at least a part of the Becraft limestone and to the basal part of the Oriskany in New York. Whereas the Rocky Gap corresponds closely to the Becraft sandstone of Butts,[150] he includes zone 7 of the above section in the Oriskany.

RIDGELEY SANDSTONE

Name.—The Ridgeley sandstone was named by C. K. Swartz[151] and others from exposures near Ridgeley (or Ridgely), West Virginia.

Distribution.—Owing to its very thin development northwest of Walker Mountain, the exact distribution of the Ridgeley sandstone

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

[150] Op. cit., p. 282.

[151] Swartz, C. K., and others, *in* Introduction: Maryland Geol. Survey, Lower Devonian; pp. 26, 30, 1913.

is not known (Pl. 1). A foot or so of sandstone, exposed along Road 625, between Walker Gap and Mt. Victory Church, contains *Spirifer arenosus* and a large, elongate *Rensselaeria*, which are considered to signify the Ridgeley. No other exposure of Ridgeley was seen in the belt of Devonian sandstone which extends along the southeastern bases of Clinch Mountain, Chestnut Ridge, and Garden Mountain. No Ridgeley was identified in Wolf Creek Valley. On the southeast slope of East River Mountain along Oneida Branch, a single slab of sandstone bearing *Spirifer arenosus* and sandstone molds suggestive of *Platyceras* was found mixed with chert float derived from the overlying Huntersville chert. No other indication of the Ridgeley was found in Nye Cove. A few feet of sandstone, apparently the same zone as is exposed at the south entrance to the ball park at Bluefield, Virginia, overlies the Rocky Gap sandstone along the road from Dills Spring north to Bluefield, Virginia. The southwestern extent of the Ridgeley in this belt could not be ascertained because of poor exposures, and the formation was not mapped separately. The only belt of Ridgeley shown separately on the geologic map is that which extends along the southeastern slope of Walker Mountain.

Lithology.—Northwest of Walker Mountain the Ridgeley consists of a few feet of friable sandstone (geologic section 36). On Walker Mountain the Ridgeley consists of 35 feet of very glauconitic sandstone, reddish-brown shale, and buff quartzose sandstone (Pl. 14). Good exposures of the belt of Ridgeley along Walker Mountain are lacking in the Burkes Garden quadrangle, but the character of the formation is seemingly the same as in the exposures along U. S. Route 52 a few miles southwest of Bland, Virginia.

Fossils.—The Ridgeley in the vicinity of Bluefield, Virginia, contains *Spirifer arenosus* (Conrad), *Rhipidomella* cf. *R. assimilis* (Hall), and *Atrypa reticularis* (Linné): Fossils collected from the Ridgeley along Walker Mountain include:

- Brachiopods
  - Anoplia nucleata (Hall)
  - Pholidops multilamellosa Schuchert
  - Spirifer sp.
  - Spirifer arenosus (Conrad)
- Pelecypods
  - Actinopteria sp.
  - Megambonia sp.
  - Palaeopinna sp.

Correlation.—The Ridgeley seems to be essentially the same, though thinner than, the Ridgeley of the northern Appalachian region. It corresponds to a part, and possibly to all, of the Oriskany of New York.

HUNTERSVILLE CHERT

Name.—Price[152] named the Huntersville chert from Huntersville, Pocahontas County, West Virginia. The formation was originally referred to the Oriskany, but it has since been found to contain the same fauna as Butts' "Onondaga" chert of southwestern Virginia, which is known to be post-Oriskany. According to G. A. Cooper[153], Butts' Onondaga chert in southwestern Virginia probably corresponds to the lower part of the Onondaga of New York and the underlying Schoharie beds. Therefore, the name Onondaga can not be considered to be applicable as a precise stratigraphic name in southwestern Virginia.

Distribution.—The Huntersville chert is present in all belts of the Devonian in the Burkes Garden quadrangle (Pl. 1). One belt extends southwestward from the south entrance to the ball park at Bluefield, Virginia. Local folding causes the Huntersville and associated beds to crop out in several belts in the area between East River and Buckhorn mountains. Several good exposures of the formation are present along Road 662. Parts of the Huntersville are well exposed along State Highway 78 on the southeast slopes of Rich Mountain and also at the north end of Mill Gap. Another good section is present along Wolf Creek near the mouth of Hemppatch Branch. The finest exposure of the Huntersville chert in the quadrangle is along the southeast slope of Garden Mountain beside the old road descending the mountain from Walker Gap. This locality is remarkable for the abundance of fossils. No good exposures of the Huntersville were seen in the Walker Mountain belt, but the lithology of the beds in this belt is the same as that in the other belts.

Lithology.—The Huntersville is composed of white, buff-gray, and black-stained chert, glauconitic siltstone, and greenish-gray siliceous shale (Pl. 14). The fresh chert is dense, hard and breaks into small irregular blocks. A prominent glauconite zone near the base of the formation is particularly well shown in the old quarry at the south entrance to the ball park at Bluefield, Virginia. In some places the glauconitic zone appears to be supplanted by a 5-foot bed of reddish-brown

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[152] Price, Paul H., Pocahontas County: West Virginia Geol. Survey, County Reports, pp. 106, 108, 233, 236-237, 397, 1929.

[153] Personal communication, Dec. 16, 1942.

siltstone which may represent a secondarily oxidized phase of the glauconite. A somewhat thinner and less conspicuous glauconitic zone is found within a few feet of the top of the Huntersville.

The only good exposures of the chert are along roads. Generally outcrops of chert beds are marked only by residual aggregates of weathered fragments. In weathered exposures, and particularly those on the southeast slope of Garden Mountain, the Huntersville is very mealy and porous, and some of it is sandy.

The exposure of Huntersville, near the ball park at Bluefield, Virginia, is peculiar in that a part of the lower zone is a coarse-grained, fossiliferous, clastic limestone. The exposed bed of limestone grades laterally into chert which shows the texture of the adjacent limestone. The granular texture of this chert and many other specimens of the Huntersville simulates so closely the texture of a coarse-grained limestone that it may be a secondary alteration product of fossiliferous limestone. The Huntersville also contains many fossils, particularly bryozoans, corals, and brachiopod shells, which originally were composed of calcium carbonate.

The thickness of the Huntersville ranges from 40 to 75 feet and averages about 50 feet. It is not more than 50 feet thick at the south entrance to the ball park at Bluefield, Virginia. The thickness on the southeast slope of East River Mountain is approximately 60 feet.

Fossils.—The following fossils were collected from weathered chert along Road 625 about one-fourth of a mile north-northeast of Mt. Victory Church, on the southeast slope of Garden Mountain:

Corals
    Cladopora sp.
    Cystiphyllum sp.
    Dendropora neglecta Rominger
    Favosites sp.
    Heliophyllum sp.
    Syringopora sp.
Brachiopods
    Ambocoelia sp.
    Ambocoelia umbonata (Conrad)
    Amphigenia curta (Meek and Worthen)
    Chonetes mucronatus Hall
    Chonetes acutiradiatus Hall

Costispirifer planicostatus (Swartz)
Lingula sp.
Orbiculoidea lodiensis (Hall)
Pentamerella sp.
Rhipidomella alsa (Hall)
Schuchertella pandora (Billings)
Spirifer duodenarius (Hall)
Spirifer varicosus Hall
Stropheodonta patersoni (Hall)

Trilobites
- Coronura aspectans (Conrad)

Age and correlation.—The Huntersville chert appears to correspond approximately to the lower part of the Onondaga of New York and possibly also to the underlying Schoharie. It seems closely related to the Camden chert of Tennessee and the Clear Creek chert of Illinois.

Stratigraphic relations.—Throughout the Burkes Garden quadrangle, the Huntersville is succeeded by the Millboro shale, with which it is thought to be conformable[154]. The Huntersville fauna has little resemblance to that in the upper part of the Onondaga as developed in the Ohio and Mississippi valleys. Very probably, a hiatus exists between the Huntersville and overlying shales in the Burkes Garden quadrangle. A hiatus also is present at the base of the Huntersville, where the Ridgeley sandstone is locally absent.

ERIAN AND SENECAN SERIES

MILLBORO SHALE

Name.—Butts[155] named the Millboro shale from a village of the same name in Bath County, Virginia. According to him, the lower part of the formation is the equivalent of the Marcellus shale of New York. He regards the upper part as being equivalent to the Naples of New York and believes that it lies unconformably on the Marcellus, with the Hamilton absent.

G. A. Cooper[156] has recently stated that the so-called Marcellus black shale of the Millboro may represent not only the Marcellus of New York, but the entire Hamilton. Millboro, as used here, refers to beds of uncertain age, which constitute a convenient mapping unit.

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[154] Butts, Charles, op. cit., p. 305.
[155] Op. cit., pp. 308-312.
[156] Cooper, G. A., Correlation of the Devonian sedimentary formations of North America: Geol. Soc. America Bull., vol. 53, pp. 1736-1737, 1942.

Distribution.—The Millboro shale crops out along the southeast base of Walker Mountain, on Brushy Mountain northwest of Ceres, and on the dip slopes of Clinch, Garden, Rich, and East River mountains. Another belt occurs a short distance north of the St. Clair fault from Bluefield, Virginia, southwestward nearly to U. S. Route 19 (Pl. 1).

"MARCELLUS" MEMBER

Name.—The Marcellus shale was named by Hall[157] from Marcellus, New York. The name is used provisionally for black shales of typical Marcellus character, which may possibly be a black-shale facies of the Hamilton as developed in northern Virginia.

Lithology.—The lower 100 to 150 feet of the Millboro, the part assigned to the "Marcellus" member, is composed mainly of black fissile shale (Pl. 14). Where weathered, the "Marcellus" shales are bleached light-gray to buff. Beds near the top are dark-gray to greenish-gray fissile shale and mealy siltstone.

Fossils.—A composite list of forms collected from the "Marcellus" member at several places is as follows:

- Brachiopods
  - Ambocoelia cf. A. umbonata (Conrad)
  - Chonetes lepidus Hall
  - Leiorhynchus limitare (Vanuxem)
  - Lingula cf. L. ligea Hall
  - Orbiculoidea cf. O. minuta (Hall)
  - Schizobolus concentricus (Vanuxem)
- Pelecypods
  - Actinopteria muricata Hall
  - Buchiola sp.
- Gastropods
  - Loxonema delphicola Hall
- Cephalopods
  - Bactrites sp.
  - Tornoceras cf. T. uniangulare (Conrad)
- Pteropods
  - Styliolina fissurella (Hall)
  - Tentaculites cf. T. bellulus Hall

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[157] Hall, James, Third annual report of the fourth geological district of the State of New York: New York Geol. Survey 3d Ann. Rept., pp. 295-296, 1839.

"NAPLES" MEMBER

Name.—The Naples was named by Clarke[158] from Naples, Ontario County, New York. It is used here in a provisional sense; the beds so named may not be equivalent to all of the Naples of New York.

Lithology.—The "Naples" member consists of greenish-gray fissile shales and siltstones and carrot-red to apricot-buff clay shales and argillaceous siltstones (Pl. 14). In the belt along Walker Mountain, most of the "Naples" is greenish-gray clay shale, but a 75-foot zone in the middle is black clay shale. On Clinch Mountain, Chestnut Ridge, and Garden Mountain and in the belts between Rich and Garden mountains, carrot-red and apricot-buff shales predominate. The best exposure of the buff and red shales is along State Highway 78, on the southeast slope of Rich Mountain. In the belt of Millboro near Bluefield, Virginia, the "Naples" is chiefly greenish-gray to black clay shale. The uppermost beds of the "Naples" are invariably greenish-gray and are almost indistinguishable from beds in the overlying Brallier.

The thickness of the "Naples" member is difficult to determine, but fairly accurate measurements made along the southeast slope of Rich Mountain show a thickness of about 250 feet. On Walker Mountain it is probably not more than 200 feet thick.

Fossils.—Buff and reddish shales exposed along State Highway 78, on the southeast slope of Rich Mountain, yielded the following fossil forms:

- Pelecypods
  - Actinopteria cf. A. boydi (Conrad)
  - Buchiola retrostriata (von Buch)
  - Buchiola halli Clarke
  - Paracardium doris Hall
  - Pterochaenia fragilis (Hall)
- Gastropods
  - Loxonema sp.
  - Pleurotomaria capillaria Conrad
  - Trachydomia praecursor (Clarke)
- Cephalopods
  - Manticoceras patersoni (Hall)
  - Manticoceras sp.
  - Orthoceras sp.

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[158] Clarke, J. M., On the higher Devonian faunas of Ontario County, New York: U. S. Geol. Survey Bull. 16, pp. 35-39, 1885.

Probeloceras lutheri Clarke
Tornoceras uniangulare (Conrad)

AGE, CORRELATION, AND STRATIGRAPHIC RELATIONS

The Marcellus shale is Middle Devonian and is considered by most geologists a part of the Hamilton group. In New York State and in the northern Appalachian region, typical Marcellus black shale is separated from Naples beds by several hundred feet of shales and sandstone, comprising the typical Hamilton. The latter contains a rather large fauna characterized by *Tropidoleptus carinatus* and *Spirifer mucronatus.* The absence of typical Hamilton beds and fossils in the Burkes Garden quadrangle is apparent, but possibly the entire Hamilton is represented by black shale assigned to the "Marcellus" member. Very probably both the "Naples" and "Marcellus" are facies of Devonian sediments, rather than precise time markers. Until the age of the "Marcellus" and "Naples" beds in southwestern Virginia is better understood, the presence of a hiatus between them, as postulated by Butts[159], can not be verified. The Millboro corresponds to parts of the Romney shale of northern Virginia and West Virginia. The "Naples" is represented in the Woodmont shale member of the Jennings formation in Maryland.

BRALLIER FORMATION

Name.—Butts[160] named the Brallier shale from Brallier Station, Bedford County, Pennsylvania.

Distribution.—The full thickness of the Brallier is exposed in the south environs of Bluefield, Virginia, along Hockman Road and along State Highway 85. Southwest of Bluefield, the overthrust block of the St. Clair fault covers the lower part of the formation, but the upper part forms a belt which is continuous across the quadrangle. Good exposures of this belt are seen along Road 656 south of Bailey and also along Road 655 south of Tiptop. The lower part of the formation is exposed in the lowlands of Little and Wolf Creek valleys. Another belt extends along the northwest sides of Brushy and Carter mountains, and on both sides of two subsidiary ridges known as Little Brushy Mountain. The Brallier is also exposed in a small area on the northwest side of Brushy Mountain northwest of Ceres. Part of the broad belt

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[159] Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. 1, pp. 308-314, 1940.

[160] Butts, Charles, Geologic section of Blair and Huntingdon counties, central Pennsylvania: Am. Jour. Sci., 4th ser., vol. 46, pp. 523, 531, 536, 1918.

of Brallier southeast of Walker Mountain lies within the limits of the Burkes Garden quadrangle (Pl. 1).

Lithology.—The Brallier formation (Pl. 16D), consists of sandstones, siltstones, and shales with an aggregate thickness of 1,500 to 2,000 feet (Pl. 14). The lower part is predominantly shale but sandstone increases toward the top of the formation. In spite of the thickness of the Brallier, no zones can be recognized or traced over a wide area. The shales are very micaceous and silty and their bedding surfaces are characteristically welted, dimpled, and furrowed. Most of them are greenish-gray to olive-drab, but some are black. The beds near the base of the Brallier are similar to the "Naples" shales. The sandstones are even bedded, blocky, fine grained, and weather rusty-brown. Those near the top are considerably thicker than those in the middle and lower parts.

Good exposures of the Brallier occur along Hockman Road and State Highway 85 south of Bluefield, Virginia (Pl. 13C), along Road 625 in Freestone Valley, and on the northwest side of Brushy Mountain along Road 623. Traverse measurements of the Brallier along this road show a thickness of about 1,800 feet. North of the St. Clair fault and in the vicinity of Bluefield the Brallier is about 1,000 feet thick.

Brallier terranes are characterized by a rough topography composed of rounded hills cut by an intricate system of gullies, for example, along the north side of Wolf Creek Valley near Grapefield School. Very little soil is formed by weathering of the Brallier, and the mantle consists mainly of shale chips.

Fossils.—Very few fossils occur in the Brallier. *Pteridichnites biseriatus* Swartz is the most common and characteristic fossil. Some of the lowest beds carry *Nuculites* and *Palaeoneilo,* and other forms are found sparsely in the "Naples" member of the Millboro. One bed of the Brallier, exposed along the Burkes Garden-Sharon Springs road contains fragments of *Spirifer mesistrialis* Hall and a small brachiopod resembling *Ambocoelia.*

Age and correlation.—The Brallier is a part of the Senecan series. It corresponds to part of the †Kimberling shale of older reports on southwestern Virginia.

SENECAN AND CHAUTAUQUAN SERIES

"CHEMUNG" FORMATION

Name.—Hall[161] named the Chemung from exposures at Chemung Narrows, New York. Butts[162] and others have used the name for a succession of interbedded sandstones and shales above the Brallier and below the Mississippian, in southwestern Virginia. The name is no longer applicable in southwestern Virginia, because the New York beds, with which the so-called Chemung of southwestern Virginia was correlated, are now known[163] to be a facies of the "Portage" (Nunda) division of the Senecan series. The name Chemung is now used in New York for the name of a group or stage embracing several units. According to Cooper and others[164], the so-called Chemung of southwestern Virginia includes beds considerably younger than the Chemung group or stage of New York. Hence, the name is here used in a tentative sense; no exact correlation with the Chemung group or stage of New York should be inferred.

Distribution.—The "Chemung" beds crop out on the northwest sides of Brushy and Carter mountains and form a U-shaped belt along the upper slopes of Little Brushy Mountain near the Tazewell-Smyth county line. Another synclinal belt extends along the crest of a low ridge, also known as Little Brushy Mountain, east of Punch and Judy Creek. The "Chemung" is well exposed along Road 623 on the northwest slope of Brushy Mountain. It crops out along the crest of Brushy Mountain near the southern border of the quadrangle. The section exposed along old U. S. Route 19 northeast of St. Clair Station shows that a part of the sandstones, possibly 10 feet or more, contains "Chemung" fossils. The "Chemung" is absent farther southwest, and along Roads 655 and 656, the Brallier is directly succeeded by Mississippian formations. A few feet of "Chemung" beds are present immediately south of black shales exposed along College Avenue (State Highway 85) in the outskirts of Bluefield, Virginia (Pl. 1).

Lithology.—The "Chemung" is composed of gray to greenish-gray, medium-grained concretionary sandstones and greenish-gray to olive-drab siltstones and shales (Pl. 14). The sandstones are notably thicker and more resistant than those of the Brallier. Most of them are very

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[161] Op. cit., pp. 322-326.

[162] Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. 1, pp. 322-323, 1940.

[163] Chadwick, G. H., Summary of Upper Devonian stratigraphy: Am. Mid. Naturalist, vol. 16, pp. 857-862, 1935.

[164] Cooper, G. A., and others, Correlation of the Devonian sedimentary formations of North America: Geol. Soc. America Bull., vol. 53, Pl. 1, 1942.

calcareous in the fresh state, but weather to a dark-brown, mealy, spongy residue, which is full of fossils. Beds of dark-maroon laminated sandstone occur in the "Chemung", particularly in the upper half, but are equally numerous in the overlying Price formation. Good exposures of the laminated sandstones of the "Chemung" are found along Road 623 and along old location of U. S. Route 19 about one-fourth of a mile northeast of St. Clair Station. Most of the shaly beds are siltstones. All of the "Chemung" is micaceous, but less so than the Brallier. None of the beds immediately above or below the "Chemung" is calcareous, and the fresh rock in this area is thereby easily distinguished from contiguous formations.

The thickness of the "Chemung" is about 400 feet along Road 623 but is not more than 300 feet in the southwestern part of the quadrangle. Sandstones comprise about half the total thickness; siltstones about 30 per cent, and micaceous clay shales the remainder.

Geologic Section 38.—"Chemung" formation along Road 623, 2 miles northwest of Sharon Springs, Bland County, Virginia

	Thickness Feet
Price formation	
"Chemung" formation (404 feet)	
16. Covered interval; contains thick beds of greenish-gray sandstone and siltstone containing a few "Chemung" fossils	150±
15. Shale, dark greenish-gray, finely micaceous, weathers lumpy but is fissile where fresh; contains intercalations of greenish-gray calcareous siltstone which is very micaceous	23
14. Sandstone, thick-bedded, concretionary, calcareous; weathers brownish-red	2
13. Sandstone, fine grained, brown, micaceous, noncalcareous; weathers lumpy; beds 1 inch to 1 foot thick	11
12. Siltstone, greenish-gray, shaly, micaceous; joint surfaces marked by flamboyant rusty stains	2
11. Sandstone, bluish-gray, blocky, calcareous; beds 1 to 6 inches thick; weathers olive-drab, with thin intercalations of clay shale	6

	Thickness Feet
10. Siltstone, greenish-gray to olive-drab, slightly calcareous; beds 1 to 3 inches thick; with few clayey shales near the base	5
9. Sandstone, greenish-gray, calcareous; weathers rusty brown	1
8. Shale, greenish-gray, micaceous; breaks in blocks; interbedded with concretionary siltstone	8
7. Shale, steel-gray to bluish-gray, fissile, not micaceous; weathers in chips, interbedded with concretionary siltstones; both types weather olive-drab, but are calcareous where fresh	2
6. Shale, greenish-gray, lumpy, micaceous, silty	6
5. Siltstone, bluish-gray, calcareous; interbedded with olive-drab shales	8
4. Sandstone, bluish-gray, calcareous; interbedded with noncalcareous shale	44
3. Sandstone, bluish-gray, calcareous, beds 3 to 14 inches thick; interbedded with olive-drab, stiff, siliceous shale; several 3-inch beds of noncalcareous sandstone intercalated in the succession; calcareous beds carry *Cyrtospirifer disjunctus, Spirifer mesicostalis,* and *Ambocoelia umbonata,* as well as poorly preserved pelecypods referable to *Cypricardella*	33
2. Sandstone, medium grained, gray, fossiliferous; weathers dark-brown; contains intercalated shales with *Cypricardella bellistriata* and *Mytilarca chemungensis*	30
1. Sandstone, thin bedded, blocky, with distinctive cuneiform jointing; few intercalated lumpy siltstones; few fossils including *Leiorhynchus, Camarotoechia,* and *Spirifer mesistrialis*	73
Brallier formation	

Fossils.—The "Chemung" is moderately fossiliferous. Most of the fossils are in the weathered calcareous beds. The following forms were collected:

Worms
    Annulated markings, unidentified

- Crinoids
    - Unidentified
- Bryozoa
    - Fenestrellina sp.
- Brachiopods
    - Ambocoelia cf. A. umbonata (Conrad)
    - Atrypa sp.
    - Camarotoechia contracta (Hall)
    - Camarotoechia eximia (Hall)
    - Camarotoechia cf. C. congregata (Conrad)
    - Chonetes scitulus Hall
    - Cyrtospirifer disjunctus (Sowerby)
    - Orthothetes chemungensis (Conrad)
    - Productella hirsuta Hall
    - Productella lachrymosa (Conrad)
    - Spirifer mesicostalis (Hall)
    - Spirifer mesistrialis Hall
- Pelecypods
    - Cypricardella bellistriata (Conrad)
    - Grammysia communis Hall
    - Mytilarca chemungensis (Conrad)
    - Palaeoneilo sp.
    - Schizodus chemungensis (Conrad)
- Gastropods
    - Bellerophon sp.
    - Loxonema sp.

Age and correlation.—The Chemung group or stage of New York is classed with the Senecan series. As indicated by Cooper and others[165], some of the "Chemung" of southwestern Virginia may be post-Senecan. Some of the "Chemung" fossils of southwestern Virginia, believed by Butts to be diagnostic of the Chemung of New York, are now known to have long range. The "Chemung" of the Burkes Garden quadrangle probably represents only a part of the Upper Devonian of New York. Late Devonian beds (Hampshire), which occur in northern Virginia, are absent in the Burkes Garden area.

Stratigraphic relations.—The contact between the Brallier and "Chemung" is transitional, but a hiatus may exist. In the belt along Brushy Mountain, a disconformity exists between the Chemung and

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[165] Cooper, G. A., and others, op. cit., Pl. 1.

overlying Price, which is indicated by the absence of the Hampshire and possibly other formations. Near Bluefield, Virginia, where the "Chemung" is very thin, the hiatuses above and below the "Chemung" are probably greater than they are in the southeastern belt. The Bluefield, Virginia, belt of "Chemung" is overlain by the Big Stone Gap shale which is older than the Price.

MISSISSIPPIAN SYSTEM

KINDERHOOK SERIES

BIG STONE GAP SHALE

Name.—Stose[166] named the Big Stone Gap shale from Big Stone Gap, Virginia. Swartz[167] has proposed that the Big Stone Gap be used as a name for the upper member of the Chattanooga formation. The writer agrees with Swartz's restriction of the name but doubts the advisability of designating the shale as a member. The geographic distribution of the unit is sufficiently extensive for the shale to be regarded as a formation.

Distribution.—So far as known, in this quadrangle the Big Stone Gap shale is present only in the belt immediately north of the St. Clair fault (Pl. 1).

Lithology.—The Big Stone Gap shale is well exposed a few feet north of the intersection of College Avenue and Roland Street, near the south edge of Bluefield, Virginia. Here, the formation consists of about 10 feet of black fissile shale (Pl. 15).

Fossils.—Only two fossils *Lingula melie* Hall and *Lingulodiscina herzeri* (Hall and Clarke) were identified from the Big Stone Gap shale, but neither can be considered diagnostic of a particular part of the Chattanooga shale.

Correlation.—The shale exposed a few feet north of the intersection of Roland Street and College Avenue, Bluefield, Virginia, was identified by Reger[168] as the Sunbury shale, but this correlation has scant supporting evidence. The writer has traced the black shale zone at the base of the Price from Bluefield, Virginia, southwestward to

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[166] Stose, G. W., Pre-Pennsylvanian rocks, *in* Geology and mineral resources of Wise county and the coal-bearing portion of Scott County, Virginia: Virginia Geol. Survey Bull. 24, pp. 46-53, 1923.

[167] Swartz, J. H., The age of the Big Stone Gap shale of southwestern Virginia: Am. Jour. Sci., 5th ser., vol. 12, pp. 513-531, 1926.

[168] Reger, D. B., Mercer, Monroe, and Summers counties: West Virginia Geol. Survey, County Reports, pp. 525-529, 1926.

Duffield, Scott County, Virginia, and is satisfied that the black shale at Bluefield, Virginia, is the upper part of the Big Stone Gap shale of Stose and the Big Stone Gap member of the Chattanooga formation of Swartz.

Stratigraphic relations.—According to Butts[169] the Big Stone Gap shale is probably a part of the Brallier formation and is, therefore, Devonian. Studies in Clinch Valley by the writer from 1938 to 1942, revealed some facts which bear on the stratigraphic position of the Big Stone Gap shale of Stose. At Bluefield, Virginia, the Big Stone Gap shale is directly underlain by "Chemung" beds containing *Cyrtospirifer disjunctus* and *Camarotoechia eximia.* The overlying beds are definitely a part of the Price formation. At St. Clair, Tazewell County, the "Chemung" is less than 5 feet thick, and it is absent along Road 656 south of Bailey Church, Tazewell County. Southwestward along the strike of this belt the Big Stone Gap shale thickens and rests on the Brallier. A black shale about 75 feet thick below the Price occurs along State Highway 4, about a mile east of Richlands, Tazewell County, Virginia. The upper part of this shale is fissile and contains *Lingula melie* and *Lingulodiscina herzeri.* The lower part contains *Leiorhynchus quadricostatus* and *Schizobolus,* both of which are generally conceded to be Devonian fossils.[170]. Still farther southwest, this black shale thickens at the expense of the Brallier until at Big Stone Gap, Wise County, the Big Stone Gap shale of Stose is about 1,000 feet thick and the Brallier is no longer separable. Many beds of the Brallier type are found in the lower half of the Big Stone Gap shale at the type locality. From the observed southwestward thickening of the black shale and the thinning of the Brallier, the body of black shale at Big Stone Gap represents, as Butts and Swartz maintain, a part of the Devonian succession as developed farther northeast in the Appalachian region. However, the topmost part of the black shale (Swartz's Big Stone Gap shale member of the Chattanooga formation) which extends as far northeast as Bluefield, Virginia, is younger than the Brallier, because at Bluefield the black shale overlies the "Chemung". The Big Stone Gap shale of Stose represents mainly a black shale facies which intertongues northeastward with the Brallier and "Chemung". However, the topmost shales comprise a thin, but persistent unit which overlaps both the Brallier and "Chemung". These relationships demonstrate the existence of a hiatus at the base of the Big Stone Gap shale northwest of the St. Clair fault in the Burkes Garden quadrangle.

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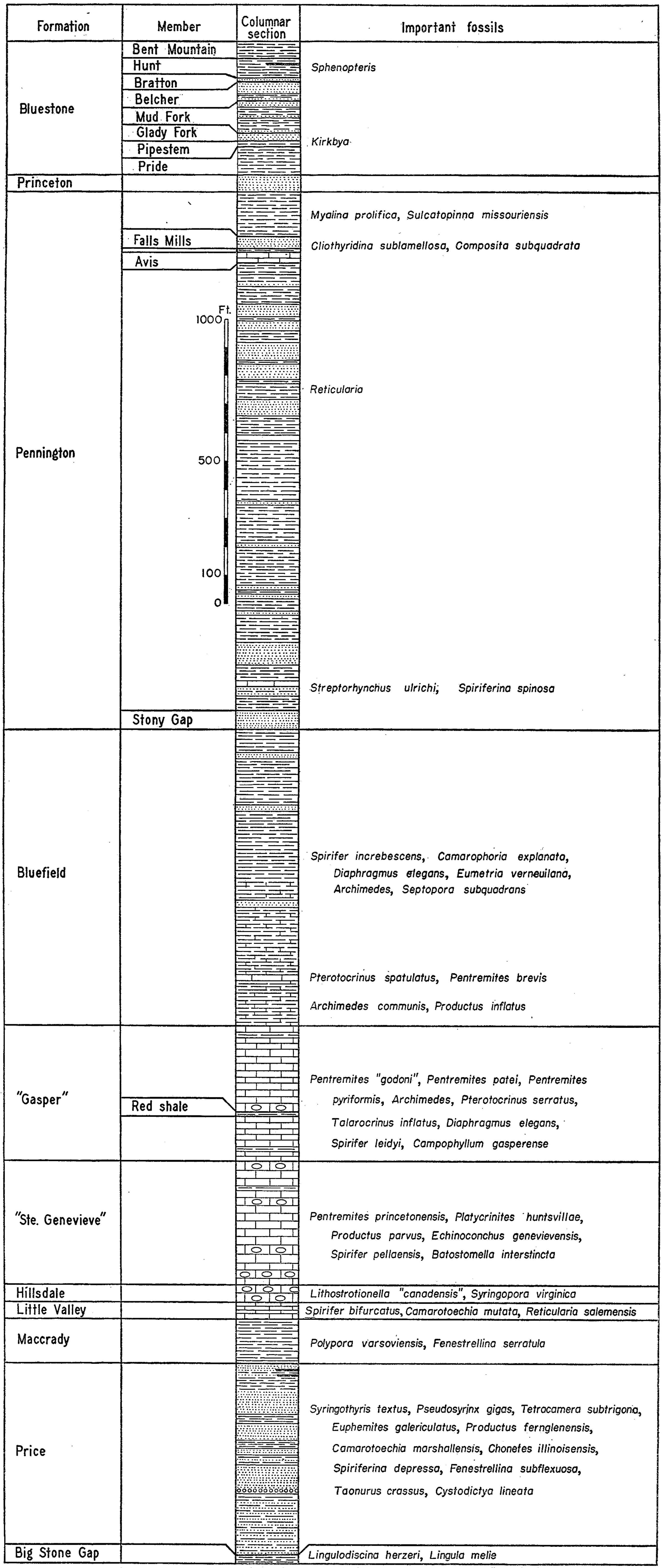
[169] Op. cit., pp. 321-322.

[170] Cooper, G. A., Correlation of the Devonian sedimentary formations of North America: Geol. Soc. America Bull., vol. 53, p. 1736, 1942.



Formation	Member	Columnar section	Important fossils
Bluestone	Bent Mountain		
	Hunt		*Sphenopteris*
	Bratton		
	Belcher		
	Mud Fork		
	Glady Fork		
	Pipestem		*Kirkbya*
	Pride		
Princeton			
Pennington			*Myalina prolifica, Sulcatopinna missouriensis*
	Falls Mills		*Cliothyridina sublamellosa, Composita subquadrata*
	Avis		
			Reticularia
			Streptorhynchus ulrichi; Spiriferina spinosa
	Stony Gap		
Bluefield			*Spirifer increbescens, Camarophoria explanata, Diaphragmus elegans, Eumetria verneuilana, Archimedes, Septopora subquadrans*
			Pterotocrinus spatulatus, Pentremites brevis
			Archimedes communis, Productus inflatus
"Gasper"	Red shale		*Pentremites "godoni", Pentremites patei, Pentremites pyriformis, Archimedes, Pterotocrinus serratus, Talarocrinus inflatus, Diaphragmus elegans, Spirifer leidyi, Campophyllum gasperense*
"Ste. Genevieve"			*Pentremites princetonensis, Platycrinites huntsvillae, Productus parvus, Echinoconchus genevievensis, Spirifer pellaensis, Batostomella interstincta*
Hillsdale			*Lithostrotionella "canadensis", Syringopora virginica*
Little Valley			*Spirifer bifurcatus, Camarotoechia mutata, Reticularia salemensis*
Maccrady			*Polypora varsoviensis, Fenestrellina serratula*
Price			*Syringothyris textus, Pseudosyrinx gigas, Tetracamera subtrigona, Euphemites galericulatus, Productus fernglenensis, Camarotoechia marshallensis, Chonetes illinoisensis, Spiriferina depressa, Fenestrellina subflexuosa, Taonurus crassus, Cystodictya lineata*
Big Stone Gap			*Lingulodiscina herzeri, Lingula melie*

OSAGE SERIES

PRICE FORMATION

Name.—Campbell[171] named the Price sandstone from Price Mountain, Montgomery County, Virginia. The formation was not fully described until 1925[172].

Distribution.—One belt of Price crops out in the south environs of Bluefield, Virginia, and extends southwestward through Bailey and Tiptop beyond the western border of the quadrangle. The full thickness of the Price is exposed along College Avenue (State Highway 85) in Bluefield, Virginia. It also crops out in a wide belt on Brushy Mountain, in Lynncamp Creek, along Road 625 across Brushy Mountain, and on the southeast slopes of Carter Mountain. The lower part of the formation caps a high knob known as Little Brushy Mountain in the southwestern corner of the quadrangle. Good exposures are present along all of the roads which cross Brushy Mountain, particularly the old logging road from Ceres to Lynncamp Creek (Pls. 1, 15).

Lithology.—The Price formation in the northern part of the quadrangle is somewhat different from the Price exposed on Brushy, Carter, and Little Brushy mountains. Near Bluefield, Virginia, the Price is composed of olive-drab, gray, brown, and reddish-brown sandstones and siltstones; red, brown, buff, olive-drab, and black shales; and quartz-pebble conglomerates. The quartz-pebble conglomerates are confined to the lower 200 feet of the formation, and some occur locally at the very base.

Although the Price resembles the Brallier and "Chemung" it can be readily distinguished by its fossils, most of which occur in bright yellowish-buff, mealy siltstones and sandstones.

The Price on Brushy Mountain is 600 to 700 feet thick. The upper 200 feet is composed largely of cross-laminated arkosic sandstone and argillaceous siltstone. The lower 400 to 500 feet is very much like the Price in the Bluefield area, except that beds of coal, none of which is very thick, are intercalated in marine sandstones.

The northern belt of the Price corresponds closely to the lower 400 to 500 feet of the Price on Brushy Mountain. Glauconitic sandstones, containing the distinctive brachiopod, *Syringothyris*, occur about 400 feet above the base of the Price, as exposed along the logging

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[171] Campbell, M. R., Paleozoic overlaps in Montgomery and Pulaski counties, Virginia: Geol. Soc. America Bull., vol. 5, pp. 171, 177, pl. 4, 1894.

[172] Campbell, M. R., The Valley coal fields of Virginia: Virginia Geol. Survey Bull. 25, pp. 23-28, 1925.

road to Lynncamp Creek, and 70 feet below the top along College Avenue in Bluefield. The coal and arkosic sandstone in the upper part of the Price on Brushy and Carter mountains are partly or wholly represented by 50 to 100 feet of fossiliferous siltstone and sandstone in the Bluefield belt.

Considerable secondary iron oxide has been concentrated in the Price beds which border the Saltville-Bland fault. Blocks of impure limonite containing Price fossils mark the fault trace all along the base of Brushy Mountain northeast of Ceres.

On Brushy Mountain the glauconite zone, 400 feet above the base of the Price, is overlain by a 100-foot zone composed of coarse-grained, cross-bedded arkosic sandstones, black fissile shales, and beds of coal. This zone is exposed at the forks of Carter and Brushy mountains north of Ceres and along the logging road to Lynncamp Creek. The basal part of the zone is soft, crumbly, ash-gray, silty clay about 30 feet thick. Above the clay is a variable thickness of arkosic sandstone which averages about 75 feet in thickness. Next above are grayish clays and black shales containing partings of pyritiferous coal. None of the coal beds are well enough exposed to determine their thickness, but three distinct blooms were seen along the roadside. Campbell[173] determined the thickness of one of the beds of coal to be 2½ feet, but this thickness is far above the average. The coal-bearing beds have an aggregate thickness of 50 feet. This part of the Price is overlain by about 100 feet of greenish-gray siltstone and interbedded, flaggy, cross-bedded arkosic sandstones.

Along Road 623 the lower part of the Price contains beds of reddish-brown to maroon sandstone which is conspicuously laminated. These beds, similar to the maroon beds in the "Chemung," weather light-gray and are casehardened. The reddish beds weather into slabs an inch or more thick and as much as 1 foot across. These slabs, in the absence of good exposures, are a rather reliable indication of the base of the Price. The crest of Brushy Mountain is upheld by several beds of quartz-pebble conglomerate.

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[173] Campbell, M. R., op. cit., pp. 265-268.

Geologic Section 39.—Price formation along College Avenue in Bluefield, Tazewell County, Virginia

	Thickness	
	Ft.	In.
Maccrady formation		
Price formation (628 feet)		
53. Covered interval, composed of micaceous ferruginous shale and micaceous sandy siltstone; contains a few *Chonetes illinoisensis*	47	
52. Sandstone, coarse grained, light-buff, somewhat arkosic, thick bedded, saccharoidal	18	
51. Siltstone, greenish-gray, fine grained, arkosic, micaceous; peppered with minute fragments of plant fossils	1	8
50. Sandstone, olive-drab, flaggy to shaly, micaceous, arkosic; contains small discoidal to ellipsoidal concretions of clay ironstone	3	7
49. Sandstone, fossiliferous, glauconitic, weathers rusty brown; contains few concretions of impure siderite		8
48. Sandstone, finely laminated, olive-drab	5	
47. Siltstone, finely laminated, olive-drab	1	2
46. Shale, micaceous, sandy, greenish-gray; peppered with carbonized plants		7
45. Sandstone, laminated, micaceous; peppered with plant fragments; weathers reddish-brown	2	11
44. Siltstone, thick bedded, greenish-gray	3	
43. Sandstone, shaly bedded, coarsely micaceous	5	7
42. Sandstone and siltstone, arkosic, greenish-gray; in beds 3 inches to 3 feet thick; flamboyant iron stains on joint faces and weathered surfaces	17	9
41. Siltstone, greenish-gray to black, nodular; with thin intercalations of black carbonaceous shale	12	2
40. Sandstone, glauconitic, silty, mealy, fossiliferous; joints and fractures lined with limonite; beds deep green where fresh; contains *Pseudosyrinx* and *Tetracamera subtrigona*	3	2
39. Shale, greenish gray, silty	3	
38. Shale, black, lumpy, with greenish glauconitic siltstones at the top	6	10

	Thickness	
	Ft.	In.
37. Sandstone, thick bedded, fine grained, micaceous, glauconitic	6	5
36. Siltstone, shaly, greenish-gray, glauconitic, micaceous; weathers rusty and mealy; contains *Chonetes illinoisensis, Euphemites galericulatus,* and *Camarotoechia* sp.	2	5
35. Sandstone, finely laminated, dark-gray; with scattered pebbles of quartz	1	2
34. Siltstone, highly micaceous, shaly, glauconitic, with lenticular beds of rusty siltstone; very fossiliferous with *Chonetes, Camarotoechia, Orthoceras, Euphemites galericulatus, Productus, Orthotetes keokuk* (Hall)	1	8
33. Siltstone and shale, grayish black; with plant fragments on bedding surfaces; intercalations of greenish siltstone at the top	17	6
32. Sandstone, one thick bed, greenish-gray, rust-stained, laminated	3	7
31. Siltstone, greenish-gray, irregularly bedded; contains beds of rusty fossiliferous sandstone	1	7
30. Siltstone, greenish-gray, finely laminated; peppered with plant fragments	3	1
29. Sandstone, ferruginous, greenish-gray, fine grained; bedding irregular; limonite along joints causes the beds to weather in angular blocks	4	4
28. Siltstone, knotty, concretionary, greenish-gray; with thin partings of silty black fissile shale	9	2
27. Siltstone and sandstone, finely laminated, greenish-gray, micaceous, shaly bedded; with few thin streaks of black shale	24	5
26. Siltstone, soft, mealy, calcareous; rinds of iron oxide on joint faces	1	1
25. Siltstone, greenish-gray, finely laminated, sandy; with thin streaks of black carbonaceous shale	23	7
24. Crumpled zone; composed of black shale and greenish-gray siltstone	4	
23. Siltstone, greenish-gray, knotty, siliceous, resistant	3	

		Thickness	
		Ft.	In.
22.	Siltstone, slightly glauconitic, mealy, fossiliferous; weathers rusty, with flamboyant stains on joint faces		10
21.	Siltstone, laminated, silty, micaceous	2	9
20.	Coal, mixed with black shale	trace	
19.	Siltstone, greenish-gray, shaly, siliceous	2	
18.	Siltstone, gray, concretionary; weathers rusty, cut by closely spaced shear planes	2	5
17.	Siltstone, fossiliferous, dark-brown; contains pebbly concretions of hematite and limonite	1	
16.	Siltstone, deep-purplish, sparsely fossiliferous; with thin intercalations of green shale	2	7
15.	Sandstone, red and green, laminated, very resistant	11	5
14.	Sandstone, greenish-gray, fine grained; with partings of siliceous shale; fossiliferous	9	3
13.	Siltstone, platy, sandy; many greenish-gray streaks; very fossiliferous	8	2
12.	Sandstone, reddish to buff, hard, calcareous; weathers rusty	7	
11.	Siltstone greenish-gray to dull-gray, platy, calcareous; somewhat micaceous	23	5
10.	Siltstone, dull-gray; peppered with plant fragments	4	6
9.	Sandstone, gray to olive-drab, platy; interbedded with sandy siltstone and black shale; few reddish sandstone lentils near the middle	24	
8.	Shale, greenish-gray, micaceous, stiff, siliceous, silty; somewhat slumped	5	
7.	Siltstone, rusty, fossiliferous	2	
6.	Sandstone, greenish-gray, streaked with deep red; thick bedded; limonite rinds along joint surfaces	6	5
5.	Sandstone, medium grained, olive-drab; irregularly bedded	2	6
4.	Conglomerate and sandstone, very coarse; irregularly bedded	4	6
3.	Sandstone, coarse grained, olive-drab, thick, lenticularly bedded, somewhat arkosic	12	5
2.	Poorly exposed interval; composed of stiff siliceous greenish-gray shale and fine grained blocky sandstone	250±	

	Thickness Ft.	Thickness In.
1. Shale, olive-drab, weathers rusty; few pelecypods..	6	9

Big Stone Gap shale

Fossils.—The Price contains virtually the same fauna throughout the Burkes Garden quadrangle. The following forms have been collected:

- Plants
    - Triphyllopteris sp.
- Worms
    - Taonurus crassus (Hall)
- Bryozoa
    - Cystodictya lineata Ulrich
    - Fenestrellina compressa (Ulrich)
    - Fenestrellina tenax (Ulrich)
    - Fenestrellina subflexuosa (Ulrich)
- Brachiopods
    - Athyris lamellosa (Leveille)
    - Brachythyris semiplicata (Hall)
    - Camarotoechia cf. C. contracta (Hall)
    - Camarotoechia marshallensis Winchell
    - Camarotoechia sappho (Hall)
    - Chonetes illinoisensis Worthen
    - Orthotetes keokuk (Hall)
    - Productus cf. P. blairi Miller
    - Productus crawfordsvillensis Weller
    - Productus cf. P. fernglenensis Weller
    - Productus sampsoni Weller
    - Punctospirifer solidirostris (White)
    - Pseudosyrinx gigas Weller
    - Spirifer missouriensis Swallow
    - Spiriferina depressa Herrick
    - Syringothyris textus (Hall)
    - Tetracamera subtrigona (Meek and Worthen)
- Pelecypods
    - Allorisma consanguinatus Herrick
    - Aviculopecten cooperi Herrick
    - Conocardium pulchellum White and Whitfield
    - Cypricardella bellistriata (Conrad)

- Leptodesma propinquum Hall
- Leptodesma sp.
- Sphenotus flavius (Herrick)
- Streblopteria cf. S. squama Herrick

Gastropods

- Bellerophon cf. B. helena Hall
- Euphemites galericulatus (Winchell)
- Oxydiscus cyrtolites (Hall)
- Pleurotomaria cf. P. stella Winchell

Cephalopods

- Orthoceras indianense Hall

Ostracodes

- Paracythere granopunctata Ulrich and Bassler

In the vicinity of Bluefield, Virginia, the glauconitic beds 70 feet below the top, carry the most distinctive fossils, including such diagnostic Keokuk forms as *Tetracamera subtrigona.* Where the Big Stone Gap shale is absent, as on Brushy Mountain, the lower beds of the Price can be distinguished from the underlying "Chemung" by the presence of *Euphemites galericulatus, Spiriferina depressa,* and *Chonetes illinoisensis.*

Age and correlation.—The Price formation is the equivalent of the Pocono sandstone of the northern Appalachian region. By fossils it is correlated with the New Providence shale of Indiana and Kentucky and with the Cuyahoga formation of Ohio. The Fern Glen, Burlington, and Keokuk formations are very probably represented in the Price.

MACCRADY FORMATION

Name.—The Maccrady formation was named by Stose[174] from Maccrady, Smyth County, Virginia. Butts[175] later restricted the Maccrady to beds below the Warsaw limestone, which were included in the original Maccrady, and above the Price.

Distribution.—One belt of Maccrady extends southwestward from Bluefield, Virginia, along the southeast side of Wright Valley beyond the western border of the Burkes Garden quadrangle. It is partly exposed along College Avenue in Bluefield, Virginia, but the

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[174] Stose, G. W., Geology of the salt and gypsum deposits of southwestern Virginia: Virginia Geol. Survey Bull., 8, pp. 51-60, 1913.

[175] Butts, Charles, Geologic map of the Appalachian Valley of Virginia with explanatory text: Virginia Geol. Survey Bull. 42, p. 54, 1933.

best section is along Road 656 south of Bailey Church. In the southern part of the quadrangle the Maccrady occurs in two places: a small area in the valley between the outlying hill southeast of Brushy Mountain and Brushy Mountain itself, and along Lynncamp Creek near the southern border of the quadrangle. Exposures of the first mentioned belt can be seen at the northeastern base of the outlying spur of Brushy Mountain about two miles northeast of Sharon Springs (Pl. 1).

Lithology.—In the northern belt the Maccrady is composed of maroon-drab and greenish-yellow shales, mealy silty mudrocks, and thin beds of yellowish argillaceous limestone (Pl. 15). Only a minor part of the formation is red, but these beds are the most conspicuous. The red beds weather to a dark-red soil which is very distinctive, as in the west environs of Bluefield, Virginia, along Road 656 south of Bailey Church, and along the road leading north from Wittens Mills.

Geologic Section 40.—Maccrady formation along the road 75 yards south of Bailey Church, Tazewell County, Virginia

	Thickness Feet
Little Valley limestone	
Maccrady formation (150 feet)	
10. Shale, yellowish-drab, silty, mealy; with few thin sandy streaks; weathers dark-brown	7
9. Covered interval; composed of yellowish shales and blocky beds of arkosic sandstone	17
8. Mudrock, yellowish-drab, very silty	29½
7. Shale, greenish-buff, slightly calcareous, with intercalations of mealy calcareous sandstone	39
6. Mudrock, yellowish-green with maroon-drab blotches; weathers buff and very silty	7½
5. Mudrock, greenish-yellow, sparsely fossiliferous, silty; contains streaks of red mudrock	13
4. Mudrock, maroon-drab, lumpy; contains discontinuous streaks of yellowish-buff shale	17
3. Shale, calcareous where fresh; contains *Fenestrellina serratula, Polypora varsoviensis, and Spiriferina* sp.	2

	Thickness Feet
2. Limestone, taupe-gray, very fine grained, argillaceous; weathers mealy	1
1. Limestone, bluish-gray, argillaceous, dense, fine grained; interbedded with bluish-gray shale which weathers reddish-brown	16½
Price formation	

The thickness of the Maccrady in the northern belt seems uniform, but no other exposures are continuous enough to be measured. In the southern belts only the lowest beds of the Maccrady are preserved. The lower 75 feet is composed of maroon-drab and bright buff mudrocks and siltstones and bright red fissile shales. All of the overlying beds are dark-maroon shales and sandy mudrocks. The total thickness of the Maccrady in the valley of Lynncamp Creek probably does not exceed 125 feet, and undoubtedly is less northeast of Sharon Springs.

Fossils.—The Maccrady is sparingly fossiliferous. A few fossils collected from buff shales about 20 feet above the base were identified as follows:

Bryozoa
  Fenestrellina serratula (Ulrich)
  Polypora varsoviensis Prout
Brachiopods
  Athyris cf. A. lamellosa (Leveille)
  Spiriferina cf. S. depressa Herrick

Age and correlation.—According to Butts[176], the Maccrady is of Osage age and corresponds to part of the Cuyahoga formation of Ohio and to part of the New Providence formation of Indiana and Kentucky. However, the Maccrady may be a phase of the Warsaw. *Tetracamera subtrigona,* which is found in the Mississippi Valley region only in the Keokuk limestone, occurs in beds 100 feet below the top of the Price formation in Bluefield, Virginia. If the *Tetracamera subtrigona* zone and succeeding beds of the Price are Keokuk equivalents, the overlying Maccrady would have the stratigraphic position of the Warsaw. Both bryozoans collected from the Maccrady are common in the Warsaw of

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[176] Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. 1, p. 354, 1940.

the Mississippi Valley and also in Butts' Warsaw of southwestern Virginia.

Stratigraphic relations.—The Maccrady seems to be conformable with overlying and underlying beds.

MERAMEC SERIES

LITTLE VALLEY FORMATION

Name.—The name Little Valley limestone was proposed by Averitt[177] for the 700 feet of beds, which overlie the Maccrady formation and underlie the "St. Louis" limestone in Little Valley, Scott County, Virginia.

Distribution.—No beds younger than the Maccrady are found southeast of Clinch Mountain in the Burkes Garden quadrangle (Pl. 1). If any post-Maccrady beds are present in that area they are covered by the Saltville-Bland overthrust block. The Little Valley formation directly overlies the Maccrady northwest of the St. Clair fault. Only three good exposures of the formation were seen: along Road 656 south of Bailey Church; in a ravine south of Sam, a siding on the Norfolk and Western Railway southwest of St. Clair; and along the railroad 2 miles west-southwest of Tiptop. Because of its poor exposure the Little Valley formation was mapped (Pl. 1) with the overlying Hillsdale limestone.

Lithology.—The Little Valley is composed of several types of limestone and drab-buff shales (Pl. 15). The most distinctive bed, and one which is identifiable in almost every exposure, is greenish-yellow, argillaceous, and silty and is commonly silicified on weathered exposures. This layer has a hackly fracture which is unlike any other bed in the Mississippian. It is fully exposed in the roadside quarry south of Bailey Church.

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[177] Averitt, Paul, The Early Grove gas field, Scott and Washington counties, Virginia: Virginia Geol. Survey Bull. 56, pp. 17-21, 1941.

Geologic Section 41.—Little Valley limestone, south of Bailey Church, Tazewell County, Virginia

	Thickness	
	Ft.	In.
Hillsdale limestone		
Little Valley limestone (57 feet)		
15. Limestone, fine grained, gray; contains few partings of calcareous shale	2	
14. Limestone, dark-gray, fine grained, argillaceous, with partings of buff shale; not very fossiliferous; weathers fluted	5	
13. Limestone, dark-gray, medium grained; weathers dull-gray with faint greenish tinge; contains a 6-inch bed of gray calcilutyte	9	
12. Limestone, drab-gray, argillaceous; weathers platy	3	
11. Limestone, gray, argillaceous; with streaks of coarse grained granulated shell fragments; *Endothyra, Productus ovatus,* and horn corals	2	3
10. Limestone, argillaceous, fine grained, dark-bluish gray; with pink calcite veins	4	
9. Limestone, crinoidal, medium grained, dark-gray; with *Fenestrellina* and *Triplophyllum compressum*	3	9
8. Limestone, argillaceous, greenish-gray where fresh and yellowish-green where weathered; beds 6 to 15 inches thick; clay partings weather out and accentuate the bedding; lower half is very fossiliferous, with crinoid plates abundant; blotches of glauconite along the bedding planes and joint faces	6	3
7. Limestone, light-gray where fresh, argillaceous, silicified on the outcrop; has distinct hackly fracture; weathers greenish yellow and mealy; most distinctive bed in the formation	2	
6. Limestone, very argillaceous, yellowish-green to buff; contains brilliant streaks of glauconite	1	3
5. Limestone, olive-drab, very argillaceous; with many calcite veins and vugs	1	6
4. Covered interval; composed chiefly of buff shale	2	6

	Thickness	
	Ft.	In.
3. Limestone, medium grained, granular, gray, argillaceous; contains *Cliothyridina* and *Spirifer bifurcatus*	2	
2. Limestone, very fine grained, compact; with few argillaceous partings; bedding surfaces of limy beds covered with brachiopods including *Spirifer bifurcatus*	6	6
1. Limestone, dull-gray, coarse grained, clastic, oolitic; beds 18 to 28 inches thick and separated by partings of buff shale; very fossiliferous, with *Spirifer bifurcatus, Cliothyridina, Camarotoechia, Fenestrellina, Orthotetes*	6	2

Maccrady formation

A distinctive feature of the Little Valley limestone is the lack of nodular chert. All the overlying Mississippian limestone formations are cherty.

Fossils.—The Little Valley is moderately fossiliferous, especially along the Norfolk and Western Railway northeast of Wittens Mills, where the following fossils were collected:

- Protozoa
  - Endothyra sp.
- Corals
  - Triplophyllum compressum (Edwards and Haime)
- Blastoids
  - Pentremites conoideus Hall
- Bryozoa
  - Fenestralia sancti-ludovici (Prout)
  - Fenestrellina serratula (Ulrich)
  - Fenestrellina tenax (Ulrich)
  - Fistulipora sp.
  - Stenopora sp.
  - Worthenopora spinosa Ulrich
- Brachiopods
  - Camarotoechia cf. C. grosvenori (Hall)
  - Camarotoechia mutata (Hall)
  - Cliothyridina sp.

- Echinoconchus biseriatus (Hall)
- Orthotetes kaskaskiensis (McChesney)
- Productus cf. P. altonensis Norwood and Pratten
- Productus indianiensis Hall
- Productus tenuicostus Hall
- Reticularia salemensis Weller
- Spirifer bifurcatus Hall
- Streptorhynchus ruginosum (Hall)

Pelecypods
- Aviculopecten amplus Meek and Worthen

Probably the most abundant and characteristic fossil in the beds here assigned to the Little Valley is *Spirifer bifurcatus.* Bryozoans are plentiful in the argillaceous beds with *Fenestralia sancti-ludovici, Stenopora* sp., and *Worthenopora spinosa* most common. Shaly intercalations near the top contain *Camarotoechia* cf. *C. grosvenori* and *Camarotoechia mutata* in great abundance. Some of the lower beds, and less commonly some of the higher beds, contain *Endothyra* sp. This fossil and others, including *Reticularia salemensis,* occur also in the Salem-Spergen limestones of Indiana.

Age and correlation.—The occurrence of numerous Warsaw fossils in the beds assigned to the Little Valley formation in this quadrangle is considered proof of the Warsaw age of the greater part of the succession; however, certain Salem fossils occur in the upper 20 feet of the Little Valley of this area. According to Butts,[178] the Salem is a part of the Warsaw, but Cumings[179] and others regard the Salem as distinct from the Warsaw.

Stratigraphic relations.—It is rather doubtful that the thin development of the Little Valley formation in the Burkes Garden quadrangle represents the entire succession of beds assigned to the formation in its type locality. A small hiatus may exist at either boundary.

HILLSDALE LIMESTONE

Name.—Reger[180] named the Hillsdale limestone from the village of Hillsdale, Monroe County, West Virginia. In its type locality the Hillsdale overlies limestones of Little Valley age but classed

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[178] Butts, Charles, personal communication, August, 1937.

[179] Cumings, E. R., Nomenclature and description of the geological formations of Indiana, *in* Handbook of Indiana geology: Indiana Dept. Conservation Pub., no. 21, p. 503, 1922.

[180] Reger, D. B., Mercer, Monroe, and Summers counties: West Virginia Geol. Survey, County Reports, pp. 487-491, 1926.

by Reger with the Maccrady. As is apparent from the original description, the name was intended to apply particularly to the first unit of dark bluish-gray limestone above the argillaceous limestones of Little Valley age. This point is emphasized because some geologists include the so-called Warsaw, or Little Valley, limestone in the Hillsdale. The writer here uses Hillsdale to replace St. Louis, a name used by Butts[181] for the same succession in southwestern Virginia. There are several objections to the continued use of the name St. Louis in southwestern Virginia. The beds so named are not areally continuous with the well known St. Louis limestone of the Mississippi Valley. It has not been definitely established that the so-called St. Louis limestone of southwestern Virginia does not contain correlatives of the Salem limestone.

Distribution.—The Hillsdale limestone has the same general distribution as the Little Valley formation and is mapped with it (Pl. 1). Good exposures are seen along Hockman Road in Bluefield, Virginia; at the road intersection at Bailey Church; and along the Norfolk and Western Railway about 2 miles west-southwest of Tiptop. The lower beds of the Hillsdale make the highest of three conspicuous limestone ledges on the southeast side of Wrights Valley.

Lithology.—The Hillsdale limestone is composed of nearly black, medium-grained cherty beds (Pl. 15). The color of the Hillsdale is generally sufficient to distinguish it from the overlying and underlying limestones. Some beds of the formation are shell limestones which contain most of the fossils. Oolitic beds are found in the lower 15 to 20 feet of the formation, but none was noted in the upper part. Several beds in the lower 12 feet of the formation are partly composed of calcareous algae which project as concentric welts on weathered surfaces. Nodules of black chert are common and contain some of the best preserved fossils. The large, silicified corals commonly seen on weathered exposures are not found in any other formation and thus are diagnostic. The average thickness of the Hillsdale is 55 feet.

Fossils.—Most of the fossils were collected from weathered chert. Bryozoans are particularly common in the shaly partings between the limestones. The following forms were collected:

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[181] Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. 1, pp. 355-359, 1940.

- Algae
    - "Girvanella" sp.
- Corals
    - Lithostrotionella "canadensis" (Castlenau)
    - Lithostrotionella prolifera (Hall)
    - Syringopora virginica Butts
- Bryozoa
    - Dichotrypa sp.
    - Fenestrellina tenax (Ulrich)
    - Hemitrypa proutana Ulrich
    - Polypora biseriata Ulrich
    - Stenopora sp.
- Brachiopods
    - Brachythyris altonensis Weller
    - Cliothyridina sublamellosa (Hall)
    - Dielasma sp.
    - Orthotetes kaskaskiensis (McChesney)
    - Productus ovatus Hall
    - Productus gallatinensis Beede
    - Productus tenuicostus Hall
    - Spirifer delicatus Rowley
    - Spirifer cf. S. pellaensis Weller
- Gastropods
    - Bellerophon cf. B. sublaevis Hall

A good exposure of the fossiliferous cherty Hillsdale is seen along Road 650 just east of Bailey Church. Corals are especially common south of Sam—a siding on the Norfolk and Western Railway—and near the railroad station at Tiptop. The algal limestones are well displayed at the north end of the roadside quarry opposite Bailey Church.

Stratigraphic relations.—The Hillsdale seems to be conformable with both overlying and underlying beds.

Correlation.—The Hillsdale appears to correspond exactly to the unit called the St. Louis limestone by Butts in southwestern Virginia. Some of the fossils in the so-called St. Louis occur also in the Salem limestone which underlies the St. Louis in Indiana. Possibly the lower 20 to 25 feet of the Hillsdale is Salem; however, the upper part, and possibly all, of the formation is linked faunally with the St. Louis limestone of the Mississippi Valley region.

"STE. GENEVIEVE" LIMESTONE

Name.—The Ste. Genevieve limestone was named by Shumard[182] from a county of the same name in Missouri. The name is used here in a tentative sense for beds which possibly, though not certainly, are the same as the Ste. Genevieve of the type region.

Distribution.—The "Ste. Genevieve" occurs in two belts; one in Wrights Valley, the other in Abbs Valley (Pl. 1). It is poorly exposed in both belts and for this reason is mapped with the overlying "Gasper". In Abbs Valley, the "Ste. Genevieve" is exposed only in the area north of Locust Knob and in Horsepen Cove. Two fairly complete sections have been found in Wrights Valley; north of the overpass of U. S. Route 19 west of Bluefield, Virginia, and along the Norfolk and Western Railway southwest of Tiptop. A part of the "Ste. Genevieve" is well exposed 3¼ miles southwest of Tiptop, on the southeast side of Wrights Valley.

Lithology.—The "Ste. Genevieve" contains light-gray calcilutytes and coarse-grained, clastic-textured oolitic limestones (Pl. 15). Most of the chert is found in the coarse-grained rocks and is more abundant in the lower 200 feet of the formation. Many of the limestones are completely silicified on the outcrop. None of the limestones is black, like the St. Louis, but the same type of chert occurs in equal abundance (Pl. 16C). Much of the argillaceous material is in the coarse-grained limestones. Considerable clay also occurs as wavy, discontinuous greenish-gray partings. One zone of greenish-gray shale, which occurs about 150 feet below the top of the formation, is very persistent and contains plant fossils. This zone is probably the Patton shale of Reger[183], in adjacent parts of West Virginia. A good exposure is seen along Road 650 about a half a mile northeast of Bailey Church.

The oolitic layers and the calcilutytes are relatively pure limestones characterized by thick bedding and light-gray color. Both make a fine showing along the Norfolk and Western Railway west of Tiptop and on the hillsides to the south. The "Ste. Genevieve" contains a few very coarse-grained crinoidal limestone beds similar to the more abundant and characteristic crinoidal limestones of the overlying "Gasper."

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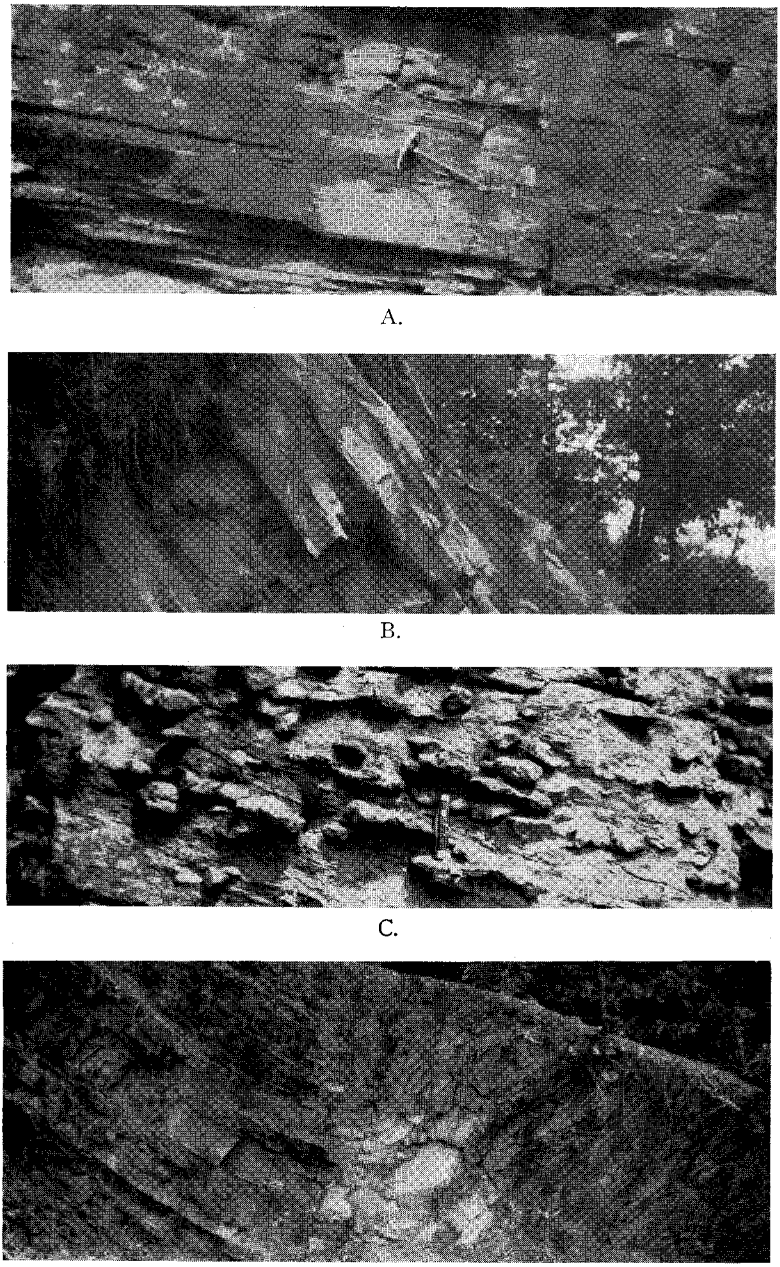
[182] Shumard, B. F., Observations on the geology of the County of Ste. Genevieve [Mis-
[183] Reger, D. B., op. cit., pp. 483-484.
souri]: St. Louis Acad. Sci. Trans, vol. 1, p. 406, 1859.



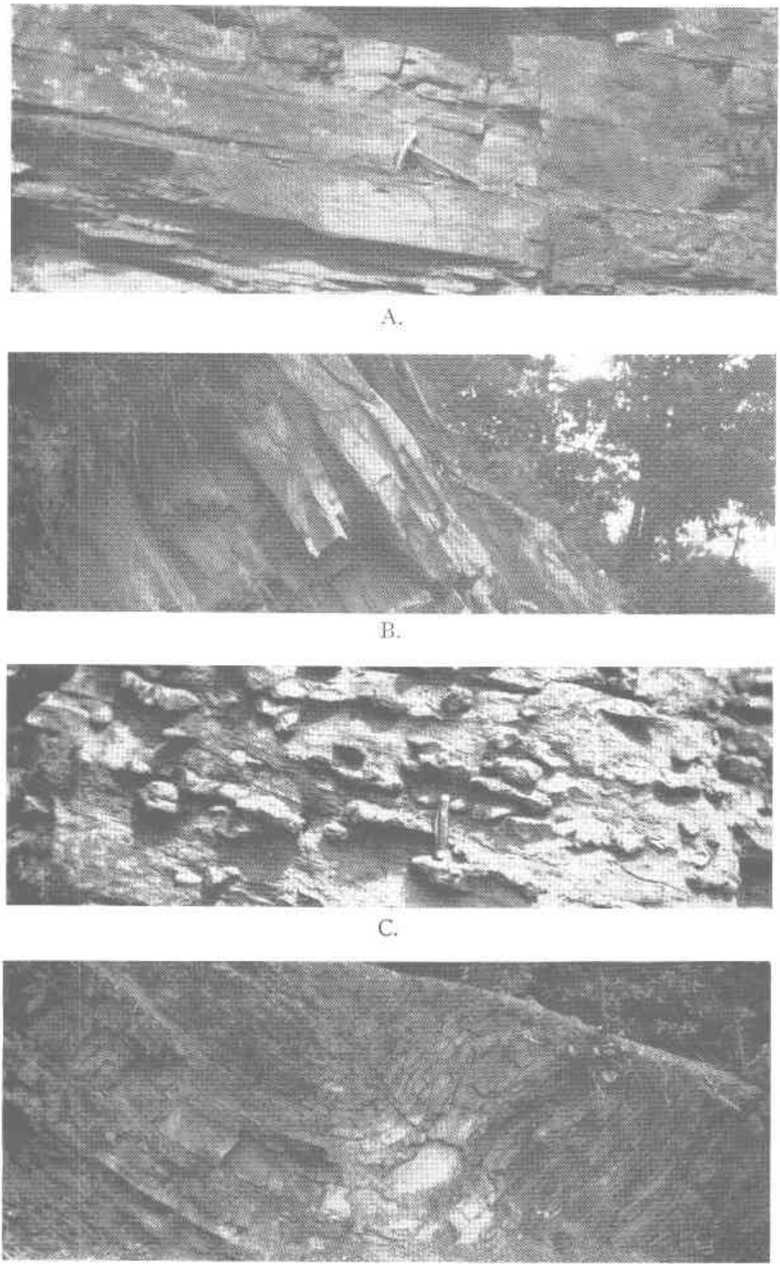
A.

B.

C.

D.

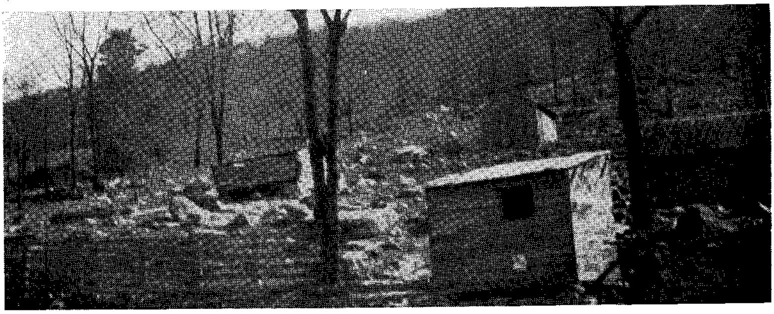
A, Princeton sandstone along Road 643; near Mud Fork village. B, Stony Gap sandstone member on Stony Ridge; north of Tiptop. C, Cherty bed in the "Ste. Genevieve" limestone; near Bluefield, Virginia. D, Syncline in Brallier shale; near Grapefield.



A, Princeton sandstone along Road 643; near Mud Fork village. B, Stony Gap sandstone member on Stony Ridge; north of Tiptop. C, Cherty bed in the "Ste. Genevieve" limestone; near Bluefield, Virginia. D, Syncline in Brallier shale; near Grapefield.

A.

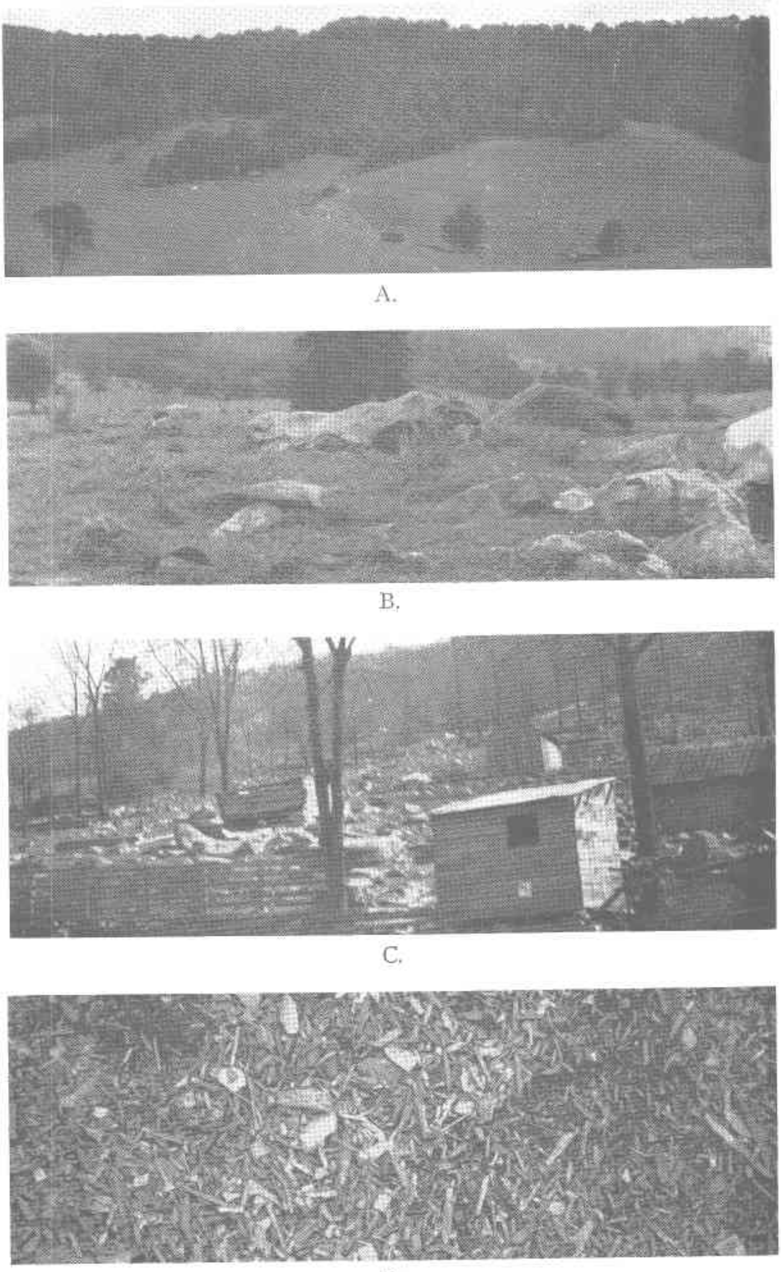
B.



C.

D.

A, Rock fan along the northwest slope of Rich Mountain; near Gratton. B, Blocks of Clinch sandstone in a rock fan on Clinch Mountain. (Photograph by R. C. Oburn.) C, Surface of rock fan on the northwest slope of Walker Mountain; along Road 621. D, Shoe-peg fracture in the Pride shale member; near Mud Fork village.



A, Rock fan along the northwest slope of Rich Mountain; near Gratton. B, Blocks of Clinch sandstone in a rock fan on Clinch Mountain. (Photograph by R. C. Oburn.) C, Surface of rock fan on the northwest slope of Walker Mountain; along Road 621. D, Shoe-peg fracture in the Pride shale member; near Mud Fork village.

The thickness of the "Ste. Genevieve" is about 525 feet at Bluefield, Virginia, but the formation thins to the southwest in Wrights Valley. West of Tiptop it is about 450 feet thick, but a mile or so west of the Burkes Garden quadrangle it is somewhat less than 300 feet thick.

Geologic Section 42.—"Ste. Genevieve" limestone along the Norfolk and Western Railway near Tiptop, Tazewell County, Virginia

	Thickness Feet
Gasper limestone	
"Ste. Genevieve" limestone (460 feet)	
35. Covered interval; composed of oolitic limestone interbedded with taupe-gray calcilutyte	120
34. Calcilutyte, taupe-gray, medium bedded, sparsely cherty	15
33. Limestone, coarse grained, clastic, crinoidal, cherty; carries *Platycrinites huntsvillae* stem plates	15½
32. Calcilutyte, gray, very dense, slightly cherty; beds 1 to 2 feet thick	6
31. Shale, calcareous, mealy; weathers buff; contains lenses of coarse crinoidal limestone; corresponds to top of Reger's Patton shale	3½
30. Calcilutyte, taupe-gray, medium bedded; contains no chert	4½
29. Shale, bluish-gray calcareous; weathers yellowish gray; contains large irregular masses of coarse-grained limestone with *Platycrinites* plates and small *Pentremites*	6¼
28. Limestone, bluish-gray, fine grained, shaly, fossiliferous; *Composita* sp., *Athyris densa, Pentremites princetonensis, Triplophyllum spinulosum, Lioclemella* sp., and *Stenopora*	2
27. Shale, calcareous, ash-gray, mealy, fossiliferous; contains few *Productus*	11½
26. Limestone, oolitic, crinoidal, light-gray, medium bedded	1
25. Limestone, bluish-gray, shaly, argillaceous, sparsely cherty	7½
24. Limestone, oolitic, taupe-gray, cherty	3

	Thickness Feet
23. Limestone, fine grained, dense, metallic-gray; with abundant nodules of black chert	5½
22. Shale, calcareous, lumpy; weathers yellowish-gray; contains fragments of plant fossils; corresponds to the base of Reger's Patton shale	18
21. Limestone, clastic textured, oolitic, medium-gray; thin bedded with shaly partings 1 to 3 inches thick	5
20. Calcilutyte, taupe-gray, dense; stylolites abundant; sparsely cherty; partly concealed	74
19. Calcilutyte, taupe-gray; sparingly fossiliferous; weathers light-gray with pitted and welted surfaces	20
18. Limestone, even bedded, taupe-gray, fine grained	17½
17. Calcilutyte, dark-taupe, sparsely cherty, with *Syringopora* and *Productus parvus*	7½
16. Limestone, granular, oolitic, brownish-gray	22
15. Calcilutyte, very dense, thick bedded; with abundant stylolites; sparsely cherty	3
14. Limestone, oolitic, granular, medium-gray; crinoidal	11¼
13. Limestone, bluish-gray, argillaceous, compact	1¼
12. Limestone, medium bedded, granular, oolitic; clastic textured; contains large inclusions of reddish clay	4¼
11. Limestone, argillaceous, shaly bedded, powder-gray; weathers buff	5½
10. Limestone, light-gray; oolitic, crinoidal	3¾
9. Limestone, taupe-gray, uneven textured, wavy-bedded, fossiliferous	3¼
8. Limestone, medium grained, medium-gray, very oolitic, fossiliferous; contains abundance of *Platycrinites huntsvillae*	6½
7. Limestone, coarse grained, oolitic, fossiliferous; composed almost entirely of matted shells; laminated structure with partings of yellowish clay	14½
6. Limestone, finely granular, compact, crinoidal, light-gray; full of crinoid stem plates	9
5. Limestone, light-gray, coarse grained, granular, oolitic; bedding surfaces pitted	6¼
4. Limestone, smoke-gray, very argillaceous, shaly; weathers greenish-gray; few plant fragments in lowest layers	20

	Thickness Feet
3. Limestone, coarse grained, very fossiliferous; weathers greenish-yellow; contains galls of dark-greenish clay	1¾
2. Calcilutyte, taupe-gray, fine grained, dense; contains white vugs and veins of secondary calcite	2¾
1. Limestone, dark-gray, shaly; with thin streaks of coarse-grained limestone	2
Hillsdale limestone	

Cherty beds in the lower 200 feet of the "Ste. Genevieve" make the middle and lower of the three conspicuous ledges of limstone which extend along the southeast side of Wrights Valley. Since the beds are overturned, "Ste. Genevieve" crops out below the ledge of St. Louis limestone.

Fossils.—Most of the fossils collected from the "Ste. Genevieve" are silicified and are found loose in the cherty soil. *Platycrinites huntsvillae* is found on weathered surfaces of crinoidal limestones. This fossil can be identified by its spinose, elliptical stem plates. Where several of the stem plates are together, the characteristic spiral twist of the stem is shown. The common fossils of the "Ste. Genevieve" of this area are listed below:

- Plants
  - Unidentified
- Corals
  - Menophyllum princetonensis (Ulrich)
  - Syringopora sp.
  - Triplophyllum spinulosum (Edwards and Haime)
- Blastoids
  - Pentremites princetonensis Ulrich
  - Pentremites buttsi Ulrich
  - Pentremites pulchellus Ulrich
- Crinoids
  - Platycrinites huntsvillae Safford
- Bryozoa
  - Batostomella interstincta Ulrich
  - Fistulipora peculiaris Rominger
  - Lioclemella sp.

Brachiopods
- Athyris densa Hall
- Cliothyridina cf. C. parvirostris (Meek and Worthen)
- Cliothyridina hirsuta (Hall)
- Cliothyridina sublamellosa (Hall)
- Dielasma sp.
- Echinoconchus genevievensis Weller
- Girtyella indianensis (Girty)
- Productus ovatus Hall
- Productus inflatus McChesney
- Productus parvus Meek and Worthen
- Spiriferina sp.
- Spirifer pellaensis Weller

Age and correlation.—A difference of opinion exists as to the age of the Ste. Genevieve. Some regard it as a part of the Meramec, but Butts and Ulrich[184] regard it as basal Chester. The "Ste. Genevieve" in the Burkes Garden quadrangle may correspond to the lower, or Fredonia, member of the Ste. Genevieve of the Ohio Valley. In West Virginia, the same beds are classified with the Sinks Grove and Patton limestones. The "Ste. Genevieve" corresponds to the lower part of the Newman and Greenbrier limestone of older reports.

Stratigraphic relations.—According to Butts[185] a hiatus exists between the "Gasper" and "Ste. Genevieve" limestones in southwestern Virginia, which is indicated by the absence of the Bethel sandstone and the upper part of the Ste. Genevieve limestone of the Ohio Valley. However, it is possible that the supposedly absent beds are represented by limestones or shales classed with the "Ste. Genevieve" in southwestern Virginia.

CHESTER SERIES

"GASPER" LIMESTONE

Name.—Butts[186] named the Gasper limestone from Gasper River in Warren County, Kentucky. Sutton and Weller[187] have stated

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[184] Wilmarth, M. G., Lexicon of geologic names of the United States: U. S. Geol. Survey Bull. 896, pt. 2, p. 1875, 1938.

[185] Op. cit., pp. 373-374.

[186] Butts, Charles, Descriptions and correlation of the Mississippian formations of western Kentucky: Kentucky Geol. Survey, Mississippian formations of western Kentucky, p. 64, 1917.

[187] Sutton, A. H., and Weller, J. M., Lower Chester correlation in western Kentucky and Illinois: Jour. Geology, vol. 40, pp. 430, 440, 441, 1932.

that Gasper is an unsuitable formation name, because it was never adequately defined nor its type locality clearly indicated. The name is used here in a tentative sense, for the limestones above the "Ste. Genevieve" and below the Bluefield shale.

Distribution.—The "Gasper" crops out in Bluefield, Virginia, and extends southwestward along Wrights Valley beyond the western border of the quadrangle. Another belt is exposed in Abbs Valley and southwestward to Horsepen Cove. North of Locust Knob the "Gasper" occurs in two belts which are separated by the "Ste. Genevieve" limestone (Pl. 1).

Continuous exposures of the "Gasper" do not occur in the quadrangle, but most of the beds crop out along the base of Stony Ridge north of the overpass of U. S. Route 19 near Bluefield, Virginia. The characteristic lithology of the "Gasper" is well shown near the old clay pit at Tiptop.

Lithology.—Most of the "Gasper" limestones are composed of the broken, abraded fragments of shells, particularly the stems of crinoids (Pl. 15). Like the "Ste. Genevieve", the "Gasper" has many beds of taupe-gray calcilutyte which contain very few fossils. Parts of the "Gasper" are oolitic, but such beds are almost as abundant in the "Ste. Genevieve". Lithologically the "Gasper" can scarcely be distinguished from the "Ste. Genevieve," but crinoidal beds are somewhat more plentiful in the "Gasper". The boundary between the two formations can be determined only by fossils.

The "Gasper" contains a distinctive 10-foot zone of maroon-drab shale about 150 feet above the base, which is an excellent key bed for mapping. Reger[188] described two similar shales at about the same stratigraphic horizon in Monroe County, West Virginia. One is called the "Lower Taggard Shale" and the other the "Upper Taggard Shale". They are separated by a limestone also known as the Taggard. The "Upper Taggard Shale" of Reger is probably the same as the beds here referred to as the *red shale member of the "Gasper."*

The thickness of the "Gasper" seems to be about the same in all belts and there is little variation in thickness along the strike. The average of four determinations gave a thickness of 425 feet.

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[188] Reger, D. B., op. cit., pp. 460-483.

Geologic Section 43.—"Gasper" limestone north of U. S. Route 19, half a mile west of West Graham, Tazewell County, Virginia

	Thickness Feet
Bluefield shale	
"Gasper" limestone (462 feet).	
28. Covered interval, composed of zones of bluish-gray flaky calcareous shale interbedded with lenticular zones of coarsely crinoidal limestone containing *Pterotocrinus serratus*	115
27. Limestone, medium bedded, coarsely crystalline, slightly oolitic, crinoidal; contains intercalations of bluish-gray shale composing about 20 per cent of the total thickness; cherty near the top; all beds weather rusty brown	30
26. Limestone, coarse grained, clastic, light-gray, crinoidal; contains *Pterotocrinus serratus* plates; few intercalations of shale as in zone 27	22
25. Limestone, medium grained, crinoidal; weathers very saccharoidal; contains intercalations of lead-gray calcareous shale	28
24. Limestone, dark bluish-gray to ash-gray, fine grained, dense, fossiliferous; contains nodules and stringers of black chert	5
23. Shale, light bluish-gray to ash-gray, fissile; contains 6 intercalations of coarse-grained limestone	27
22. Limestone, dull-gray to drab-gray, argillaceous, fine grained; weathers nodular because of wavy intersecting partings of mealy buff clay	5
21. Calcilutyte, taupe-gray, dense, medium bedded; with wavy seams of buff clay along bedding surfaces	15
20. Limestone, dark-gray, thin bedded, argillaceous; contains intercalations of buff-weathering shale	14
19. Covered interval, composed chiefly of brownish-gray limestone	17
18. Limestone, fine grained, light-gray, medium bedded; weathers welted; contains large fragments of pink calcite	3
17. Limestone, fine grained, argillaceous, cherty, bluish-gray; weathers nodular	5

	Thickness Feet
16. Limestone, crinoidal, taupe-gray; texture very uneven; matrix of medium-grained limestone encloses large pinkish fragments of crinoid stem plates; carries *Pterotocrinus serratus* and *Talarocrinus*	8
15. Calcilutyte, light taupe-gray, medium bedded; distinct conchoidal fracture	10
14. Limestone, greenish-gray, buff weathering; with irregular meshwork of silty partings; somewhat glauconitic	2
13. *Red shale member of the "Gasper."* Lumpy, silty, calcareous shale containing a large *Productus* and small blastoids	11
12. Limestone, fine grained, dense, taupe-gray; weathers in fluted patterns	45
11. Limestone, dark-gray, fine grained, argillaceous, thin bedded; contains intercalations of soft shale	21
10. Shale, buff, weathers rusty brown; mealy, calcareous; contains bryozoans in abundance	6
9. Calcilutyte, taupe-gray; weathers bluish-gray; abundant stylolites	9
8. Shale dark-gray, calcareous; weathers rusty-brown	13
7. Limestone, dark-gray, fine grained, even bedded	8
6. Limestone, very coarse grained, light-gray; crinoidal, with *Pterotocrinus serratus*	1
5. Limestone, light-gray, argillaceous; contains irregular masses of whitish argillaceous limestone	2
4. Limestone, bluish-black, argillaceous; with thin shaly streaks containing *Cliothyridina sublamellosa;* many fragments of *Pentremites*	17
3. Limestone, dark brownish-gray, medium bedded; with flattish nodules of black chert	11
2. Shale, bluish-gray, fossiliferous; weathers brown	2
1. Limestone, dark taupe-gray, fine grained; weathers light-gray	10

"Ste. Genevieve" limestone

Fossils.—The coarser-grained beds of the "Gasper" carry an abundance of fragmental crinoids and several species of blastoids. The most characteristic fossil is *Pterotocrinus serratus* whose wing plates can be found in nearly every bed of crinoidal limestone in the "Gasper." The "Ste. Genevieve" does not contain this fossil, and the only species of *Pterotocrinus* in the overlying Bluefield formation is *P. spatulatus.* This form, which also occurs in the "Gasper," is distinct from *P. serratus.* The main elements of the "Gasper" fauna, collected from exposures along the Norfolk and Western Railway a short distance west of Tiptop, are listed below:

- Corals
    - Campophyllum gasperense Butts
    - Triplophyllum spinulosum (Edwards and Haime)
- Blastoids
    - Pentremites "godoni" Ulrich
    - Pentremites pyriformis Say
    - Pentremites sp.
    - Pentremites cervinus Hall
    - Pentremites patei Ulrich
- Crinoids
    - Agassizocrinus sp.
    - Agassizocrinus cf. A. conicus Wachsmuth and Springer
    - Platycrinites sp. (stem plates not spinose)
    - Pterotocrinus serratus Weller
    - Pterotocrinus spatulatus Wetherby
    - Talarocrinus inflatus Ulrich
    - Talarocrinus ovatus Worthen
- Bryozoa
    - Archimedes proutanus Ulrich
    - Archimedes sp.
    - Cystodictya sp.
- Brachiopods
    - Chonetes cf. C. chesterensis Weller
    - Cliothyridina sublamellosa (Hall)
    - Composita trinuclea (Hall)
    - Diaphragmus elegans (Norwood and Pratten)
    - Echinoconchus sp.
    - Eumetria verneuilana (Hall)
    - Orthotetes cf. O. kaskaskiensis (McChesney)
    - Spirifer leidyi Norwood and Pratten
    - Spiriferina cf. S. spinosa (Norwood and Pratten)

Age and correlation.—The "Gasper" is of early Chester age and corresponds mainly to the Gasper or Girkin limestone of Kentucky. That a part of the "Gasper" is of Glen Dean age is suggested by the occurrence of *Pterotocrinus spatulatus,* a characteristic crinoid of the Glen Dean limestone of Kentucky, in the upper part of the "Gasper."

BLUEFIELD SHALE

Name.—The Bluefield shale was named by Campbell[189] from exposures at Bluefield, West Virginia.

Distribution.—The Bluefield shale occurs in three belts in the northern part of the Burkes Garden quadrangle (Pl. 1); southwest from Bluefield, Virginia, along the southeast slope of Stony Ridge; along the northwest slope of Abbs Valley Ridge; and on the north side of Abbs Valley. The third belt ends against the Richlands fault near the head of Horsepen Creek.

Lithology.—The Bluefield shale constitutes a thick transitional zone between the limestones below and the overlying Pennington formation (Pl. 15). In the type section at Bluefield, West Virginia, the Bluefield is about 1,250 feet thick, and is equally as thick throughout the belt which extends southwest from that city. Both of the belts in Abbs Valley show a thickness of about 1,000 feet. Most of the formation is composed of bluish-gray calcareous shale. The weathered shales are bright-buff and fissile. Zones of maroon-drab shale which occur in the upper 500 feet are identified with red shales in the overlying Pennington formation. The upper 200 to 250 feet of the Bluefield contains blocky siltstones and sandstones, some of which are impregnated with limonite. Two thin coal seams, 2 to 3 inches thick, are present; one about 300 feet below the top, and the other about 450 feet above the base of the formation. Both coals show along an abandoned road which crosses Stony Ridge northwest of West Graham (Hockman Road). Only one coal bed was identified in Abbs Valley. In the Stony Ridge belt two prominent sandstones occur in the upper part of the formation. Both are greenish-gray, thin bedded, micaceous, and medium grained. The upper sandstone is distinctly quartzitic and so similar to the Stony Gap sandstone at the base of the Pennington that southwest of the Tiptop road on Stony Ridge they are almost indistinguishable.

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[189] Campbell, M. R., Description of the Pocahontas quadrangle: U. S. Geol. Surv. Geol. Atlas, Pocahontas folio (No. 26), p. 3, 1896.

A very conspicuous ledge of coarse-grained crinoidal limestone occurs about 150 feet above the base of the Bluefield shale in all belts. A prominent outcrop of this zone occurs along the southeast side of Abbs Valley. Less than 2 miles beyond the western edge of the Burkes Garden quadrangle this limestone is 20 to 25 feet thick, but in the quadrangle it is not more than 10 feet thick.

Reger[190] has subdivided the Bluefield into thirty-one named units, few of which can be identified beyond the localities where named. Possibly Reger's Clayton sandstone is the same as the upper sandstone of the Bluefield formation in the Burkes Garden quadrangle; also his Graham sandstone may be the same as the sandstone which occurs 450 feet above the base of the Bluefield north of Bailey and Tiptop. Possibly the uppermost coal seam exposed along Hockman Road is the Graham coal of Reger. The distinctive limestone near the base of the Bluefield is not mentioned by Reger.

Geologic Section 44.—Bluefield shale along Road 655 on the northwest slopes of Abbs Valley Ridge, Tazewell County, Virginia

	Thickness Feet
Pennington formation (Stony Gap member)	
Bluefield shale (1,007 feet)	
18. Shale and siltstone, greenish-gray; lumpy; calcareous where fresh; weathers reddish-buff and disintegrates into paper-thin chips; limonite veinlets along joint and fracture surfaces	108
17. Shale, drab-gray, siliceous, micaceous, fissile; changes color very little on weathering	153
16. Shale, lumpy, calcareous where fresh; weathers to greenish-gray chips; contains a few thin sandy siltstones near the top	54
15. Shale, bluish-gray, calcareous; weathers to buff flaky chips	11
14. Shale, buff, flaky; no fresh exposures	13
13. Shale, maroon-drab, flaky	2
12. Shale, buff, flaky; contains few pelecypods	12
11. Shale, greenish-gray, soft, unctuous, lumpy	22
10. Shale, maroon-drab and reddish-buff, fissile, noncalcareous	7

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[190] Reger, D. B., op. cit., pp. 383-386.

	Thickness Feet
9. Shale, olive-drab, fissile, finely micaceous, weathers mealy	23
8. Shale, apricot-buff, silty, lumpy; contains few beds of fossiliferous mudstone carrying *Cliothyridina* and *Archimedes*	2
7. Shale, maroon-drab, noncalcareous; weathers to paper-thin chips	3
6. Shale, tan to olive-drab where weathered but bluish-gray where fresh; a few of the more calcareous beds are bluish-gray even where deeply weathered	14
5. Shale, light-drab, micaceous, fissile; where fresh the shale is bluish-gray	105
4. Covered interval, containing a 11-foot zone of sandstone near the base	86
3. Shale, very calcareous where fresh, light-gray, lumpy; weathers reddish-buff and flaky	51
2. Covered interval, composed of buff weathered shale	190
1. Shale, bluish-gray, calcareous, fossiliferous, weathers buff; contains an 8-foot limestone bed about 40 feet below the top, which carries *Pterotocrinus spatulatus*	149

"Gasper" limestone

Fossils.—The Bluefield shale contains many fossils, but few of them are sufficiently well preserved to be identified. The forms listed below were collected from exposures along the northwest slope of Abbs Valley Ridge, 1½ miles north of the village of Mud Fork:

- Blastoids
  - Pentremites brevis Ulrich
  - Pentremites maccalliei Schuchert
- Crinoids
  - Pterotocrinus spatulatus Wetherby
- Bryozoa
  - Archimedes communis Ulrich
  - Archimedes sp.
  - Fenestrellina cf. F. tenax (Ulrich)
  - Fistulipora sp.
  - Polypora sp.

  - Septopora subquadrans Ulrich
  - Stenopora sp.
- Brachiopods
  - Camarophoria explanata (McChesney)
  - Cliothyridina sublamellosa (Hall)
  - Diaphragmus elegans (Norwood and Pratten)
  - Eumetria verneuilana (Hall)
  - Orthotetes cf. O. kaskaskiensis (McChesney)
  - Productus cf. P. inflatus McChesney
  - Reticularia setigera (Hall)
  - Spirifer cf. S. increbescens Hall
  - Spiriferina cf. S. transversa (McChesney)
- Pelecypods
  - Aviculopecten sp.
  - Edmonia sp.
  - Myalina sp.
  - Sphenotus sp.

Age and correlation.—The brachiopods and bryozoans in the Bluefield include many species which are common in the Glen Dean limestone and the two formations probably are equivalent. *Pentremites maccalliei,* found in the lower 150 feet of the Bluefield shale near Tiptop, is very similar to *P. obesus* which occurs in the Golconda limestone of Illinois and Kentucky, and it may indicate that the Golconda is represented in the Bluefield.

Stratigraphic relations.—Although the upper and lower contacts are lithologically transitional, there may be a hiatus at either boundary.

PENNINGTON FORMATION

Name.—The Pennington formation was named from Pennington Gap, Lee County, Virginia, by Campbell[191]. The name Hinton was also applied to this formation by Campbell and Mendenhall[192], but Butts[193] has recently shown that the Pennington and Hinton are the same. Since Pennigton (1893) has priority over Hinton (1896), it is used by the Virginia Geological Survey.

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[191] Campbell, M. R., Geology of the Big Stone Gap coal field of Virginia and Kentucky: U. S. Geol. Survey Bull. 111, pp. 28, 37, 1893.

[192] Campbell, M. R., and Mendenhall, W. C., Geologic section along the New and Kanawha rivers in West Virginia: U. S. Geol. Survey 17th Ann. Rept,, pt. 2, p. 487, 1896.

[193] Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. 1, pp. 293-401, 1940.

Distribution.—The Pennington occurs in three belts in the northwestern part of the quadrangle (Pl. 1). One extends along the northwest side of Stony Ridge; another makes Abbs Valley Ridge; and the third belt, containing only a part of the formation, lies between the Richlands and Boissevain faults at the foot of the Allegheny plateau. The Stony Gap sandstone, the basal member of the Pennington, has been mapped separately.

Lithology.—The Pennington consists of a heterogeneous, varicolored succession of shales, mudrocks, siltstones, argillaceous limestones, and granule conglomerates (Pl. 15). Maroon-drab shales and mudrocks are the most conspicuous and characteristic beds, but make up less than half the total thickness. Sandstones of various types, most of which are very even bedded, are distributed throughout the formation. They cause the Pennington to uphold broad hilly areas rather than narrow hogbacks. The calcareous shales are bluish-gray where fresh, but weather buff. Red and green shales are micaceous and silty. The most resistant beds are light-gray to greenish-gray quartzites and quartzitic conglomerates, which are prominent at the base and also near the top of the formation.

Two good exposures of the formation are present along Road 655. The Stony Ridge belt is about 1,000 feet thick, but the thickness measured along the same road over Abbs Valley Ridge is about 1,700 feet.

Reger[194] has subdivided the Pennington [Hinton] in near-by areas into forty-five units, only three of which can be recognized with certainty in the Burkes Garden quadrangle.

STONY GAP SANDSTONE MEMBER

Name.—The Stony Gap sandstone was named by Reger[195] from Stony Gap, Mercer County, West Virginia.

Lithology.—The Stony Gap sandstone member directly overlies the Bluefield shale and is composed of coarse-grained, buff to white sandstone containing quartzite pebbles up to an inch in diameter. The thickness of the sandstone is 45 to 75 feet. North of Tiptop near the crest of Stony Ridge, the sandstone is 55 feet thick (Pl. 16B); north of Bailey it is 43 feet thick; and on Scotts Knob it is at least 75 feet thick and markedly conglomeratic. Northwest of Tiptop on Stony Ridge, the Stony Gap sandstone thins and becomes shaly. Along Road 655 across Abbs Valley Ridge, the sandstone is nonresistant and

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[194] Op. cit., pp. 330-378.
[195] Idem, p. 372.

contains much shale. The same belt of Stony Gap near both eastern and western borders of the quadrangle, is 75 feet thick and is composed of quartzitic sandstone.

Geologic Section 45.—Stony Gap sandstone member, along Road 655, 1½ miles north of Mud Fork Village, Tazewell County, Virginia

	Thickness	
	Ft.	In.
Stony Gap sandstone member (68 feet)		
9. Sandstone, white to buff, thick bedded; weathers rusty brown; repeated three times by folding	5	
8. Shale, light greenish-gray, micaceous, silty; contains intercalations of nodular, rusty weathering sandstone	22	6
7. Sandstone, rough, irregular, blocky; stained rusty brown	5	8
6. Shale, micaceous, fissile, greenish-gray; contains intercalations of light-brown quartz sandstone	9	
5. Sandstone, drab-gray, fine-grained	3	
4. Sandstone, thin bedded, wavy; contains partings of sandy shale	2	10
3. Sandstone, coarse grained, quartzitic; wavy bedded, closely spaced joints; minor intercalations of shale	7	
2. Sandstone, wavy bedded; partings of sandy shale	6	3
1. Shale, greenish-gray, fissile, very sandy	6	
Bluefield shale		

AVIS LIMESTONE MEMBER

Name.—The Avis limestone was named by Reger[196] from Avis Village, near Hinton, Summers County, West Virginia.

Lithology.—In the Burkes Garden quadrangle, the Avis limestone consists of 15 to 40 feet of bluish-gray shaly limestone. North of the village of Mud Fork, along Road 655, several beds of shell limestone occur at the base. The Avis is rather poorly exposed on Stony Ridge, except in roadcuts, but the member can be traced almost continuously along Abbs Valley Ridge. The interval between the Avis and the top of the Pennington is 275 to 350 feet.

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[196] Op. cit., pp. 347-351.

FALLS MILLS SANDSTONE MEMBER

Name.—The Falls Mills sandstone was named by Reger[197] from Falls Mills, Tazewell County, Virginia.

Lithology.—Near the type locality, the Falls Mills sandstone is mainly shaly rock with a few intercalated thin layers of white quartzite. In the Burkes Garden quadrangle, the Falls Mills is a fine- to medium-grained, light-buff sandstone 30 to 60 feet thick. It makes the crest of Abbs Valley Ridge, but it is not topographically prominent on Stony Ridge. The best exposure is along the road across Abbs Valley Ridge, about one-fourth of a mile north of Mud Fork Village.

Geologic Section 46.—Pennington formation along Road 655 north of Mud Fork Village, Tazewell County, Virginia

	Thickness	
	Ft.	In.
Princeton sandstone		
Pennington formation (1,704 feet)		
80. Shale, greenish-gray, weathers yellow; with intercalations of brown earthy siltstone	74	
79. Mudrock, maroon-drab, silty, micaceous; contains few quartzose sandstones near the base	93	6
78. Falls Mills sandstone, light-buff to olive-drab, even bedded; weathers light-brown	42	
77. Covered interval	9	
76. Avis limestone, bluish-gray, argillaceous; contains numerous fossils including *Spiriferina spinosa, Composita subquadrata, Spirifer increbescens, Stenopora* sp., *Archimedes* sp., and *Streptorhynchus ruginosum*	36	6
75. Shale, calcareous, bluish-gray, lumpy	10	
74. Covered interval	25	
73. Siltstone and sandstone, greenish-gray, buff-weathering; with thin intercalations of drab-gray micaceous shale	68	6
72. Siltstone, greenish-gray, rusty weathering; with intercalations of silty shale	23	
71. Siltstone, maroon-drab, lumpy; with a few 3-inch intercalations of blocky white sandstone	10	

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[197] Op. cit., p. 372.

	Thickness	
	Ft.	In.
70. Shale, bright yellowish-buff, fissile; weathers olive-drab	9	6
69. Siltstone, maroon-drab, irregularly bedded; contains thin streaks and beds of greenish-gray sandstone	38	
68. Mudrock, maroon-drab, interbedded with greenish-gray shale	36	6
67. Sandstone, gray, medium grained, interbedded with reddish-brown, silty mudrock	4	
66. Shale, bright reddish-brown, lumpy	2	
65. Shale, greenish-gray, lumpy, silty	3	
64. Sandstone, bright olive-green	1	3
63. Siltstone, maroon-drab, shaly	8	
62. Siltstone, bright olive-green, shaly	13	
61. Siltstone, maroon-drab, micaceous, firmly indurated; contains greenish streaks	11	6
60. Sandstone and shale, dark brownish-red, micaceous, silty, interbedded; some beds are greenish-gray	21	
59. Shale, greenish-gray, micaceous, weathers buff	10	
58. Sandstone, maroon-drab, fine grained; in thick beds	62	6
57. Mudrock, maroon-drab to reddish-brown, very silty; contains intercalations of olive-drab mudrock	58	
56. Sandstone, dark-gray, blocky, ferruginous; beds lenticular	4	3
55. Shales, maroon-drab and greenish-gray, weather buff	9	6
54. Siltstone, greenish-gray, rusty weathering, platy	20	6
53. Sandstone, greenish-gray, sideritic, wavy bedded, weathers flaggy	15	
52. Shale, greenish-gray, fissile shale	3	6
51. Sandstone, thin bedded, light-gray, knotty	10	
50. Shale, platy, greenish-gray, siliceous; sandy toward the top	65	6

	Thickness	
	Ft.	In.
49. Sandstone, coarse grained, light-buff, medium to thick bedded; regularly bedded, weathers dark brown	7	
48. Shale, paper-thin beds, greenish-gray; contains few thin-bedded sandstones 2 to 3 inches thick	26	
47. Shale, light-maroon-drab silty sandstone	14	6
46. Shale, dark-gray, very fissile; shows spheroidal weathering	41	
45. Shale, platy, greenish-gray, fissile, micaceous, mealy, weathers buff	29	
44. Mudrock, greenish-drab, micaceous, silty; contains several beds of quartz sandstone 3 to 6 inches thick	51	6
43. Covered interval; containing buff shales and rusty weathering blocky sandstones	64	
42. Sandstone, greenish, micaceous, silty, argillaceous	10	
41. Mudrock, lumpy, maroon-drab, micaceous, very silty; with about 5 feet of yellowish-brown shale intercalated near the top	13	
40. Shale, buff, silty, deeply weathered	8	
39. Siltstone, greenish-gray, buff weathering; peppered with fragments of plants	6	
38. Mudrock, maroon-drab, silty	6	
37. Shale, light greenish-gray, silty; weathers light-buff	19	
36. Mudrock, maroon-drab to greenish-gray, silty	44	
35. Shale, greenish-gray; very sandy and micaceous	42	6
34. Siltstone and shale, light-gray, soft, lumpy	15	6
33. Sandstone, coarse grained, quartzitic, light-buff; contains partings of lumpy clay	8	
32. Shale, maroon-drab, lumpy, rather mealy	8	
31. Sandstone, greenish-gray, blocky; beds separated by partings of maroon fissile shale	7	
30. Shale, greenish-gray; weathers fissile	8	6
29. Clay, dark purplish-gray, soft, unctuous; contains plant fragments	6	
28. Shale, greenish-gray, lumpy, micaceous, sandy; weathers buff	36	

		Thickness	
		Ft.	In.
27.	Shale, maroon-drab, micaceous, fissile	7	6
26.	Sandstone, olive-drab, sandy, very finely laminated	2	
25.	Shale, olive-drab to greenish-gray; contains thin partings of dark-maroon fissile shale	5	
24.	Shale, olive-drab, paper-thin beds	12	
23.	Shale, olive-drab, micaceous, silty; contains minor intercalations of maroon-drab shale	32	
22.	Shale, greenish-gray, micaceous, fissile; contains pelecypods; includes several lenses of sandstone about 2 feet thick	22	6
21.	Shale, olive-drab, fissile	36	
20.	Siltstone, blocky, micaceous, dark-brown	4	
19.	Shale, silty, fissile, greenish-gray; contains streaks of quartz grains	9	6
18.	Sandstone, platy to blocky, micaceous; peppered with minute fragments of carbonized plants	27	
17.	Sandstone, blocky, unevenly laminated; contains plant fragments	18	
16.	Sandstone, greenish-gray, sideritic, blocky; beds thin and irregular	16	
15.	Shale and sandstone; shale dark greenish-gray; sandstone white and quartzitic and contains nests and veinlets of marcasite	8	6
14.	Shale, greenish-gray, fissile, micaceous; contains clay ironstone concretions	20	6
13.	Siltstone, thin bedded, greenish-gray; interbedded with brown siltstone containing stringers of siderite	5	
12.	Covered interval	30	
11.	Shale, maroon-drab, stiff, siliceous	8	
10.	Siltstone, sandy, micaceous, rather blocky	2	
9.	Shale, maroon-drab and greenish-gray mottled, fissile		6
8.	Siltstone, greenish-gray, lumpy, micaceous; contains intercalations of fissile shale	17	5
7.	Siltstone, mealy, lumpy; contains a few beds of argillaceous limestone carrying pelecypods	4	

	Thickness	
	Ft.	In.
6. Limestone, bluish-gray, argillaceous; with intercalations of calcareous shale; possibly Reger's Middle Bellepoint limestone	6	6
5. Shale, greenish-gray, micaceous, fissile	10	
4. Siltstone, lumpy, mealy; weathers light-brown	9	
3. Coal, bony, mixed with bituminous shale		5
2. Shale, light greenish-gray, silty; beds fractured and joints filled with limonite; sandy toward the base; transitional with the underlying sandstone	54	
1. Stony Gap sandstone member (see geologic section 44)	67	9

Bluefield shale

FOSSILS

Parts of the Pennington are extremely fossiliferous. Most of the limy zones, particularly the Avis member, contain many bryozoans and brachiopods. Some of the calcareous shales contain pelecypods, most of which are too poorly preserved to be identified specifically. Some of the carbonaceous shales contiguous to coal beds carry plant fossils. The following forms were identified from the Pennington exposed along the road from Tiptop to the head of Abbs Valley:

- Plants
  - Asterocalamites sp.
- Bryozoa
  - Archimedes sp.
  - Fenestrellina cf. F. tenax (Ulrich)
  - Polypora sp.
- Brachiopods
  - Athyris papilioniformis McChesney
  - Camarophoria explanata (McChesney)
  - Cliothyridina sublamellosa (Hall)
  - Composita sp.
  - Composita subquadrata (Hall)
  - Derbya sp.
  - Diaphragmus sp.
  - Eumetria sp.

- Lingulodiscina sp.
- Martinia sp.
- Orthotetes cf. O. kaskaskiensis (McChesney)
- Productus ovatus Hall
- Reticularia sp.
- Streptorhynchus ulrichi Hall and Clarke
- Spirifer increbescens Hall
- Spirifer cf. S. pellaensis Weller
- Spiriferina spinosa (Norwood and Pratten)

Gastropods
- Euphemites sp.

Pelecypods
- Allorisma sp.
- Aviculopecten sp.
- Cypricardella sp.
- Leda sp.
- Schizodus sp.
- Sphenotus sp.

Ostracodes
- Kirkbya sp.

AGE AND CORRELATION

The Pennington seems to correlate with the upper part of the Chester series of the Lower Ohio Valley region. *Myalina prolifica* and *Sulcatopinna missouriensis,* both of which occur in the Menard and Clore formations of Kentucky, occur in Pennington shales a few feet above the Avis limestone in the section exposed along State Highway 85 opposite the railroad station at Falls Mills, Virginia.

STRATIGRAPHIC RELATIONS

Both boundaries of the Pennington are conformable. The upper part of the Bluefield shale, the Pennington, and the Bluestone formation are so similar lithologically that there can be no doubt but that sedimentation in this area was essentially continuous throughout middle and late Chester time.

PRINCETON SANDSTONE

Name.—The Princeton conglomerate was named by Campbell[198] from Princeton, Mercer County, West Virginia. Between Falls Mills,

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[198] Campbell, M. R., and Mendenhall, W. C., op. cit., pp. 487, 489.

Tazewell County, Virginia, and the eastern border of the Burkes Garden quadrangle, the Princeton loses its conglomeratic character and becomes a coarse-grained sandstone.

Distribution.—Two narrow belts of Princeton sandstone extend across the northern part of the quadrangle (Pl. 1). The belt on Stony Ridge forms the northern line of ridge crests which are somewhat lower than the crest made by the Stony Gap sandstone member. West of the road from Tiptop to Mud Fork, the Stony Gap sandstone thins and becomes shaly, and the top of Stony Ridge is made by the Princeton. The northern belt of Princeton crops out along the southeast side of Abbs Valley Ridge and makes conspicuous flatirons.

Lithology.—On Stony Ridge, the Princeton is a hard quartzite 30 to 50 feet thick (Pl. 15). The rock in the northern Princeton belt is a coarse-grained friable sandstone, as far southwest as the village of Mud Fork, but farther southwest it is finer grained and quartzitic (Pl. 16A). In this part of the area the Falls Mills and Princeton are differentiated only with great difficulty. During the summer of 1941, S. E. Harris and the writer traced the Princeton from the vicinity of Falls Mills southwest across the Burkes Garden quadrangle to State Highway 16, near Adria, Tazewell County, Virginia. This work made possible the correct identification of the Princeton in the vicinity of Mud Fork Village, where lithologically similar sandstones in the lower part of the Bluestone formation are prominently exposed.

Age and correlation.—No fossils were found in the Princeton of this area. A few fossil plants found in the Princeton by Butts[199] near Bluefield, West Virginia, indicate its late Mississippian age.

BLUESTONE FORMATION

Name.—The Bluestone formation was named by Campbell[200] from Bluestone River which crosses the main outcrop of the formation in Mercer County, West Virginia.

Distribution.—The formation is confined to a belt in Mud Fork Valley and is well exposed along Roads 653 and 655 near Mud Fork Village (Pl. 1).

Divisions.—Reger[201] named many subdivisions of the Bluestone in near-by areas in West Virginia. These units are herein redefined

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[199] Op. cit., p. 402.

[200] Campbell, M. R., Description of the Pocahontas sheet: U. S. Geol. Survey Geol. Atlas, Pocahontas folio (No. 26), p. 3, 1896.

[201] Op. cit., pp. 314-325.

and renamed as members of the Bluestone formation (Pl. 15). Not all of the Bluestone formation is present in Mud Fork Valley. The uppermost beds, with an aggregate thickness of 200 to 300 feet have been entirely removed by erosion. The members of the Bluestone are described in ascending stratigraphic order.

PRIDE SHALE MEMBER

Name.—Reger named the Pride shale member from Pride, Mercer County, West Virginia.

Lithology.—This member consists of dark bluish-gray finely laminated calcareous shale which weathers rusty-brown and mealy. The rock spalls into an aggregate of pencil-shaped slivers (Pl. 17D), which in Mud Fork Valley are a diagnostic characteristic of the Pride shale. The shale is broken by well-defined joints, along which percolating waters have deposited iron oxide and calcium carbonate. The best exposure of the Pride is in the bluff along Road 655 immediately south of Mud Fork Village. Other exposures are along Road 643 northeast of Mud Fork Village. The thickness of the Pride averages about 100 feet.

PIPESTEM SHALE MEMBER

Name.—The Pride shale member is directly overlain by brown sandy shales which were named the Pipestem shale by Reger from Pipestem, Summers County, West Virginia.

Lithology.—In near-by areas in West Virginia, the Pipestem is 30 to 45 feet thick, but in the Burkes Garden quadrangle it is not more than 20 feet thick. Along Road 655, south of Mud Fork Village, the shale is less than 10 feet thick and contains a parting of bony coal (Reger's Pipestem coal) near the base. The fresh rock is dark-gray, but weathering changes the color to dark-brown.

GLADY FORK SANDSTONE MEMBER

Name.—The Glady Fork sandstone was named by Reger from a small creek which crosses the Bluefield-Princeton road in Mercer County, West Virginia.

Lithology.—The Glady Fork member is composed of saccharoidal sandstones, conglomerates, and sandy shales, which collectively resemble the Princeton sandstone as developed near Falls Mills, Virginia. In the

Burkes Garden quadrangle, the member is 25 to 40 feet thick. A typical development of the Glady Fork is fully exposed along Road 655 south of Mud Fork Village.

Geologic Section 47.—Glady Fork sandstone member, along Road 655, south of Mud Fork village, Tazewell County, Virginia

	Thickness Ft.	Thickness In.
Glady Fork sandstone member (27 feet)		
11. Sandstone, greenish-gray, irregularly bedded, argillaceous; weathers lumpy	3	5
10. Sandstone, greenish-gray, compact; breaks into rectangular blocks	1	4
9. Shale olive-drab, micaceous; contains 6-inch sandstone bed at the top	1	3
8. Sandstone, fine grained, compact, greenish-gray; one bed	2	8
7. Shale, olive-drab, micaceous; interbedded with blocky beds of quartz sandstone	3	9
6. Sandstone, arkosic, even bedded, gray; mottled with black fragments of fossil plants; bedding very lenticular	2	
5. Shale, sandy, olive-drab; contains thin streaks of coal		4
4. Sandstone, coarse grained, lenticularly bedded, arkosic; peppered with plant fragments; gray to greenish-gray	2	
3. Mudrock, olive-drab, lumpy; contains a lens of quartz- and limestone-pebble conglomerate at the base, and two thinner lenses of conglomeratic sandstone near the top	1	
2. Coal, pyritic, bony; pinches out locally	1	
1. Sandstone, bluish-gray, coarse grained, lenticularly bedded; interfingers with lenses of coarse conglomerate containing pebbles of bluish-gray fossiliferous limestone and quartz; base irregular	2	
Pipestem shale member		

MUD FORK MEMBER

Name.—Reger subdivided the 90-foot succession of red beds immediately above the Glady Fork sandstone into four units which he named, in ascending stratigraphic order, the Lower Mud shale, Lower Mud sandstone, Upper Mud shale, and Upper Mud sandstone. The type section for these units is along Road 656 about 1½ miles north of Bailey. All were named from Mud Fork, a tributary of Bluestone River. The writer groups the four units into a single member named the Mud Fork member of the Bluestone formation.

Lithology.—The Mud Fork member is easily distinguished by the fact that it is the lowest red zone above the Princeton sandstone. The character of the Mud Fork member is well shown along Roads 655 and 656, on the northwest slope of Stony Ridge.

Geologic Section 48.—Mud Fork member along Road 656 about 1½ miles north of Bailey, Tazewell County, Virginia

	Thickness (estimated) Feet
Mud Fork member (91 feet)	
4. Sandstone, chocolate-brown, micaceous, silty	5
3. Mudrock, maroon-drab, silty, interbedded with fissile shale	42
2. Sandstone and mudrock, lumpy, mottled red and green, very micaceous, silty	6
1. Shale and mudrock, maroon-drab and greenish-gray; contains intercalations of silty sandstone	38
Glady Fork sandstone member	

BELCHER MEMBER

Name.—The Mud Fork member is overlain by 80 to 100 feet of beds classified by Reger into the following units, in ascending order: Lower Belcher shale, Lower Belcher sandstone, Upper Belcher shale, and Upper Belcher sandstone. The writer also considers it advisable to group these divisions into a single member, herein named the Belcher member of the Bluestone formation. The type locality is that given by Reger, along the Bluefield-Princeton road across Big Ridge, near Belcher School, Mercer County, West Virginia.

Lithology.—The Belcher is composed of sandstones and argillaceous beds like those in the Mud Fork member, and it constitutes the second red zone above the Princeton sandstone. The best exposure is along Road 656 north of Bailey.

Geologic Section 49.—Belcher member along Road 656 about 1½ miles north of Bailey, Tazewell County, Virginia

	Thickness (estimated) Feet
Belcher member (99 feet)	
4. Sandstone, medium grained, silty, dark greenish-gray; beds 1 to 3 feet thick	30
3. Shale and mudrock, light-maroon, silty, noncalcareous; contains mud cracks and desiccation breccias	22
2. Siltstone and sandstone, greenish-gray and chocolate-brown, micaceous; weathers slabby	34
1. Mudrock and siltstone, maroon-drab, mealy; weathers lumpy	13
Mud Fork member	

BRATTON SANDSTONE MEMBER

Name.—The Bratton sandstone was named by Reger from Bratton Branch, Mercer County, West Virginia. It is herein considered a member of the Bluestone formation.

Lithology.—The Bratton sandstone member is composed of greenish-gray micaceous silty sandstone with an aggregate thickness of about 10 feet. The best exposure is along Road 653 on the northwest slope of Stony Ridge.

HUNT MEMBER

Name.—Reger subdivided the succeeding 50 feet of the Bluestone into three units, in ascending order: the Hunt shale, Hunt sandstone, and Hunt coal. The three are here considered as a member of the Bluestone. The type locality is near Hunt School, Mercer County, West Virginia.

Lithology.—In the Burkes Garden quadrangle, the Hunt member is 50 to 75 feet thick and consists of maroon-drab, apple-green, and reddish-buff shales. The red beds are overlain by a 12-foot zone of black carbonaceous shale, gray underclay, and coal. The coal bed seems to be absent west of Road 656 in Mud Fork Valley. At the "Stony Ridge mine," a coal prospect, the coal bed at the top of the Hunt is about 13 inches thick and is overlain by about 1½ feet of unctuous clay shale containing plant fossils. The same beds crop out again about 75 feet below the main prospect pit, but here the unctuous clay underlies the coal. The relations indicate that the Hunt member is in the trough of an overturned syncline.

BENT MOUNTAIN MEMBER

Name.—The Bent Mountain member, as herein defined and used, consists of four of Reger's subdivisions of the Bluestone, namely, the Lower Bent shale, Bent limestone, Upper Bent shale, and Bent sandstone. The name is taken from Bent Mountain, Mercer County, W. Va.

Lithology.—In the Burkes Garden quadrangle, the Bent Mountain member[202] of the Bluestone formation consists of only the lower 60 feet of the member as developed in the type locality; the higher beds, comprising the Bent sandstone of Reger, have been removed by erosion. Most of the 60-foot thickness is red and green shale and mudrock.

THICKNESS

The total thickness of the Bluestone formation is 450 to 525 feet in the Burkes Garden quadrangle.

FOSSILS

Sphenopteris and Asterocalamites occur in the carbonaceous shales associated with the Hunt coal at the "Stony Ridge mine." Shales in the Belcher member, exposed along the road south of the village of Mud Fork, contain unidentified species of *Allorisma, Edmondia, Caneyella, Myalina,* and *Aviculopecten. Kirkby* sp. and several small, unidentified brachiopods were collected from the Pride shale member.

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[202] Reger's Lower Bent shale and Bent limestone are the same as his Upper Bent shale. A double thickness of the Upper Bent shale, produced by close folding, is exposed along Road 656 about 1½ miles north of Bailey. Here, Reger apparently mistook the repeated Upper Bent shale for his Lower Bent shale and Bent limestone. The Bent sandstone of Reger, which overlies the Upper Bent shale on Bent Mountain, West Virginia, is not present in the Burkes Garden quadrangle.

AGE AND CORRELATION

According to Butts[203] the Bluestone may be equivalent to the Degonia sandstone and Kincaid limestone of southern Illinois. Possibly the Bluestone is younger than any of the Chester formations in the Ohio and Mississippi valleys.

STRATIGRAPHIC RELATIONS

The Bluestone seems to be conformable with the Pennington. Near Pocahontas, Tazewell County, Virginia, the Bluestone underlies the Pennsylvanian Lee formation in normal sequence. In the Burkes Garden quadrangle, the Bluestone has been faulted out along the southeastern edge of the Pennsylvanian belt, and in Mud Fork Valley the Pennsylvanian and the upper part of the Bluestone have been removed by erosion.

PENNSYLVANIAN SYSTEM

POTTSVILLE SERIES

LEE FORMATION

Name.—The Lee formation was named by Campbell[204] from Lee County, Virginia.

Distribution.—The Lee formation is confined to an area of about 2 square miles in the northwestern corner of the Burkes Garden quadrangle (Pl. 1).

Lithology.—Where all the Lee is present, the formation is 1,530 to 1,800 feet thick[205]. In the Burkes Garden quadrangle between 500 and 600 feet of the Lee is exposed; the upper 450 feet of the formation has been removed by erosion. A similar thickness of beds in the lower part of the Lee occurs below the surface near Horsepen Creek (Fig. 5).

The lowest exposed beds crop out along Road 644 west of the junction of Yokel Branch and Horsepen Creek. A 3-inch bed of bony coal which crops out in the bed of Horsepen Creek one-fourth of a mile from the west edge of the quadrangle is at the base of the exposed part of the formation. This coal is overlain by 25 to 40

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[203] Op. cit., p. 405.

[204] Campbell, M. R., Geology of the Big Stone Gap coal field of Virginia and Kentucky: U. S. Geol. Survey Bull. 111, p. 36, 1893.

[205] Harnsberger, T. K., The geology and coal resources of the coal-bearing portion of Tazewell County, Virginia: Virginia Geol. Survey Bull. 19, p. 16, 1919.

Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. 1, p. 412, 1940.

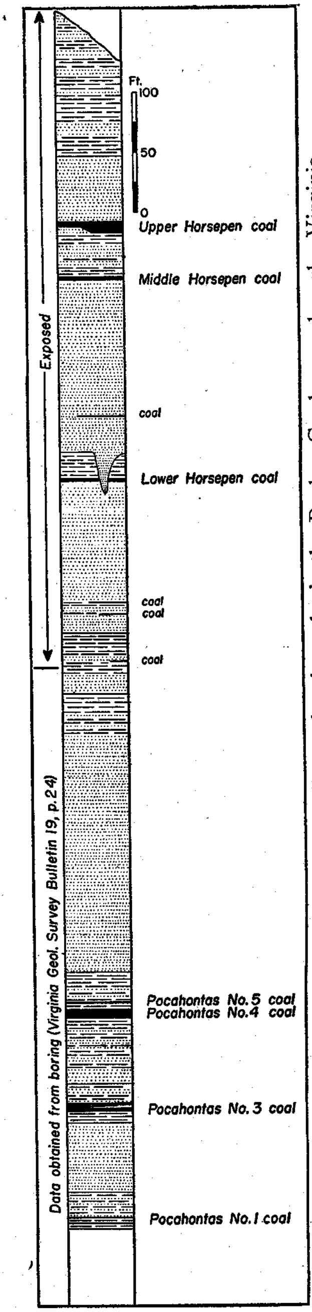

FIGURE 5.—Columnar section of the Pennsylvania rocks in the Burkes Garden quadrangle, Virginia.

feet of greenish-gray sandy shale and siltstone and blocky arkosic sandstone. The conspicuous rocky ledge near the mouth of Yokel Branch is made by arkosic beds near the base of the unit.

The next higher zone is about 130 feet thick and is composed of thick-bedded, coarse-grained arkosic sandstone which forms bold cliffs along Yokel Branch and Horsepen Creek. Two thin coal seams were noted in the lower 40 feet of the arkosic sandstone. The fresh sandstones are light-gray and somewhat mottled as a result of the kaolinization of the feldspar grains. The uppermost bed of the sandstone zone is conglomeratic.

Directly above the conglomeratic sandstone lies the "Lower Horsepen coal," a bed informally named by Harnsberger[206] from exposures half a mile south of Horsepen store. The Lower Horsepen coal averages about 30 inches in thickness and generally contains two clay partings. The maximum thickness, including partings, measured in this area is 57 inches. On the north slope of Lost Ridge, the Lower Horsepen coal rests upon a thin underclay, but nowhere else was a clay seen at the base of the coal. This coal is easily located because it crops out at the top of a thick, resistant ledge of sandstone (Fig. 5).

Above the Lower Horsepen coal is 15 to 25 feet of buff shale, some layers of which are filled with plant fossils. A thick sandstone overlies this shale zone. In some places along Horsepen Creek this shale and part of the coal have been cut by channels which are filled by this sandstone. This upper sandstone is not a good ledge-maker, nor is it as arkosic as the lower sandstone. The thickness ranges from 110 feet on Lost Ridge to 175 feet on the opposite side of the valley of Horsepen Creek.

The second sandstone zone is overlain by 20 to 50 feet of buff shales and brown mudstones, which contain thin coal streaks near the middle of the zone. A 3-foot seam of coal near the top is exposed on the west side of the low knob northwest of the mouth of Yokel Branch. Possibly, this is the bed identified elsewhere in northeastern Tazewell County as the Middle Horsepen coal.

About 40 feet of blocky, arkosic sandstones and shales occupy the 40-foot interval between the Middle Horsepen and Upper Horsepen coals. The Upper Horsepen coal of Harnsberger[207] is the thickest and most prominent coal bed in the Burkes Garden quadrangle. It is well exposed about 125 feet above the highway

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[206] Harnsberger, T. K., op. cit., pp. 49, 51, 83-89.
[207] Idem, pp. 52, 93-95.

along Horsepen Creek and north of the Boissevain fault. The maximum thickness is about 11 feet, but in some places the coal with all of the partings is not more than 4½ feet thick.

The beds above the Upper Horsepen coal are found only on the highest hills. A zone of white to buff arkosic sandstone 20 to 50 feet above the Upper Horsepen coal is the only prominent bench maker. The highest beds of the Lee formation in this quadrangle are mostly concealed by a dense growth of vegetation.

Fossils.—No marine fossils have been found in the Lee beds exposed in the quadrangle, but plant fossils are common in the beds associated with the coal. Two of the most common genera of plants are *Asterocalamites* and *Sphenopteris,* both of which occur in the Hunt member of the Bluestone formation (Mississippian), but the species are not the same.

Age and correlation.—The Lee formation is known to be early Pottsville from the occurrence in it of plant remains [208] which are found also in early Pottsville beds in the anthracite coal fields of Pennsylvania.

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[208] Butts, Charles, op. cit., pp. 412-414.

STRUCTURAL GEOLOGY

GENERAL FEATURES

The geologic structures of the rocks exposed in the Burkes Garden quadrangle (Pl. 1) are similar to those in other parts of the Appalachian Valley of southwestern Virginia. Most of the folds are asymmetrical and overturned to the northwest. Several great overthrusts, with vertical and horizontal displacements of thousands of feet, cross the area from northeast to southwest and roughly parallel the strike of the folds. Some of the larger anticlines and synclines extend for miles without cross folding or minor faulting. Severe crumpling is rather common in thick, structurally incompetent formations, particularly in the broad belt of Martinsburg west of Dial Rock. An extraordinary example of intricately folded and faulted strata is prominently displayed at the intersection of U. S. Route 19 and State Highway 61, about 1½ miles east of Tazewell (Pl. 10). The structures seen here show in miniature the characteristics of the larger, regional structures.

The area south of Brushy Mountain is a part of one great thrust block. The area between this mountain and the southeast foot of the Allegheny plateau contains parts of three similar thrust blocks. Pennsylvanian rocks in the plateau in the northwestern corner of the quadrangle are gently folded, except near the Boissevain fault, where they are vertically upturned.

Deformation of the rocks in the Appalachian region occurred during the latter part of the Paleozoic era. All of the folds and faults were not formed at the same time, but the chronological order is unknown.

SALTVILLE-BLAND OVERTHRUST

The Saltville-Bland fault is one of the principal thrusts in the southern Appalachian region. It is known[209] to extend for over 200 miles from Craig County, Virginia, southwestward to Cassard, Tennessee. It crosses the Burkes Garden quadrangle along the southeast base of Brushy Mountain (Pl. 1). Northeast of Ceres, Bland County, Virginia, this fault is a single well-defined break, along which the Copper Ridge, Nolichucky, and Honaker have been thrust over the Maccrady and Price formations. The trace of the fault is marked by a localized zone of silicified dolomite and by

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[209] Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. 1, p. 457, 1940.

concentrations of manganese and iron oxides. Several old prospects are located along the trace of the fault on the northwest side of Shewey Valley.

Two prominent breaks in the trace of the Saltville-Bland overthrust, one northeast of Sharon Springs and the other north of Effna, were interpreted by Campbell[210] to be the result of folding subsequent to overthrusting. The offset in the belt of Nolichucky shale north of Sharon Springs, which is in line with the abrupt "bend" in the trace of the Saltville-Bland fault, strongly suggests the existence of a tear fault. The other "bend" in the trace of the overthrust, north of Effna, may also be a tear fault. Very probably, the tear faults were formed during waning stages of the advance of the Saltville-Bland overthrust block. .

Northeast of Road 625 (Bland County) the general dip of the Saltville-Bland fault is about 50° SE. The overridden Mississippian rocks dip about 35° SE., whereas the overthrust Cambrian is vertical or slightly overturned.

Near the Ceres-Freestone Valley road (Road 625), the Saltville-Bland fault splits into three branches, each of which shows less stratigraphic displacement than that of the single fault north and northwest of Sharon Springs. The northernmost of the three slice faults extends along the northwest side of Brushy Mountain to the old logging road leading to the valley of Lynncamp Creek, thence it swings southward and cuts across 350 feet of "Chemung" and 1,100 feet of Brallier beds. The middle slice fault occurs about 100 feet below the crest on the northwest side of Brushy Mountain. Along it, the Clinch sandstone, dipping 45° to 55° SE., overlies the "Naples" member of the Millboro. The middle fault parallels closely the northern one and, like it, bends southward near the old logging road. The third slice fault extends along the southeast slope of Brushy Mountain and ends against the middle fault near the same road. The southern slice fault appears again one-fourth of a mile to the south and parallels the other two faults for a mile or more beyond the southern border of the quadrangle.

CERES OVERTHRUST

The main structure of the rocks in the valley of the North Fork of Holston River is anticlinal, but the fold is broken by an overthrust fault· which diverges from the Saltville-Bland overthrust

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[210] Campbell, M. R., The Valley coal fields of Virginia: Virginia Geol. Survey Bull. 25, p. 260, 1925.

about 2 miles beyond the southern border of the quadrangle. This fault was discovered only after detailed stratigraphic studies in the area south of State Highway 42, near Ceres (Pl. 1). It parallels the highway and is marked by the contact of the Copper Ridge with the Honaker. At Ceres, a lenticular slice of Nolichucky shale also has been brought up along the fault. Near the southern border of the quadrangle, the position of the Ceres fault is shown by sharp variations in the strike of the beds. (See Pl. 1). The overridden Beekmantown strikes nearly south, whereas the Honaker strikes northeast parallel to the Honaker-Beekmantown fault contact. The fault continues northeastward to a point near Sharon Springs, where it seems to die out in the Copper Ridge dolomite.

SHEWEY VALLEY ANTICLINE

Strata along the northwestern border of the Saltville-Bland overthrust are folded into an overturned anticline which was probably produced by the drag of the overthrust rocks along the fault surface (Pl. 1). The strike of the axis of the fold diverges slightly from the trace of the Saltville-Bland fault toward Ceres. Less than a mile southwest of this village, the crest of the anticline passes beneath the overthrust Honaker dolomite. The anticlinal structure is delineated by the outcropping belts of Nolichucky shale north and west of Sharon Springs. Beds on the north flank of the fold in this vicinity are overturned and their dips range from 65° SE to vertical. Those on the south flank dip 20° to 75° SE. Half a mile north of Ceres the overturned Ordovician limestones dip 45° to 80° SE.

WALKER MOUNTAIN HOMOCLINE

All of the beds southeast of State Highway 42 dip toward the southeast to form a regional homocline (Pl. 1). In Foglesong Valley, the Beekmantown and Copper Ridge dip 40° to 50° SE. Southeastward across Walker Mountain to Six Valley, the dip gradually decreases to 20°, the dip of the Brallier formation in the southeastern corner of the quadrangle. The southeast slope of Walker Mountain is a dip slope. Two shallow cross synclines are shown by corresponding bends in Walker Mountain. A much more conspicuous cross fold in the Walker Mountain homocline occurs in the "Big Bend" of the mountain, about 1½ miles beyond the southeastern corner of the quadrangle. The cross folds on Walker

Mountain were probably produced by differential compression of the rocks during overthrusting.

GREENDALE SYNCLINE

The northwestern part of the Saltville-Bland overthrust block partly covers an overturned, asymmetrical syncline in the Price and Maccrady formations (Pl. 1). This fold is one of the regional structures of southwestern Virginia and northeastern Tennessee[211]. Northwest of Ceres, the course of Lynncamp Creek follows the axis. The southeast flank of the syncline is overturned, as shown in exposures along the logging road on the southeast slope above Lynncamp Creek. Between the Ceres-Freestone Valley road and the Sharon Springs-Burkes Garden road, the overthrust Cambrian covers the southeast limb of the syncline. Northeast of Sharon Springs, where the Saltville-Bland fault swings southeast, both limbs are exposed. The valley between Brushy Mountain and the outlying ridge to the south is synclinal. Here, as in the area northwest of Ceres, the southeast limb of the syncline is overturned to the southeast.

STRUCTURES ON THE SOUTHEAST SIDE OF FREESTONE VALLEY

Lick Creek anticline.—Southwest of Mt. Victory Church in Freestone Valley, the belts of Devonian shale widen considerably as a result of minor folding (Pl. 1). Lick Creek is located on the axis of a sharp anticline in the Brallier. This structure pitches northeast and dies out near the junction of Big Branch and Lick Creek. The beds on the northwest limb are vertical; those on the southeast side dip 35° to 55° SE. The Lick Creek anticline is an *en echelon* fold on the northwest limb of the Greendale syncline.

Totten Branch syncline.—Along the road paralleling Totten Branch, the Brallier beds are folded in a shallow, asymmetrical syncline (Pl. 1), whose axis follows the crest of the low ridge between Lick and Punch and Judy creeks. The Chemung on the southeast slope of this ridge is almost vertical, whereas on the northwest side it dips only 25° SE.

Punch and Judy anticline.—Punch and Judy Creek is located on the axis of a northeast-pitching anticline in Devonian beds (Pl. 1).

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[211] Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. 1, pp. 457-459, 1940.

It is one of the few symmetrical structures in the quadrangle, with prevailing dips of 25° on either limb. The fold dies out to the northeast near the Bland-Tazewell county line.

Little Brushy Mountain syncline.—The major fold in the shale belts of Freestone Valley is a broad shallow syncline delineated by the elbow in Little Brushy Mountain (Pl. 1). Brallier beds flanking the lower slopes dip into the mountain at angles of 15° to 20°. The Price sandstones on the upper slope dip somewhat less than 15°. The fold dies out in the Brallier shale near the Bland-Tazewell county line.

BURKES GARDEN DOME

General features.—Burkes Garden is one of the best examples of a dome in the southern Appalachian region (Pl. 1). It is almost completely rimmed by Garden Mountain, a high ridge made by Clinch sandstone. The Clinch and Juniata on the south side of the valley dip about 23° SE. On the northwest side in Mill Gap, the same beds dip about 28° NW. At the northeast and southwest ends of the valley, the Clinch and Juniata dip away from Burkes Garden at angles of 10° to 23°. East of Burkes Garden and beyond the eastern limit of the quadrangle, the dome narrows into a northeast-pitching anticline of Silurian and Devonian beds. U. S. Route 52 skirts the end of this structure about 10 miles east of Burkes Garden. Beartown, west of Burkes Garden, is the only part of the original dome of Silurian sandstone which has not been removed by erosion. If the original dome were restored so that the Clinch sandstone formed the crest of the fold, there would be a broadly rounded, symmetrical mountain rising to an elevation of about 6,500 feet. The Ordovician rocks exposed on the floor of Burkes Garden are more complexly folded. Most of the anticlines and synclines in the Ordovician beds probably merge upward into the dome of Clinch sandstone.

Banks Ridge anticline.—The most conspicuous structure on the floor of Burkes Garden is an anticline which is marked topographically by a low wooded ridge known as Banks Ridge (Pl. 1). Dips on either flank of this fold are shown along State Highway 78. Near Central Church the Beekmantown dips about 20° NW.; 1½ miles southeast along the same road the Blackford member of the Cliffield dips 15° to 20° SE. The crest is marked by flat-lying Beekmantown beds exposed about one-fourth of a mile east of State Highway 78. The anticline dies out in the vicinity of the road which skirts the eastern part of the valley floor. On the southwest, the anticlinal structure continues through Heninger Gap and dies out in the Juniata formation on the northwest slope of Chestnut Ridge. Below the lookout tower on Chestnut Ridge, tributaries of Roaring Fork have stripped off the Juniata to expose inliers of Martinsburg shale.

Blue Spring syncline.—Southwest of Central Church the Middle Ordovician limestones are folded into a sharp syncline which pitches southwest (Pl. 1). Along its southeast flank the beds dip 50° to 80° NW., but on the other flank they dip only 5° to 15° SE. The asymmetry of the syncline is less distinct. The dip slope descending from Beartown to Roaring Fork has been dissected by numerous tributaries of Roaring Fork into bold facets or flatirons. Cove Branch has cut deep enough to expose a large inlier of Martinsburg shale.

Castle Farm anticline.—In the northwestern end of Burkes Garden the Benbolt, Gratton, Wardell, Witten, and Moccasin beds are warped into a low anticline which causes the relatively thin Benbolt to crop out over an unusually large area (Pl. 1). This fold plunges beneath the surface at the base of Hall Ridge, and on the northeast the fold dies out west of State Highway 78. The structure is best shown in the vicinity of Castle farm, along Station Spring.

Other structures.—In the vicinity of Burkes Garden Post Office and for a distance of a mile east of State Highway 78, the Cliffield and Benbolt formations are approximately horizontal, but in a number of localities the surface beds dip slightly in different directions. Solution of some of the limestones has been accompanied by slumping of the surficial rocks.

THOMPSON VALLEY ANTICLINE

The Thompson Valley anticline, northwest of Clinch Mountain and Beartown, heads into the divide between Burkes Garden and Thompson Valley. Only the northeast end of the fold is shown on Plate 1, but it extends southwestward for 18 miles to the head of Ward Cove in western Tazewell County. Beds on the northwest flank of the anticline dip 40° to 90° NW., whereas the southeast flank shows dips of 25° to 45° SE. The arch is well shown along the road north of the 2,822-foot bench mark, where a sandstone at the top of the Copper Ridge is repeated. The northeast end of the Thompson Valley anticline is separated from the Burkes Garden dome by a structural saddle, on which are located Hutchinson Rock and the divide between Burkes Garden and Thompson Valley. The Burkes Garden dome and Thompson Valley anticline are examples of numerous en echelon structures developed on the northwest side of the Clinch Mountain homocline in Virginia.

WOLF CREEK SYNCLINE

Immediately north of Burkes Garden and Thompson Valley is a relatively symmetrical, upright syncline which opens northeastward down the valley of Wolf Creek (Pl. 1). Near the western border of the quadrangle the synclinal axis is marked by Rich Mountain. The fork in the mountain at the head of Little Valley denotes the opening of the syncline to the northeast. The fold is constricted locally by a cross fold near the Bland-Tazewell county line. East of the county line, the syncline broadens abruptly. The axis is well shown (Pl. 16D) in a small quarry along Road 614 near Grapefield School. The white sandstone near the top of the Rose Hill formation, exposed along State Highway 78 and also along the road east of Crabtree Gap, dips northwestward, whereas the other beds on the southeast slope of Rich Mountain dip steeply to the southeast. If the northwest-dipping sandstones indicated minor folding on the northwest flank of the Wolf Creek syncline, the belt of Rose Hill would be wider. Where the northwest dips were observed, the belt of outcrop of the Rose Hill is so narrow that scarcely all of the formation could be present between the mapped boundaries, even if the beds were dipping at right angles to the slope of the mountain. Therefore, a minor fault is thought to be present within the belt of the Rose Hill. Minor folding in the Silurian and Lower Devonian formations is shown near the junction of Hemppatch Branch with Wolf Creek. In Bland County, the opposing sides of Rich and Garden mountains are dip slopes. West of the Bland-Tazewell county line the beds on the southeast side of Rich Mountain dip considerably steeper than the slope.

GRATTON ANTICLINE

The general structure of the area between Rich and Buckhorn mountains is anticlinal (Pl. 1). Along Buckhorn Mountain, the northwest flank of the Gratton anticline is vertical or overturned to the southeast. Along the northwest slope of Rich Mountain the Ordovician limestones dip 25° to 65° SE. An anticline of Beekmantown makes the low ridge which extends down the middle of the valley of the South Fork of Clinch River. The crest of the fold is shown by horizontal beds of Beekmantown limestone, about one-fourth of a mile west of Marys Chapel. The Gratton anticline narrows toward Tazewell, but opens again southwest of town and extends into Russell County. Less than a mile west of Marys Chapel minor folds occur on the south limb of the anticline. North of the Tazewell County Farm, the crest of the Gratton anticline is broken by a normal fault, along which the Ward Cove limestone member of the Cliffield on the downthrow side is in contact with the Beekmantown. A minor syncline in the upper Beekmantown and lower Cliffield near the fault causes the relatively thin basal clastics of the Cliffield to crop out over a wide area. The northwest flank of the Gratton anticline is broken by the Narrows fault which ends near Benbolt. Near the west border of the quadrangle the beds on the northwest flank of the fold are vertical, as shown along State Highway 61 north of Benbolt. Northeastward, where displacements along the Narrows fault are greater, the northwest flank of the anticline is overturned to the southeast.

NARROWS OVERTHRUST

The Narrows fault extends along the southeast flank of Buckhorn Mountain and dips approximately 45° SE. In Clear Fork Valley, the northwest margin of the Narrows overthrust block is broken by minor faults which branch pinnately from the main rupture (Pl. 1). Some of the included slivers between the main fault and branch faults are parts of the overthrust block, but others seem to have been dislodged from the tread of the overridden block and pushed up with the overthrust rocks. Northeast of Cove Creek two closely parallel faults occur; one between the Rose Hill and Martinsburg, and the other between the Moccasin and Honaker formations. Southwest of Cove Creek another fault splits off the main break but joins it again north of Kinzer Church. The south branch diverges from the faults on the north and cuts diagonally across the strike of the Ordovician limestones. The succession of faulted beds on the southeast side of Buckhorn Mountain is best shown along Perry Branch. The first fault encountered going upstream is marked by the contact of the Honaker with the *Camarocladia* beds of the Witten limestone. Farther north, the middle fault is shown by the contact of the lower Martinsburg with the *Mastigobolbina lata* zone of the Rose Hill. The third fault is shown by the contact of the Rocky Gap and Huntersville with the upper Martinsburg.

The faulted slice composed of Silurian and Devonian beds was probably broken off the overridden block.

EAST RIVER MOUNTAIN SYNCLINORIUM

General statement.—East River and Buckhorn mountains outline a broad rugged tract underlain by complexly folded Ordovician, Silurian, and Devonian formations (Pl. 1). As shown along Road 662 crossing Nye Cove, the general structure is synclinal. The same general structure extends northeastward to New River, Giles County, Virginia, and southwestward across Tazewell County to Cedar Creek, Russell County, Virginia.

Structure of Buckhorn Mountain.—West of the meridian of Kinzer Church, Buckhorn Mountain is made by a faulted syncline of the Juniata, Clinch, and Rose Hill formations. Both limbs and the trough of the fold are well displayed at the west end of the mountain, but less than one-fourth of a mile northeast the southeast limb of the fold has been cut off by the Narrows fault. From this point northeastward to Kinzer Church the ridge is made by southeast-dipping Clinch and Rose Hill sandstones. East of the gap in Buckhorn Mountain north of Kinzer Church, the ridge is made by another belt of Clinch and Rose Hill which dips 50° to 90° SE. West of Perry Branch the mountain swings abruptly north, across the strike of the Rose Hill, Cayugan, Rocky Gap, and Huntersville formations. Farther northeast the mountain is made by a narrow belt of vertical Clinch sandstone which is exposed in the west bluff of the gorge of Cove Creek through Buckhorn Mountain. Less than half a mile east of this gorge, the belt of vertical Clinch is cut off by the Narrows fault. East of Cove Creek, Buckhorn Mountain is made by an anticline of Rose Hill sandstones and conglomerates, some of which closely resemble the Clinch. This anticline has been deeply eroded in the gorge of Cove Creek, where a symmetrical arch of Clinch sandstone is well displayed along the road through the gorge (Pl. 1).

Cox Branch anticline.—A sharp anticline in the rocks immediately north of Buckhorn Mountain causes the Martinsburg formation to be exposed along Cox Branch. This fold persists westward into the cove between Short Ridge and Buckhorn Mountain and northeastward beyond the head of Cox Branch (Pl. 1).

Dial Rock syncline.—North of the Tazewell reservoir, the Clinch and Rose Hill formations are repeated in a narrow syncline (Pl. 1). This fold splits into two branches, one of which makes Dial Rock and the other Short Ridge. The cove between these ridges is anticlinal. The Dial Rock syncline continues northeastward for 4 miles to the divide between Cox Branch and Mudley Branch. The cliff of Clinch sandstone on Dial Rock is on the southeast flank of the structure.

Chimney Rock anticline.—The crest of East River Mountain south of Springville is made by an anticline of Clinch sandstone (Pl. 1). The fold persists westward through the cove between Havens Spur and Dial Rock, and extends northeastward along Chestnut Ridge. The east end of this ridge is a pitch slope which marks the eastern end of the anticline. Erosion of the dip slopes on either side of the crest of the anticlinal ridge has exposed inliers of Juniata. Chimney Rock is a conspicuous flatiron a short distance below the crest of East River Mountain south of Springville.

Havens Spur syncline.—Havens Spur forms part of an asymmetrical syncline of Clinch and Rose Hill sandstones, developed on the northwest flank of East River Mountain (Pl. 1). Below Chimney Rock, the beds on the southeast flank of the fold dip 50° to 70° NW. The lower limb of the fold, shown by the bluffs of Clinch sandstone near the base of the mountain, dips 30° to 40° SE. The Havens Spur syncline is almost an exact duplicate of the Dial Rock syncline on the other side of East River Mountain. The fold dies out along East River Mountain south of Bluestone School.

Nye Cove syncline.—Nye Cove, comprising the wooded lowlands along the forks of Cove Creek, is a syncline of Millboro shale (Pl. 1). The southeast flank of the syncline is complexly folded, so that the Rocky Gap and Huntersville formations are repeated. One of the folds is isoclinal, which causes the Cayugan to be repeated. In the eastern half of the cove, the Nye Cove syncline is split into two parts by an anticlinal nose of Rose Hill sandstone. The south part of the syncline is a close fold with vertical dips on either flank.

Big Ridge anticline.—On the east, Nye Cove heads against a broad, irregular cross fold of Silurian sandstone, which makes Big Ridge (Pl. 1). This mountain is bordered on all sides by dip slopes. A nose of the Big Ridge anticline extends down Adz Ridge, an east-west spur of Big Ridge, and splits the Nye Cove syncline into two parts.

Structures west of Dial Rock.—The wide belt of Martinsburg shale beyond the west end of East River Mountain is synclinal, but the general structure is complicated by crumpling (Pl. 1). Road cuts at the intersection of U. S. Route 19 and State Highway 61 show some of the finest examples of flowage folds and drag folds in the southern Appalachian region (Pl. 10). Similar but less spectacular folds in the Martinsburg are seen in cuts along U. S. Route 19 nearer Five Oaks.

PUCKETT HOLLOW ANTICLINE

The Cambrian and Ordovician formations northwest of East River Mountain are folded into a broad anticline which is broken on the northwest side by the St. Clair overthrust (Pl. 1). The anticlinal structure is evident along all of the roads crossing the belts of Nolichucky and Honaker, north of U. S. Route 19. The best exposure of the crest of the fold is along the Norfolk and Western Railway. The northwest limb of the anticline is steeply overturned to the southeast, from the western border of the quadrangle, northeastward to a point three-quarters of a mile south of Tiptop. Northeast of the road from Bailey to U. S. Route 19, the northwest limb is cut off by the St. Clair fault. North of Wittens Mills, the anticline is broken by minor faults, along which the upper beds of the Rome have been thrust upon lower Honaker.

The same general anticlinal structure persists northeastward beyond the eastern border of the quadrangle, but is complicated by minor folding and faulting.

DILLS SPRING ANTICLINE

The broad belt of Ordovician limestones south of Bluefield, Virginia, is an anticline complicated by minor crumpling and faulting (Pl. 1). Along one fault, well shown near Dills Spring, the upper beds of the Beekmantown have been thrust upon the Blackford member of the Cliffield. Along another minor fault, the lower members of the Cliffield have been thrust upon the Gratton.

SAUNDERS FARM SYNCLINE

Immediately south of the St. Clair fault, in the vicinity of the Saunders farm[212], the Ordovician rocks are folded in a syncline which is terminated on the south by a minor overthrust fault (Pl.

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[212] The Saunders farm is located at the intersection of Road 650 and State Highway 85, about 1 mile south of Bluefield.

1). Northeast of the Saunders farm, slice faults which split from the St. Clair overthrust enclose a narrow wedge of the Beekmantown and lower Cliffield.

ST. CLAIR OVERTHRUST

The St. Clair overthrust (Pl. 1), first described by Campbell[213], was named from St. Clair Station on the Norfolk and Western Railway, about 2½ miles southwest of Bluefield, Virginia. In the western half of the quadrangle, the St. Clair fault is a single break along which the Honaker has been thrust over the Brallier formation. The dolomite next to the fault has been silicified and local concentrations of manganese and iron oxides occur along the sole of the overthrust block. Fault breccia, found in a few places along the fault west of the meridian of Bailey, is composed of pieces of chert imbedded in a matrix of manganese and iron oxides.

Northeast of Bell Hill, a branch of the St. Clair overthrust cuts across the belts of dolomite and rejoins the main fault near the Saunders farm. Manganiferous chert breccia occurs along this fault as far northeast as U. S. Route 19. The St. Clair fault closely parallels State Highway 85 from the Saunders farm eastward to the border of the quadrangle. Shales and sandstones of the Rose Hill formation are exposed on the north side of the highway, whereas Ordovician limestones crop out on the south side. Minor slice faults diverge from the main fault near the eastern border of the quadrangle.

The bends in the fault trace north of Dills Spring are reflections of primary irregularities on the sole of the overthrust mass. East of St. Clair, the overthrust rocks have overridden a huge projection of autochthonous rocks, which rises above the general surface of the tread of the overridden block. Possibly the added resistance which this projection offered to movement of the overthrust mass accounts for the shearing and crumpling of the overthrust limestones exposed south and east of the Saunders farm.

The best exposure of the fault contact is along the Norfolk and Western Railway a short distance south of Wrights Valley. A fine exposure of the tread of the overridden block occurs along State Highway 85 opposite the Saunders farm. The sheared and macerated beds exposed here are part of the Rose Hill formation.

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[213] Campbell, M. R., U. S. Geol. Survey Geol. Atlas, Pocahontas folio (No. 26), p. 4, 1896.

In the vicinity of Tiptop the fault dips about 25° SE., but elsewhere in the quadrangle the dip of the St. Clair overthrust is 45° to 60° SE. The south branch of the overthrust, which passes by Dills Spring, dips 60° to 80° SE.

HURRICANE RIDGE SYNCLINE

The Hurricane Ridge syncline was named by Reger[214] who mapped the structure in adjacent parts of West Virginia. The southeast limb of this syncline abuts against the St. Clair fault and is steeply overturned (Pl. 1). North along State Highway 85 from the Saunders farm to Bluefield the beds dip 45° to 85° SE., as a result of overturning. The lower dips are found in the Rose Hill formation close to the fault. Overturning of the southeast limb of the syncline is more pronounced farther southwest. Along Road 656 from Bailey to Mud Fork Valley, all the beds up to the Pennington atop Stony Ridge dip southeast. The axis of the syncline is between the two southeast-dipping belts of Hunt coal, in the vicinity of the Stony Ridge mine. Southwestward, the axis extends along the northwest slope of Stony Ridge midway between the crest of the ridge and Mud Fork. From a point one mile east of Mud Fork village to the eastern border of the quadrangle, the Glady Fork sandstone on the northwest flank of the fold makes a number of prominent flatirons.

ABBS VALLEY ANTICLINE

The Mississippian beds in Abbs Valley are folded in a sharp anticline (Pl. 1). The oldest exposed beds are "Gasper" and "Ste. Genevieve" limestones which crop out in the bottom of the valley. Part of the northwest limb is concealed by faulting. Nearly all the beds northwest of the axis are vertical. Dips on the southeast flank range from 80° in the Mississippian limestones to about 25° on Abbs Valley Ridge.

RICHLANDS AND BOISSEVAIN FAULTS

Severe compression of the Abbs Valley anticline resulted in the formation of a rupture far down on the northwest flank of the fold (Pl. 1). The trace of this break has been followed from the vicinity of Boissevain in Tazewell County, southwestward beyond

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[214] Reger, D. B., Mercer, Monroe, and Summers counties: West Virginia Geol. Survey, County Reports, pp. 146-149, 1926.

the Tazewell-Russell county line. Movements along the Boissevain fault failed to relieve the compressive stresses, and another thrust, the Richlands fault, developed high on the northwest limb of the Abbs Valley anticline. The Pennington beds between the two faults are crumpled and sheared. The Richlands fault dies out one-fourth of a mile south of Laurel School (Pl. 1).

POCAHONTAS SYNCLINE

Northwest of the Boissevain fault the Pennsylvanian beds are warped into a broad asymmetrical syncline (Pl. 1). Drag along the thrust has upturned the overridden Pennsylvanian beds near the fault, but less than one-fourth of a mile north of the fault trace the coal-bearing beds are nearly horizontal. The Pocahontas syncline pitches southwestward about 75 feet per mile. The only parts of the structure in the limits of the Burkes Garden quadrangle are the vertical southeast limb and the trough. Northeast and southwest of this quadrangle, the Pocahontas syncline yields large quantities of high-grade bituminous coal. The southwest pitch of the syncline is a structural feature of great economic importance, because it has made possible the construction of a tunnel which drains enormous deposits of coal in the Pocahontas coal field.

GEOMORPHOLOGY

GENERAL FEATURES

The Burkes Garden quadrangle embraces segments of the major drainage divides between the New and Tennessee and the New and Sandy rivers. These rivers empty into the Ohio; the New (Kanawha) near Point Pleasant, West Virginia; the Sandy at Kenova, West Virginia; and the Tennessee at Paducah, Kentucky. Areas to the east of the New-Tennessee divide are drained by Walker and Wolf creeks and Bluestone River, all of which empty into New River. The area on the west side of this divide is drained by Holston and Clinch rivers. Horsepen Creek, tributary to Sandy River, drains a small area in the northwest part of the quadrangle. The distance from the divides to the Gulf of Mexico is approximately 2,025 miles by way of Clinch River, about 2,050 miles by way of New River, and approximately 1,850 miles by way of Sandy River[215]. The drainage basin of Sandy River is enlarging at the expense of the New and Tennessee river systems. Drainage at the head of Abbs Valley, which was formerly into the Bluestone River, now flows into Horsepen Creek. About 12 miles southwest of the village of Mud Fork, the divide between the Sandy and Clinch is being shifted southeastward. Farther southeastward migration of the headwaters of the Big Sandy for only 1½ miles will result in the diversion of Clinch River above Maxwell, Tazewell County, Virginia. Until this major piracy takes place, the divide between New and Clinch rivers will not be shifted appreciably.

Because of its location at the headwaters of three major drainage systems, the general altitude of the Burkes Garden quadrangle is greater than that of most other comparable areas in the Appalachian Valley and Ridge province.

PREVIOUS INTERPRETATIONS

According to most geologists, the topography of the Appalachian Valley and Ridge province bears impressions of several erosion cycles. After its general emergence during the Appalachian revolution at the close of the Paleozoic era, the Appalachian region is believed to have been uplifted repeatedly. The successive uplifts were separated by relatively long periods of crustal stability during

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[215] Distances from the divides to the Gulf of Mexico were obtained from data furnished by the United States Geological Survey.

which streams reduced the general altitude and relief of the region. According to the generally accepted view, long-continued erosion of a stable region by running water would form an extensive surface of low relief approximately that of sea level. Such a surface is commonly called a peneplain[216], that is, almost a plain.

According to one interpretation, the Appalachian region was reduced to a peneplain in late Mesozoic time. On this surface, which beveled hard and soft rocks, the major streams shifted their courses without regard to the resistance of the bedrock. Subsequently, the region was elevated and the drainage rejuvenated. The uplift was sufficiently slow for the master streams to maintain their courses. Eventually, the less resistant rocks were eroded to a surface of low relief, but those parts of the old uplifted peneplain which were underlain by the most resistant rocks, were reduced only slightly. Hence, the peneplain remnants were preserved on the linear, sandstone ridges whereas the areas underlain by softer rocks, such as shales and limestones, became parts of the younger erosion surface developed at a lower level in the second cycle. This region, characterized by broad valleys and intervening generally narrow, even-crested ridges, was subjected to another uplift. Parts of the old valley floors were cut away as a system of new valleys was developed at a third and lower level. A third uplift caused the main streams to entrench themselves in the second set of valley floors. This last rejuvenation has been so recent geologically that stream entrenchment has not worked headward to the main divides.

Some of the previously published work which elaborates upon this general interpretation of the erosional history of the Appalachian Valley refer specifically to the Burkes Garden area. Campbell[217], interpreting the surface features of the Pocahontas quadrangle, which includes the Burkes Garden area, states:

> "In the Appalachian province there are remnants of peneplains which indicate two periods of relative stability of the surface of the earth. The exact time at which these features were formed is not known, but their relation to the sediments around the margin of the province serves, in a general way, to fix their ages. The earlier and more extensive peneplain was formed in the Cretaceous period. During a very long epoch of erosion without

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[216] Davis, W. M., Topographic development of the Triassic formation of the Connecticut Valley: Am. Jour. Sci., 3d ser., vol. 37, pp. 423-434, 1889; The peneplain, Am. Geologist, vol. 23, pp. 207-239, 1899.

[217] Campbell, M. R., U. S. Geol. Survey Geol. Atlas, Pocahontas folio (No. 26), p. 1, 1896.

marked uplift the surface was worn down to an almost featureless plain. This period of tranquility was interrupted by gradual earth movements which extended over most of the province and which raised the surface far above its former position, but the elevation was unequal and the plain was warped. In the Eocene and Neocene periods other peneplains were formed, but the time during which the relation of the land and the sea remained constant was short, and only the softer rocks were worn down nearly to the baselevel of erosion. Again the process of baseleveling was terminated by an uplift which affected the entire province and which warped the latter peneplains in a manner similar to the warping of the Cretaceous plain.

"The more recent history of the province is one of general elevation by oscillations, which have caused the margin of the sea to vary in different portions of the epoch. During this time the modern river gorges were cut and much of the low-level topography was produced.

" . . . the surface was reduced to the level of the Cretaceous peneplain, except a few of the higher summits which now stand from 3,300 to 4,200 feet above sea-level. Clinch Mountain, west of Burkes Garden, is the most conspicuous of these high points and in Cretaceous time probably constituted a ridge rising 500 to 700 feet above the plain. The highest summits of East River and Big Walker mountains also probably stood in low relief above this plain, the surface of which is represented by portions of the crest-line of . . . Big Walker, Brushy, Rich, and East River mountains . . .

"Although raised to a considerable elevation by the uplift that warped the Cretaceous peneplain, the Pocahontas district, located upon the principal divide of the Appalachian Valley, was so far removed from the main drainage lines that its surface was subsequently carved into valleys and ridges only. The hills were not planed away during Neocene time, although the valleys in the southern part of the area were probably slightly widened; but even there there is no definite plain remaining. North of East River Mountain a peneplain is recognizable in the gently rolling surface which stands at an elevation of about 2,600 feet. Standing above and nearly separated from the plain are several elevations which in some manner have been protected more than the surrounding areas and remain as *monadnocks,* or unreduced remnants of a once greater altitude of land.

> " . . . The total uplift since Cretaceous time has been from 3,000 to 3,500 feet, the sum of the two general movements, of which the later was 2,600 feet. Besides the general peneplains described above, this region possesses a well-developed local baselevel, entirely independent of the general surrounding conditions. This is Burke[s] Garden, a unique feature, a garden in a wilderness of sharp ridges and narrow valleys. It is a limestone area surrounded by mountainous walls of hard sandstone. Wolf Creek has cut a gorge on its northern side, through which its surplus waters are discharged, but the removal of the calcareous rocks within the barrier progresses as fast as the creek can cut its gorge; hence the floor of the garden is planed to the level of the outlet of the draining stream."

Summarizing the above statements, Campbell believed in the existence of (1) an ancient (Cretaceous) peneplain marked by monadnocks and having certain existing remnants, namely, ridge crests ranging in altitude from 3,300 to 4,200 feet; (2) a later erosion surface resulting from rejuvenation and dissection of the belts of softer rocks; and (3) more recent entrenchment of the main drainage lines as a result of another uplift.

Stose[218] has discussed the general features of the topography of western Virginia. He recognizes: (1) a summit peneplain, which has been greatly eroded and whose exact level can not be determined, with remnants preserved on some ridge crests at altitudes of 3,500 to 4,000 feet; (2) an upland peneplain, remnants of which are ridge crests ranging in altitude from 3,000 to 3,500 feet; (3) an intermediate peneplain, marked by still lower ridges and foothills along the bases of the higher ridges; (4) one or more valley-floor peneplains which are indicated by the general level of the principal valleys and minor hills on the valley floors; and (5) still younger, narrow terraces and benches at variable levels below the valley-floor peneplains. According to Stose, the summit peneplain antedates the late Jurassic or early Cretaceous peneplain which he called the upland peneplain; the intermediate peneplain is Middle or Late Cretaceous; the valley-floor peneplains are early Tertiary; and the benches and terraces along the main drainage lines are Pleistocene. The highest knobs and ridges in the Burkes Garden quadrangle, such as, Big Ridge east of Nye Cove, the summit of East River Mountain near Chimney Rock and the mountain rimming Burkes

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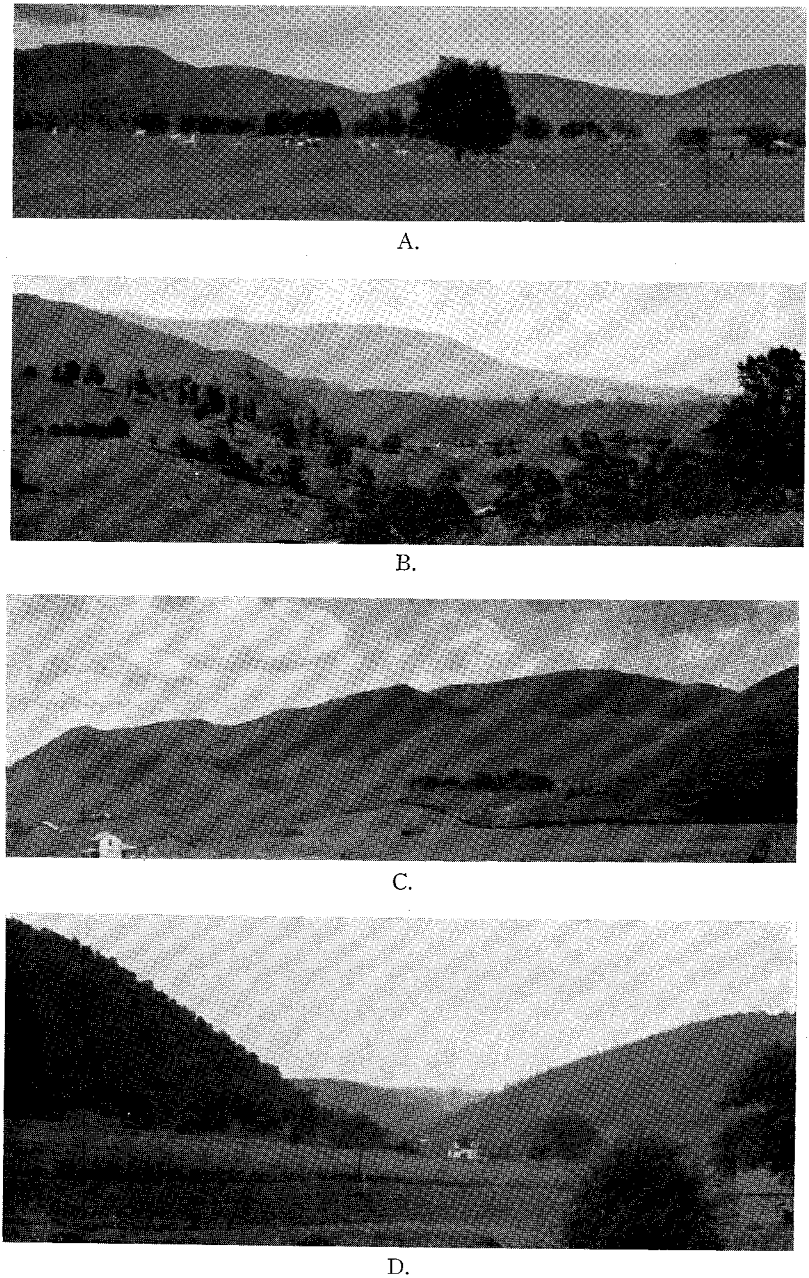
[218] Stose, G. W., Physiographic forms, *in* Manganese deposits of western Virginia: Virginia Geol. Survey Bull. 23, pp. 16-24, 1922.



A, Hutchinson Rock from the floor of Burkes Garden. B, Southwest toward "The Peak," at west end of Rich Mountain. (Photograph by J. K. Roberts.) C, Havens Spur, Dial Rock, and Short Ridge (from left to right) at the west end of East River Mountain. D, Mill Gap from the floor of Burkes Garden.

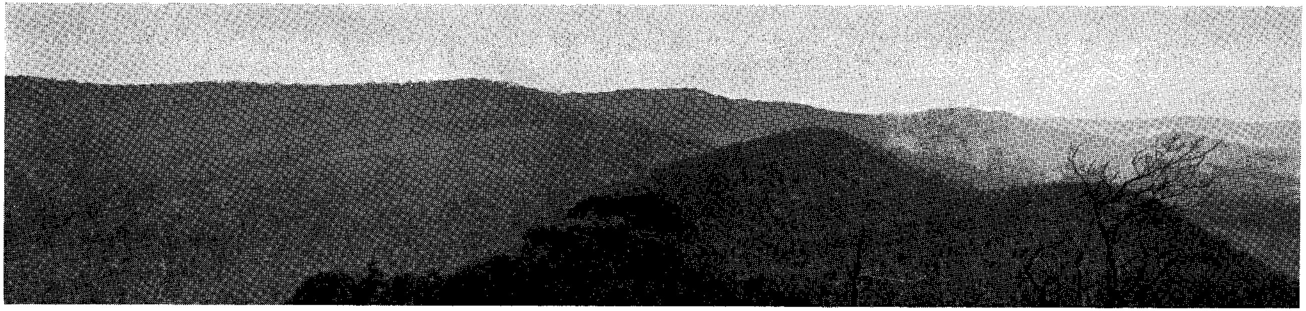
A.

B.

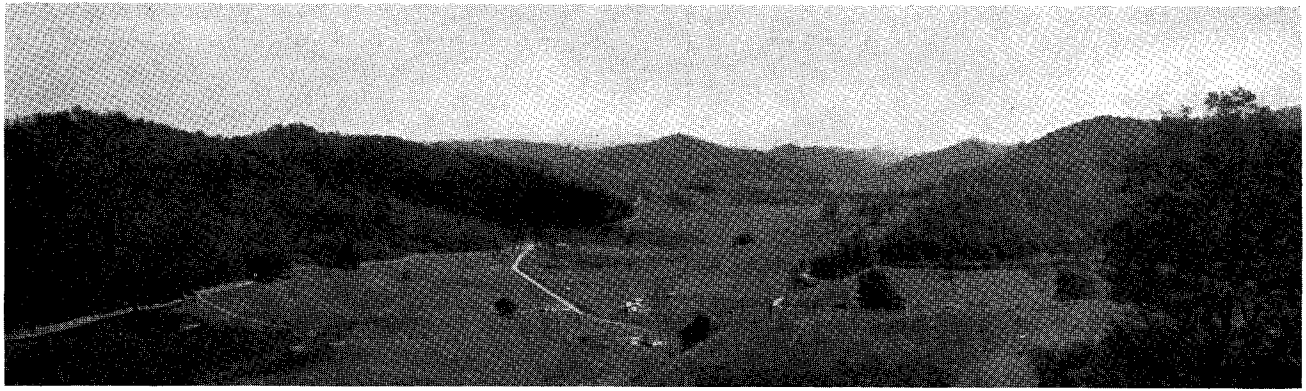
C.

D.

A, Hutchinson Rock from the floor of Burkes Garden. B, Southwest toward "The Peak," at west end of Rich Mountain. (Photograph by J. K. Roberts.) C, Havens Spur, Dial Rock, and Short Ridge (from left to right) at the west end of East River Mountain. D, Mill Gap from the floor of Burkes Garden.

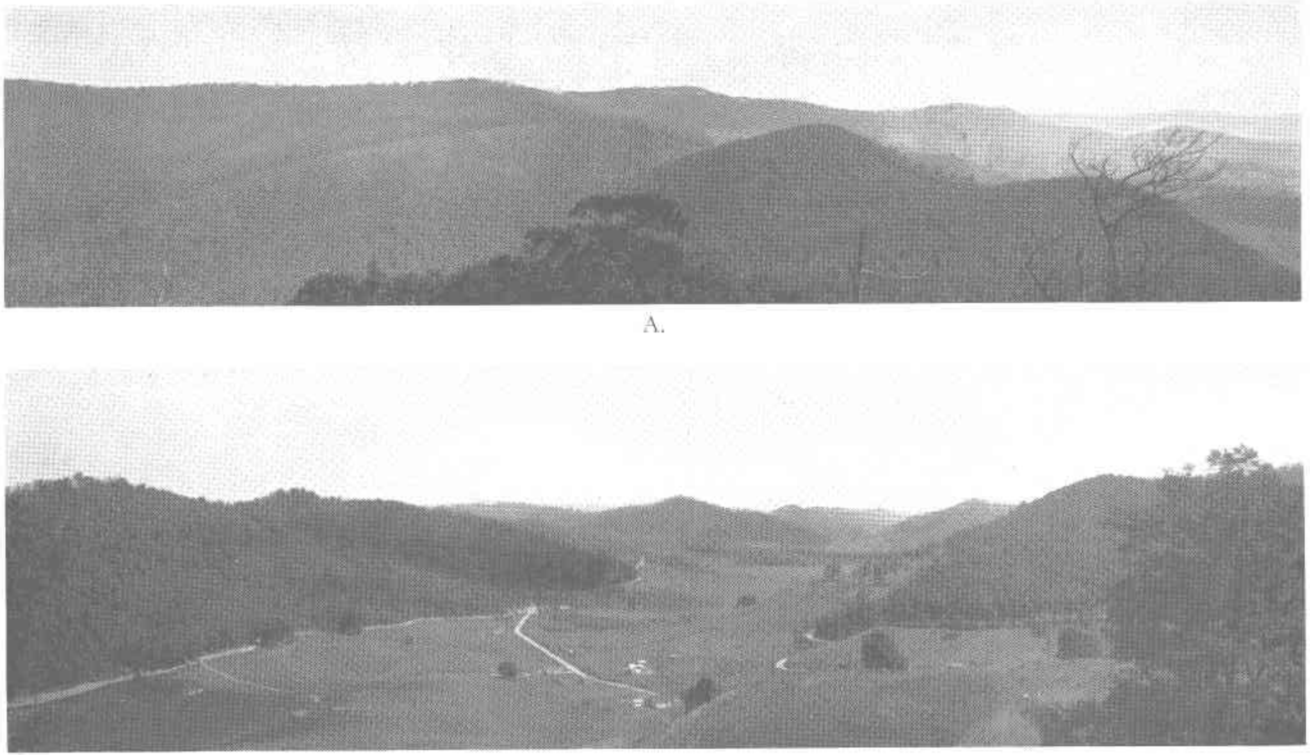


A.



B.

A, Beartown, looking northwest from the fire tower on Chestnut Ridge. B, Abbs Valley, looking northeast from the fire tower on Abbs Valley Ridge.



A.

B.

A, Beartown, looking northwest from the fire tower on Chestnut Ridge. B, Abbs Valley, looking northeast from the fire tower on Abbs Valley Ridge.

Garden would probably be considered remnants of the summit peneplain of Stose. The crests of the lower ridges, including Walker, Brushy, Rich, Buckhorn, and East River mountains would be referred to the upland peneplain. Minor ridges such as Stony Ridge and Abbs Valley Ridge, would be considered remnants of the intermediate peneplain. All, or nearly all, of the features at lower altitudes would be included with the valley-floor peneplains.

Wright[219] mentions some of the geomorphic features of the Burkes Garden quadrangle as they relate to the regional geomorphology of the southern Appalachian region. He interprets the more or less even crests of Walker, Brushy, Garden, Clinch, Rich, Buckhorn, and East River mountains as remnants of the Schooley peneplain. The only other peneplain Wright recognizes in this area is the younger Harrisburg surface which is essentially the same as the valley-floor peneplain of Stose. The approximate elevation of this peneplain is inferred by Wright to be somewhat above the limestone floors of the valleys and somewhat below the tops of minor ridges upheld by shale and cherty dolomite. Wright interprets the general level of the limestone areas to be the result of post-Harrisburg erosion.

Butts[220] recognizes three peneplains. The highest peneplain remnants he assigns to a summit peneplain. Presumably such prominences as Beartown (Pl. 19A), and Big Ridge, east of Nye Cove, would be parts of this erosion surface. He refers the higher ridges, with altitudes of 2,500 to 3,500 feet, to the Schooley level. The Harrisburg, or valley-floor, peneplain is represented by the broad, undulatory surfaces below the ridges. In the Burkes Garden quadrangle, areas with altitudes ranging from 2,500 to 2,750 feet, and locally 3,100 feet in Burkes Garden, are remnants of the Harrisburg surface. According to Butts, the summit peneplain may have been completed by the end of the Jurassic, the Schooley level by the close of the Cretaceous, and the Harrisburg surface during the late Tertiary.

Shaw[221], Ashley[222], and Knopf[223] have expressed doubts of the existence of any remnants of erosion surfaces as old as the Cretaceous.

Johnson[224] has developed a clear and engaging picture of a possible origin of such rivers as the Susequehanna and Potomac, which cross the

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[219] Wright, F. J., The newer Appalachians of the South, part 2; South of the New River: Denison Univ. Bull., Jour. Sci. Lab., vol. 31, art. 3, pp. 93-142, 1936.

[220] Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. 1, pp. 505-511.

[221] Shaw, E. W., Ages of peneplains of the Appalachian province: Geol. Soc. America Bull., vol. 29, pp. 575-586, 1918.

[222] Ashley, G. H., Age of the Appalachain peneplains: Geol. Soc. America Bull., vol. 41, pp. 695-700, 1930.

[223] Knopf, E. B., Correlation of residual erosion surfaces in the eastern Appalachian highlands: Geol. Soc. America Bull., vol. 35, pp. 633-668, 1924.

[224] Johnson, D. W., Stream sculpture of the Atlantic slope; a study of the evolution of Appalachian rivers: Columbia Univ. Press, 142 pp., 1931.

Appalachian province in seemingly anomalous courses. According to his interpretation, the present courses of the southeast-flowing streams were developed long after the formation of an ancient peneplain. This erosion surface subsided below sea level and was covered with Cretaceous sediments. The region was later raised and tilted to the east. Streams developed on the Cretaceous mantle without any relation to the kind and structure of the buried rocks. Continued uplifts enabled the streams to cut through the cover of Cretaceous sediments. Thus the drainage was superimposed on the beveled, folded Paleozoic strata in the Appalachian Valley.

The tangible evidence in support of this hypothesis is not impressive. The postulated Cretaceous cover, if it ever existed, has been removed. Some of the southeast-flowing streams, particularly the James and Potomac[225], show rather marked adjustment to structure and relative resistance of the bedrock—a condition hardly in keeping with the concept of regional superposition evolved by Johnson.

Meyerhoff and Olmstead[226] have presented evidence to show that the "modern drainage on the Atlantic slope has evolved, directly and without benefit of Cretaceous marine sedimentation, from the initial fluvial systems which drained the Appalachian Mountains immediately after they were folded in Permian time." They believe that the evolution of the present drainage lines is largely the result of "competitive erosion upon rocks which differed greatly in resistance, and upon structures which have shifted and changed radically as dissection has burrowed ever deeper into the foundations of the mountain system." They do not rule out the hypothesis of superposition but believe that the process was local and that it could have been accomplished by stream penetration of thrust sheets or the limbs of strongly overturned folds. They postulate also that the streams took advantage of every kind of structural weakness in acquiring their present courses.

Ashley[227] has shown how existing transverse structures have influenced the courses taken by the master streams which cut through Kittitany Mountain in Pennsylvania.

Thompson[228] believes that the anomalous courses of the James and Potomac have resulted from the gradual northwestward shifting of the major drainage divide by progressive stream piracy and local superposition of some streams by down-cutting through relatively nonresistant

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[225] Thompson, H. D., Drainage evolution in the southern Appalachians: Geol. Soc. America Bull., vol. 50, pp. 1334-1342, 1939.

[226] Meyerhoff, H. A., and Olmstead, E. W., The origins of Appalachian drainage: Am. Jour. Sci., 5th ser., vol. 32, pp. 21-42, 1936.

[227] Ashley, G. H., Studies in Appalachian mountain sculpture: Geol. Soc. America Bull., vol. 46, p. 1406, 1935.

[228] Op. cit., pp. 1323-1336, 1939.

formations. The northwestward shifting of the drainage divide has progressed as far south as the headwaters of Roanoke River. This stream is the imminent pirate of New River[229] and has already diverted considerable drainage from the New River system. According to Thompson's hypothesis, the present divide between New River and the Atlantic drainage in North Carolina and in Grayson and Carroll counties, Virginia, is a remnant of the divide which extended northeast along the Blue Ridge anticlinorium during early Mesozoic time. By headward erosion and piracy, streams flowing into the Atlantic have shifted this ancient divide westward. The obvious encroachment of the Roanoke upon the drainage area of New River is strong evidence in support of Thompson's interpretation.

In summary, recent interpretations dealing with the probable origins of Appalachian drainage indicate that the assumed relation of the anomalous courses of the principal streams to ancient peneplains or to an ancient peneplain covered with Cretaceous marine sediment is unnecessary.

The other principal evidence commonly believed to favor the peneplain theory, namely, even-crested ridges, may have less significance than was formerly believed. Fenneman[230] has emphasized that no part of the Appalachian area has escaped erosion during the entire erosional history of the region. He believes that certain even-crested ridges, commonly interpreted as remnants of the Schooley peneplain, have been worn down considerably below the theoretical Schooley level. The gradual lowering has been accomplished without loss of even crests.

Gradual wastage of peneplain remnants without loss of their evenness is not a new idea. Hayes[231] in 1896 expressed the belief that some of the ridges may have been lowered as much as 300 feet below the level of the uplifted peneplain. More recently, Ashley[232] has estimated that peneplain remnants are being lowered at the minimum rate of 1 foot every 10,000 years. If none of the supposed peneplain remnants has escaped erosion, the problem of determining and correlating remnants of a particular peneplain is complicated. Considering this problem, Fenneman[233] says:

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[229] Wright, F. J., The newer Appalachians of the South, part 1; Between the Potomac and the New rivers: Denison Univ. Bull., Jour. Sci. Lab., vol. 29, art. 1, pp. 61-70, 1934.

[230] Fenneman, N. M., Cyclic and noncyclic aspects of erosion: Geol. Soc. America Bull., vo.l 47, pp. 173-185, 1936.

[231] Hayes, C. W., The southern Appalachians, *in* Physiography of the United States: pp. 305-336, New York, American Book Co., 1896.

[232] Ashley, G. H., Studies in Appalachian Mountain sculpture: Geol. Soc. America Bull., vol. 46, pp. 1395-1436, 1935.

[233] Op. cit., pp. 182-183.

> "Considering first the case of narrow ridges like those of the Ridge and Valley province, it is to be observed that this process of surficial wasting does not destroy the horizontality of a crest but only lowers it. If the amount of such wasting were everywhere the same, the record of cyclic erosion would not be defaced and the count of cycles and peneplains would not be confused. Confusion begins when one ridge has been lowered 30 feet and another 300 feet. Both crests received their flatness at the same time, i. e., when both summits were parts of the same peneplain. Neither has at any time lost its flatness. Both are lowering now as fast as ever, and neither is at base level. Yet a casual view, and perhaps the present vogue, would assign them to different cycles, with the tacit implication that neither summit has been lowered since uplift and that the summit plane of each cuts the mass now just where it did when the peneplain was made.
>
> "Theory would indicate that the rate of erosion without valleys would vary with the hardness of the rock and the width of the outcrop, the latter being determined by the thickness of the stratum and dip. Even a casual examination of the Appalachian ridges is sufficient to indicate that such correlations of altitude with structure exist. Thick strata make higher ridges than thin ones, and the ends of pitching folds where the outcrops are broad, are almost invariably high. Much ingenuity has been expended in depicting a series of base levels so that each mountain crest may fall in one of the assumed planes. When an equal amount of exact study has been given to correlating each height with the character of the rock and breadth of outcrop, the time will have come to decide how many base levels must be assumed. Perhaps three would be enough, or two; the last and extremest suggestion is one. More than three may be needed."

Rich[234] has also stated that even-crested ridges are the product of erosion processes which are currently active. He emphasizes the importance of slope wash and creep in the lowering of interstream areas.

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[234] Rich, J. L., Rock resistance and interfluvial degradation as dominant factors in geomorphology (abstract): Geol. Soc. America Bull., vol. 44, pt. 1, p. 97, 1933; The development of even-crested ridges without peneplanation (abstract): Assoc. Am. Geographers Annals, vol. 24, no. 1, p. 66, 1934.

In summary, the existence of former peneplains in the Appalachian region is not demonstrated by even-crested ridges or by streams which cross the folded rocks. Correlation of peneplains by comparison of altitudes is unreliable because the ridge crests are being lowered at different rates.

ORIGIN OF EVEN-CRESTED RIDGES

In the Burkes Garden quadrangle, the development and maintenance of more or less even-crested ridges are the work of erosional agencies now active. That the ridge crests have been and are still being lowered is shown by the rock fans occurring on the obsequent slopes of the ridges. These fans (Pls. 17A, B, C), extending from the crests to the bases of the ridges, are composed of blocks of ridge-making sandstone enclosed in soil, the sandy part of which is derived from the disintegration of some of those blocks. Each fan heads in a slight sag in the ridge crest, where sandstone blocks are found in all stages of separation from the parent ledges and cliffs. On ridges made by the Clinch, blocks of this resistant rock are dislodged by sapping or undermining of the Juniata and Martinsburg, both of which are relatively soft and easily eroded. After their detachment, the Clinch blocks are moved down the obsequent gullies during and soon after heavy, washing rains. Most of the blocks disintegrate into sand or are corraded to small pieces before reaching the main streams. The sandstone blocks in each fan were derived from the sag in the ridge crest at the head of the fan, but the total amount of sandstone dislodged from a given sag is considerably greater than the volume of sandstone blocks in the rock fan below. Some blocks have disintegrated and mixed with the soil. Both sandstone blocks and soil are now being carried away by the principal streams.

In order to determine a reliable minimum estimate of the volume of Clinch sandstone in one fan, on the northwest slope of Rich Mountain southeast of Gratton, the area of the fan and the thickness and dip of the ridge-making Clinch were determined. Three plots of 250 square feet each were marked off on the surface of the fan, one near its midlength and the others some distance down slope. All blocks larger than one cubic foot were counted. The total volume of Clinch sandstone in each of the sampled areas was determined by assuming the fan to be only 3 feet thick—a conservative estimate.

The computed volume of the blocks of Clinch sandstone in this fan, if restored to the segment of the Clinch outcrop from which the blocks were dislodged, would raise the ridge crest about 75 feet. The amount of sand in the soil, derived by disintegration of dislodged blocks, and the quantity in pieces smaller than one cubic foot are probably together much greater than the total volume of the larger blocks which were counted. Thus the figure obtained in the approximation probably could be increased several times without overestimating the amount of Clinch sandstone removed from the crest. The obsequent rock fans occurring along the slopes of the ridges in the Burkes Garden quadrangle demonstrate clearly that the ridges have been recently, and are now being, lowered and that the even crests are not actual remnants of peneplains.

The development and maintenance of more or less even-crested ridges in the Burkes Garden quadrangle are determined by the relative resistance and structure of the bedrock. The more nearly level crests are without exception made by uniform thicknesses of Clinch sandstone of uniform dip. The obsequent slopes below the even crests are invariably drained by evenly spaced streams. The expectable product of erosion under such conditions could scarcely be other than a more or less even-crested ridge. The farther removed that a given ridge is from the main drainage lines and the lower the dip of the ridge-making rock, the higher the altitude of the ridge. Two ridges made by the same resistant beds and similarly located with respect to the main drainage may have different altitudes as a consequence of differences in structure. The significant factors determining the height of more or less even-crested ridges are, in order of decreasing importance, relative resistance of the ridge-making beds, their dip, and the location of the outcropping beds with respect to the main drainage lines.

Under this interpretation, the crests of Stony Ridge and East River Mountain do not represent remnants of two different peneplains. Both even-crested ridges acquired their characters during essentially the same time. Stony Ridge is lower because the resistant sandstone member which makes the crest is thinner and dips at a steeper angle than the Clinch sandstone making East River Mountain. Two mountains of the same general elevation, for example, Walker Mountain and the south fork of Garden Mountain, are not remnants of the same peneplain but are ridges being eroded and lowered at essentially the same rate.

The fact that several ridges, taken together, show a general decline in elevation in a certain direction is not alone a reliable basis for postulating the tilting of a peneplain. In general, ridges in the same drainage basin, composed of similar rocks and having a similar structure, should show a general decline in altitude in the downstream directions.

Possibly the Appalachian region has been reduced in the past to a peneplain, but no remnants of the peneplaned surface have been preserved in the Burkes Garden area. Indeed, the evidence which has been used by others in postulating the existence of former peneplains is more simply interpreted as the result of continuous erosion such as is now active.

PROPOSED INTERPRETATION OF LAND FORMS

General statement.—The surface features of the Burkes Garden quadrangle are the result of long and continued erosion which has been accelerated from time to time by renewed uplift of the land. Evidences of old erosion surfaces have been obliterated by later erosion. Most probably the Appalachian region throughout its erosional history maintained a perennially mature topography. Only the later rejuvenations are clearly marked. Butts[235] and others have noted the entrenchment of the major streams below the so-called Harrisburg, or valley-floor, peneplain. For example, New River flows through Pulaski, Montgomery, and Giles counties in a gorge 200 to 400 feet deep. This entrenchment has been so recent that it has not yet worked headward to the main divides. The nick points of all the principal streams heading in the Burkes Garden quadrangle are beyond the limits of this area. Naturally, the Burkes Garden area will be one of the last to have entrenchment caused by this late rejuvenation.

Effect of structure and character of the bedrock.—The highest areas in the Burkes Garden quadrangle, including Beartown (altitude 4,705 feet), Big Ridge (4,116 feet), parts of East River Mountain (4,117 to 4,361 feet), the west end of Rich Mountain (4,245 feet), and Chestnut Ridge (4,402 feet), are all made by essentially horizontal Silurian sandstones (Fig. 6). The highest of these prominences is formed by the broadest arch of Clinch sandstone. All of the homoclinal ridges of Clinch sandstone, except Brushy Mountain, have about the same altitude, 3,650 to 4,000 feet. Brushy Mountain, with an altitude of 3,100 to 3,400 feet, is lower by reason of the steeper dip

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[235] Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. 1, pp. 508-510, 1940.

(55° to 65° SE.) of the Clinch sandstone, part of which has been faulted out by one of the slice faults along the Saltville-Bland overthrust. Southwestward from Gratton and away from the New-Tennessee drainage divide, Rich Mountain (Pl. 18B) rises from an altitude of 3,650 feet to 4,245 feet at the west edge of the quadrangle, which corresponds to the northeastward pitch of the Wolf Creek syncline in the Clinch and Rose Hill sandstones. The relatively lower altitude of Buckhorn Mountain, as compared with other ridges made by the Clinch and Rose Hill, is a consequence of the generally steeper dips and discontinuity in structure of the ridge-making rocks. Stony Ridge is lower than the other ridges because it is made by Stony Gap and Princeton sandstones, both of which are considerably thinner and dip more steeply than the Clinch upholding the higher ridges. Abbs Valley Ridge, about 200 feet higher than Stony Ridge, is made by the Falls Mills sandstone whose thickness is greater than the Stony Gap and the Princeton and less than the Clinch. Also, the Falls Mills sandstone dips at a considerably lower angle than do the sandstones making Stony Ridge. Brushy Mountain and its continuance, Carter Mountain, are upheld by coarse sandstones and conglomerates at the base of the Price. The relatively low altitude of these ridges indicates that the ridge-making beds are considerably less resistant to weathering and erosion than the Silurian sandstones (Fig. 6).

The general altitude of the areas below the sandstone ridges denotes the relatively nonresistant character of the Cambrian, Ordovician, and Devonian beds and also of the greater part of the Mississippian rocks. Close scrutiny of the seemingly accordant altitudes of the valley floors discloses numerous low ridges and benches, each of which is made by slightly more resistant beds. Sandstone zones in the Copper Ridge formation make low but well-defined ridges 150 to 350 feet high. Big Ridge southwest of Sharon Springs, the most prominent ridge of this type, is made by a 75-foot zone of sandstone at the base of the Copper Ridge. The somewhat lower ridge on the southeast side of Foglesong Valley is made by cherty zones in the Beekmantown dolomite. Banks Ridge in Burkes Garden, which is also made by the Beekmantown, reflects the difference in resistance of the bench-making dolomite and the Ordovician limestones which underlie the valley floor. In the Nolichucky belt north of U. S. Route 19, the shale makes a low but locally conspicuous ridge which rises 150 to 250 feet above stream level. The same shale makes a linear series of low rounded hills along the south base of Buckhorn Mountain in Clear Fork Valley (Fig. 6).

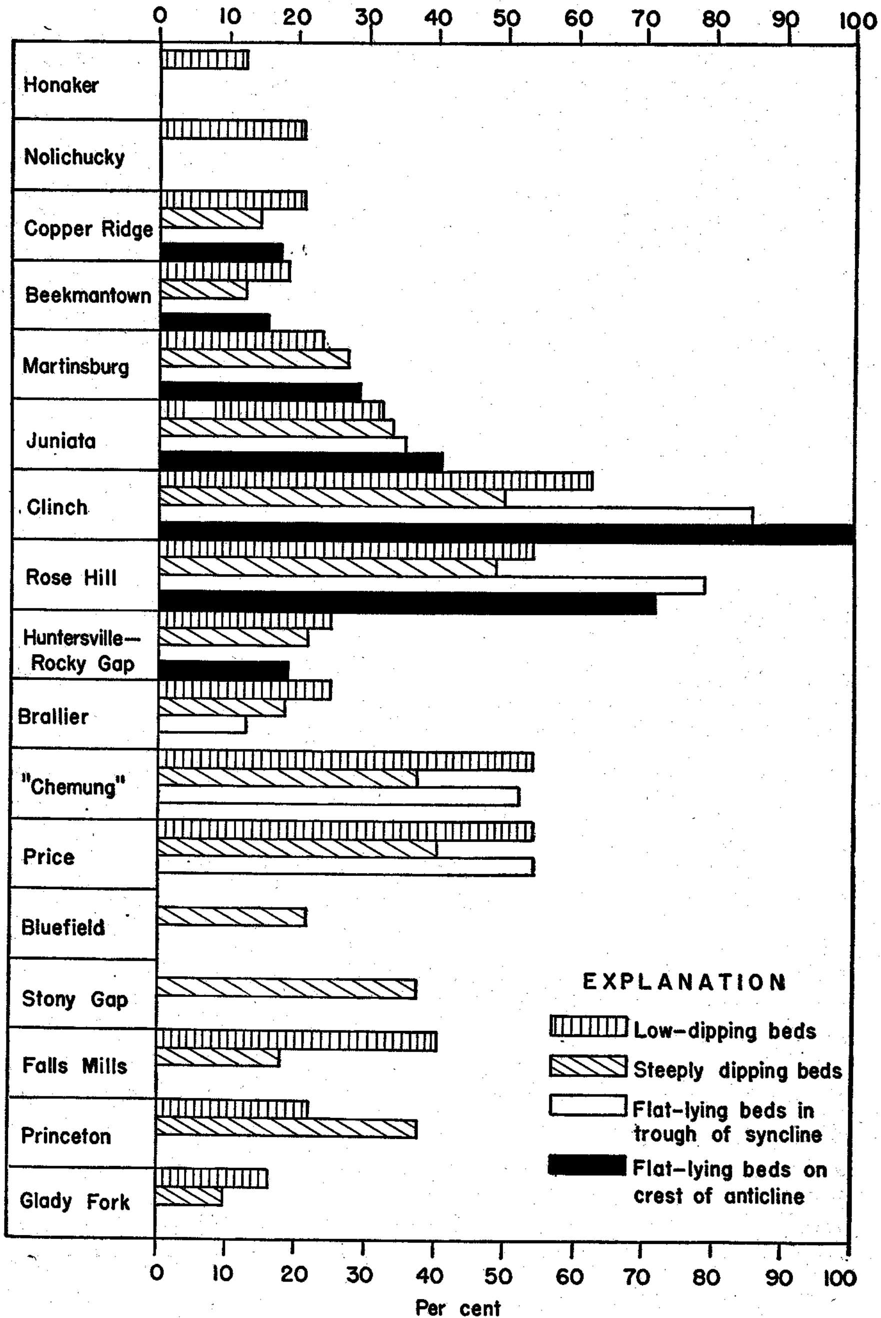

FIGURE 6.—Relative topographic potency of the various ridge-makers in the Burkes Garden quadrangle, Virginia.

UNDERGROUND DRAINAGE

The abundance of underground drainage is known chiefly from the presence of countless sinks and sink-holes[236] and, to a lesser extent, from limestone springs and caverns. Most of the underground streams are not far beneath the surface and are very closely related to the surface drainage. The most common type of subsurface stream links runoff descending the sides of the valleys with the principal streams. In valleys underlain by Ordovician limestones and dolomites, surface waters commonly enter sinks in the Witten, Gratton, and Benbolt formations and reappear as surface seeps and springs at lower altitudes along the principal streams commonly near the Beekmantown-Cliffield contact. A stream of this type occurs west of Marys Chapel. A surface stream descending Rich Mountain (Fig. 7B) enters a sink-hole in the bed of the stream within the outcrop of the Witten limestone and emerges in a large spring one-fourth of a mile to the northeast, near the Beekmantown-Cliffield contact.

Some ravines descending the obsequent slopes of the ridges have no surface streams. At the lower ends of these dry ravines relatively large springs commonly occur. Evidently nearly all of the rainfall enters the ground and is gradually concentrated into channels which feed the springs. Underground drainage of this type is particularly well developed along the southeast slope of Buckhorn Mountain west of Gratton. Cave Spring and another large spring, half a mile northwest of Concord Church, represent emergence of two subsurface streams of this type.

A third type of underground drainage is particularly well shown in Burkes Garden. Surface water descending the mountain slopes disappears into sink-holes upon reaching the valley floor. These waters are concentrated by a series of shallow ramifying channels and emerge in a few large springs. Station, Blue, and Fish springs are the principal outlets of subsurface streams of this type.

Underground streams are also related to some subsequent streams. Near the drainage divide at Gratton, the headwaters of the South Fork of Clinch River enter a sink-hole at the Beekmantown-Cliffield contact and reappear a mile or more down the valley in a large spring at Natural Bridge (Fig. 7) near Marys Chapel. The subsurface channel seems to follow a system of vertical joints which strike approximately N. 70° E. The abandoned part of the valley contains stream gravel which is in-

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[236] Few of the many sinks in the quadrangle are shown on the Burkes Garden topographic map, because the contour interval of 50 feet does not permit delineation of the many small, shallow depressions. None of the 27 sinks counted in the immediate vicinity of Fish Spring in Burkes Garden are shown on the topographic map.

dicative of the former presence of a surface stream. Another stream of the same type forms a link in the middle fork of Clinch River, which drains southwestward from Divide Church (Fig. 10C).

Abbs Valley is almost unique among valleys in the southern Appalachian region in that it lacks throughout its entire length of 12 miles any sign of a surface stream. Runoff descending the sides of the valley enters a series of large sinks which extend down the middle of the valley. The waters emerge along Bluestone River near Nemours, West Virginia, several miles beyond the northern limits of the Burkes Garden quadrangle.

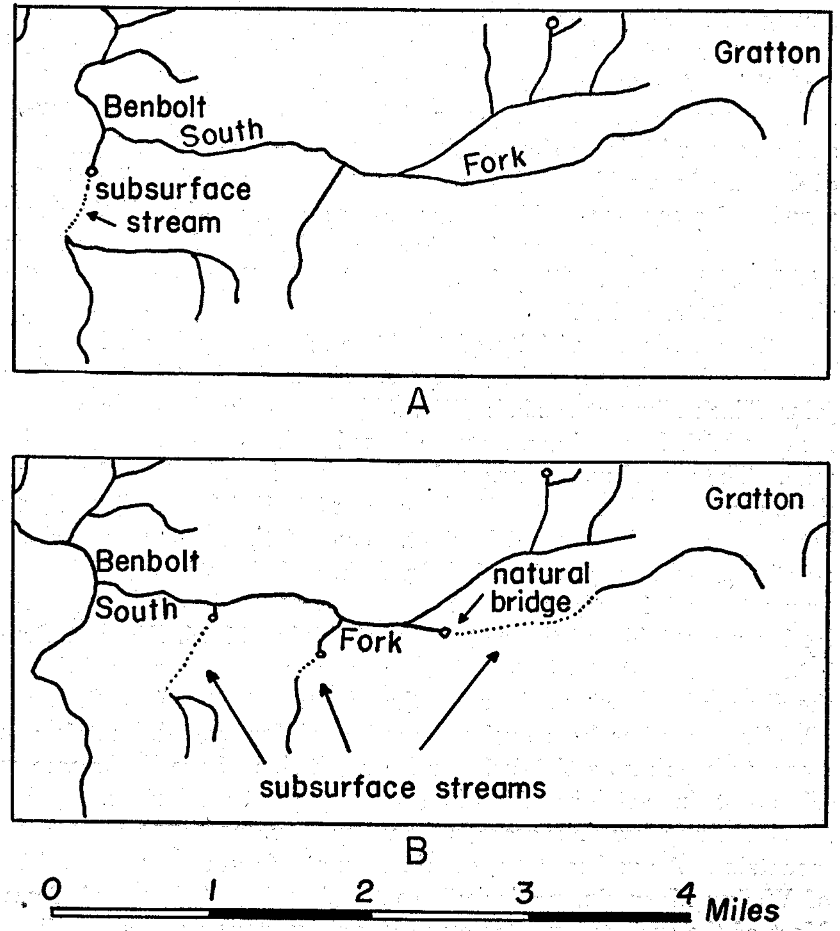

FIGURE 7.—Drainage changes along the South Fork of Clinch River, near Benbolt, Virginia. A, Former drainage; B, present drainage.

Near Dills Spring, underground streams in the Beekmantown dolomite and Ordovician limestones have pirated some of the surface drainage (Fig. 8). The low ridge just north of Road 650, which is made by the Rose Hill, Healing Springs, and Rocky Gap sandstones, has been notched in three places by surface streams. Two of the gaps have been abandoned as surface waters were diverted into underground channels. One stream, which originally extended across the low ridge, now enters a sink half a mile west of the 2,508-foot bench mark and probably emerges at Dills Spring. The other stream enters a sink hole near the 2,508-foot bench mark and probably flows northeastward and emerges in a large spring at the Saunders Dairy Farm, near the intersection of State Highway 85 and Road 650.

Southwest of Divide Church, numerous sinks occur in the Middle Ordovician limestones. Some of the streams descending East River Mountain and Havens Spur enter sinks before reaching Clinch River and connect with it by short underground channels. The middle fork of Clinch River, which drains southwestward from Divide Church, has abandoned a segment of its former surface course (Fig. 10) in favor of a subsurface channel marked by a line of sinks immediately south of U. S. Route 19. The old highway location is along part of the abandoned stream bed.

The area in the vicinity of the Tazewell County Farm is almost wholly drained by subsurface streams. Formerly the tributary which joins Clinch River at Benbolt (Fig. 7A), headed in the shallow valley between Rich Mountain and a prominent bench of Beekmantown dolomite. The runoff now enters sinks in front of the County Farm and flows northward beneath the Beekmantown bench, joining Clinch River between Marys Chapel and Benbolt. One of the underground channels has since been abandoned (Fig. 8B), and the stream which once flowed through it now flows on the surface around the west end of the Beekmantown hill and thence northward joining Clinch River at Benbolt. The entrance to the abandoned cavern is seen along Road 647 to the County Farm, about three-fourths of a mile south of U. S. Route 19. The cave has been explored northward for over 400 yards and seems to open into a sink-hole on the north side of the Beekmantown hill, about three-eighths of a mile south-southwest of Benbolt.

Relatively few sinks occur in the valley between Walker and Brushy mountains. A number of large springs emerge from the northwest base of Walker Mountain, particularly south of Redoak School and Ceres. Most of the springs issue from the Effna limestone or from the limestone at the base of the Beekmantown. Most of the permanent springs

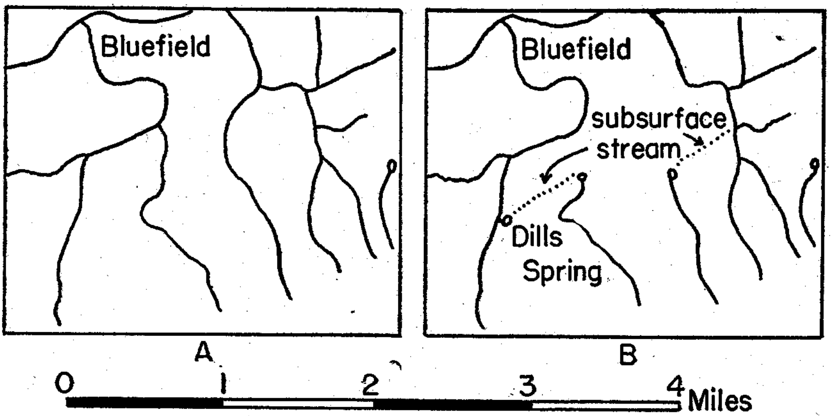

FIGURE 8.—Drainage changes of some tributaries of Bluestone River, south of Bluefield, Virginia. A, Former drainage; B, present drainage.

in these two localities occur at the foot of dry ravines which are catchment areas for surface waters feeding the springs.

Underground drainage is best developed in Burkes Garden, where sinks and sink-holes are found in great profusion. Streams descending the mountain rim in the western part of the valley enter sink-holes upon reaching the valley floor and flow underground at shallow depths, emerging at Station and Blue springs. In the northeastern part of the valley, the streams descending Morris Knob enter a large sink-hole on the Lawson farm, about one-fourth of a mile southeast of the 3,116-foot bench mark. Two other large sink-holes occur southwest of the 3,157-foot bench mark in the northwest corner of Burkes Garden. The sunken waters probably emerge at Fish Spring. Possibly some of the "lost streams" of Burkes Garden emerge as springs along the northwest slope of Rich Mountain and near the head of Thompson Valley. Water entering sinks in the eastern and northern parts of Burkes Garden at an altitude of about 3,100 feet could migrate down the southeast flank of the Wolf Creek syncline, thence up the northwest flank, and emerge as springs in Cambrian and Ordovician limestones and dolomites, at altitudes of 2,600 to 2,750 feet. Similarly, sinking waters in the western part of Burkes Garden could move down the dip of the beds under the divide between Thompson Valley and Burkes Garden and emerge as springs in Ordovician limestone near the head of Maiden Spring Creek. The lack of large springs in the upper end of Thompson Valley and along the northwest slope of Rich Mountain, would seem to indicate that not much water leaves Burkes Garden through underground channels. On the contrary, the high rates of discharge of Station, Blue, and Fish springs suggest that practically all of the sunken waters in Burkes Garden feed these springs.

MODIFICATIONS IN SURFACE DRAINAGE

Besides numerous drainage changes resulting from the pirating of surface drainage by subsurface streams, diversion of one surface stream by another has occurred in several places. As shown in Figure 9, the upper course of Laurel Creek has been pirated by Lick Creek. Lowering of Laurel Creek Valley has been considerably retarded by the natural barrier of Price sandstone and conglomerate which is traversed by this stream in the gap through Brushy Mountain at the Tazewell-Smyth county line, north of Broadford. Lick Creek, which at one time headed on the southeast slopes of Carter (Brushy) Mountain, has breached this ridge by working headward along the axis of a cross anticline in the Upper Devonian and Mississippian beds. The point of capture of Laurel Creek by Lick Creek was probably near the mouth of Totten Branch.

Several minor drainage changes have taken place along the North Fork of Clinch River north of Witten Mills (Pl. 20). The river once flowed from Tiptop southwestward along Wrights Valley to a point about 2 miles north-northwest of Wittens Mills (Fig. 10A). Headward growth of tributaries entering the river about half a mile north of Wittens Mills resulted in the notching of the sandstone ridge on the south side of Wrights Valley (Fig. 10B), and the diversion of drainage through the newly made gap. This process was later duplicated farther northeast by another tributary of Clinch River (Fig. 10C), and the drainage course through the middle gap was abandoned in favor of the present course of the river through the sandstone ridge. The abandoned courses in Wrights Valley are now drained by subsurface streams which feed the surface streams heading in the abandoned gaps (Fig. 10C).

Some of the tributaries of Sandy River have worked headward through Big Stone Ridge and have diverted from Bluestone River the drainage of the headward part of Abbs Valley. The strongly asymmetrical divide between Horsepen Creek and Abbs Valley indicates that further headward growth of Horsepen Creek is inevitable. A few miles west of the Burkes Garden quadrangle, north of Cliffield, Tazewell County, Big Sandy River has worked headward to a point within 1½ miles of Clinch River and has cut a deep valley several hundred feet

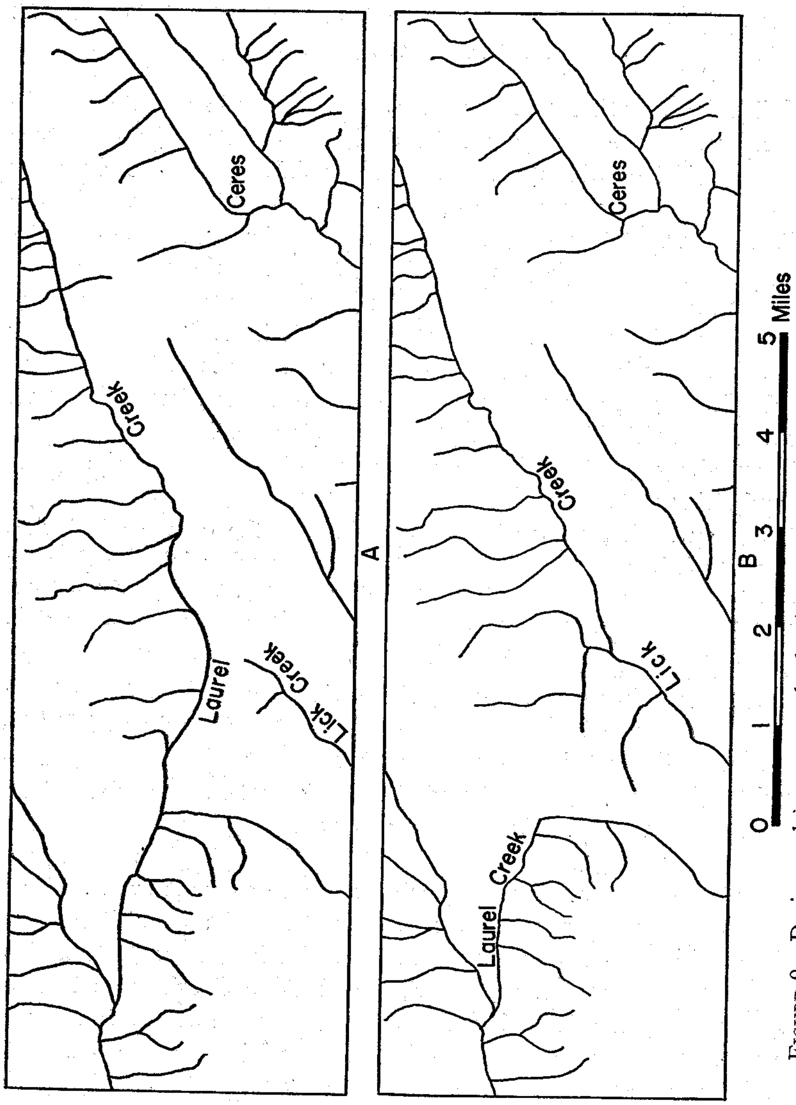

FIGURE 9.—Drainage changes near the headwaters of Lick and Laurel creeks. A, Former courses; B, present courses, after beheading of Laurel Creek by Lick Creek.

below Clinch River. The imminent intercision of Clinch River by Sandy River foreshadows major shifts in the drainage divides between New, Clinch, and Sandy rivers.

RELATION OF DRAINAGE TO STRUCTURE AND CHARACTER OF THE BEDROCK

With the exception of Burkes Garden and a small area in the northwestern part of the quadrangle, the drainage patterns of the surface streams are of the trellis type. All of the main streams have cut their valleys in relatively nonresistant rocks. These subsequent streams are fed by short tributaries descending the mountain slopes. Some of the tributary streams are being modified by extension of their valleys headward along the strike of the softer rocks in directions parallel or nearly so to the principal valleys. Indianfield Branch in Wolf Creek Valley and Oneida Branch in Nye Cove are resequent streams which are being extended headward along subsequent courses. Most of the obsequent streams descending the northwest side of Stony Ridge are growing headward along the strike of relatively soft rocks between the Stony Gap and Princeton sandstones.

Between Fish Spring and Central Church, the course of Burkes Garden Creek is controlled by two sets of intersecting joints. One set strikes about N. 55° E.; the other approximately N. 45° W. Tributaries of Burkes Garden Creek in the area southeast of Central Church follow both sets of joints.

The location of the gap of Cove Creek seems to have been determined largely by structure. Prior to the notching of Buckhorn Mountain by this stream, the overthrust rocks on the southeast side of the mountain extended farther northwest and the belt of Clinch sandstone, which now passes beneath the overthrust block about one-fourth of a mile east of Cove Creek, passed beneath the overthrust rocks near the position of the present gap. When Cove Creek first extended its course northward across Buckhorn Mountain, it did not flow across the belt of Clinch sandstone which is now exposed at the south entrance of Cove Creek gap; but as the stream deepened its valley and cut through the overthrust rocks it was superimposed upon the Clinch beds which had been buried beneath the margin of the Narrows overthrust block. The upper course of Cove Creek has developed along a principal synclinal axis extending from Chimney Rock on the west to Big Ridge on the east.

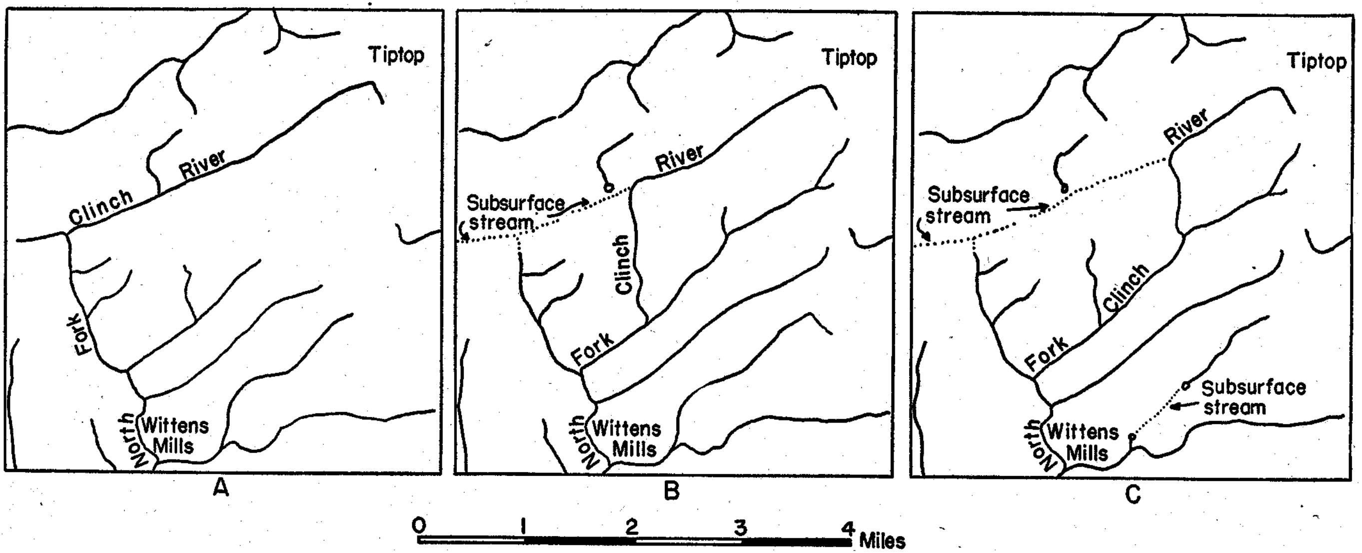

FIGURE 10.—Drainage changes near the head of the North Fork of Clinch River. A, Early course of the river; B, intermediate stage, after first piracy; C, present course of the river, after second piracy.

The lowest subsequent valleys are those of Lick, Six, and Laurel creeks, which have been cut in Devonian shales on the southeastern flanks of Garden, Walker, and Clinch mountains, respectively. The structure of the eroded shales does not impede lowering of the valley floors, for as the valleys are lowered they migrate laterally down dip. Other valleys in the same shales, but located along the axes of synclines, are distinctly higher. The Devonian shale in these synclinal valleys is removed without lateral migration of the valley, and eventually the streams are superimposed on the resistant Silurian sandstones. Roaring Fork, an example of this type of stream, is now lowering its valley at a much slower rate than it did before removal of all the Devonian shales.

Drainage of Burkes Garden is an excellent example of the dendritic pattern which results from long-continued erosion of wide belts of strata of relatively uniform resistance to erosion. Although the limestones which form the floor of Burkes Garden are folded, a trellis type of drainage has failed to develop because all the folded rocks are being eroded at essentially the same rate.

SCENIC FEATURES

Burkes Garden.—Burkes Garden (Pl. 2) is unique among valleys in the southern Appalachian region. Except for the water gap in Garden Mountain on the north side of the valley (Pl. 18D), Burkes Garden is completely rimmed by mountains. The valley floor is uncommonly flat and is perched about 400 feet above the neighboring limestone valleys. Except for a narrow row of low hills, known as Banks Ridge, all the valley floor is cleared. A few remnants of the primeval forest, penetrated by Colonel Patton and his party in 1748, have been preserved. One magnificent tree which was felled during the summer of 1939 had more than 300 annual rings.

Before the coming of the early settlers, Burkes Garden must have been densely forested. According to the journal of Captain Preston[237], the Sandy Expedition which crossed Burkes Garden in 1765 did not leave that place by the most convenient way through Mill Gap. The party probably crossed the mountain rim north of Hutchinson Rock (Pls. 2, 18A), thence into Little Valley through Low Gap, and over Rich Mountain to the divide between the South Fork of Clinch River and Clear Fork. Evidently Mill Gap was completely obscured by the forest. Indian tribes which roamed this section prior to 1750 spoke of Burkes Garden as "The Great

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[237] Pendleton, W. C., History of Tazewell County and southwest Virginia, 1748-1920, p. 221, Richmond, Virginia, W. C. Hill Co., 1920.

Swamp." South of Gose Mill, swampy conditions still prevail, and it is reasonable to suppose that this condition was more extensive when the entire valley was forested. The oval shape of the valley and the swampy conditions prevalent near Mill Gap have led many local residents to believe that Burkes Garden was once a lake, but this hypothesis completely overlooks the processes by which Burkes Garden has been formed.

The resistant sandstones, which rim the valley, at one time extended upward over Burkes Garden in the form of a huge dome of solid rock. The apex of this dome, if restored, would rise about 3,400 feet above the present valley floor, to an altitude of about 6,500 feet. Probably the first stream to breach the sandstone dome was Roaring Fork. The Banks Ridge anticline, a subsidiary flexure on the general dome-shaped structure, was attacked by this stream and a typical canoe-shaped valley was probably excavated. This valley may have stood some 1,500 to 2,000 feet above the present Banks Ridge. At this stage, the head of Roaring Fork probably did not extend east of the meridian of the present Mill Gap. Drainage of this valley coursed southwestward through Heninger Gap and emptied into Laurel Creek. At that time, the area south of Beartown and north of Chestnut Ridge was underlain by soft Devonian shales. Later, when Roaring Fork had removed all of these rocks, its rate of downcutting was greatly retarded because of the greater hardness and resistance of the underlying Silurian sandstones. Wolf Creek, heading in the synclinal valley between the Burkes Garden dome and Rich Mountain, succeeded in breaching the dome along the axis of a sharp cross fold or transverse offset in the northwest flank of the dome in the location of the present Mill Gap. As a result of the relative sharpness of the synclinal fold in the rocks of Wolf Creek Valley, in contrast to the shallow character of the Roaring Fork syncline, all of the Devonian shale was removed from the valley of Roaring Fork long before the base of the shale was penetrated in the valley of Wolf Creek. Since Roaring Fork began to flow upon the resistant Silurian sandstones, Wolf Creek has possessed a distinct advantage over it, which has resulted in the enlargement of the headward part of Wolf Creek Valley at the expense of the valley cut in the Burkes Garden dome by Roaring Fork. Piecemeal diversion of the Burkes Garden watershed from Holston drainage into the New River drainage has not led to a stabilized condition. Maiden Spring Fork by headward erosion has removed all of the barrier of resistant sandstone separating Thompson Valley from Burkes Garden. The remaining shale divide between these two valleys, below Hutchinson Rock, is being lowered and pushed northeastward at a rapid rate by Maiden Spring Fork. Eventually Thompson Valley will annex the drainage of Burkes Garden by creation of a gap below Hutchinson Rock (Pl. 18A), and Mill Gap (Pl. 18D), the present outlet, will become a wind gap.

Beartown.—Beartown (Pl. 19A), located on the divide between New and Tennessee rivers with an altitude of 4,705 feet, is the highest area in the Appalachian Valley of Virginia. It is made by a broad arch of sandstone, which is an unreduced part of the dome of sandstone which once extended over Burkes Garden. Sheer cliffs on the northeast and northwest sides are maintained by headward sapping of Maiden Spring Fork, Station Spring Creek, and Blue Spring Creek. The south and west sides of Beartown are dip slopes composed of an alternating series of high flatirons and deep ravines. Cove Branch, which has cut a gorge nearly 1,000 feet deep, has penetrated the cover of resistant sandstone on the south slope of the mountain and is working headward toward Station Spring Creek. Enormous blocks of Clinch sandstone found below the outcropping ledges of sandstone are evidence of the gradual areal reduction of this prominence. However, as long as there is any sandstone capping this mountain its altitude will remain essentially unchanged, since sapping rather than direct downcutting is the dominant erosive process reducing this elevated area.

Hutchinson Rock.—Hutchinson Rock (Pls. 2, 18A) is an isolated, residual mass of essentially horizontal Clinch sandstone on the divide between Burkes Garden and Thompson Valley. The "rock" is not monolithic, but is parted by large, gaping joints which are being enlarged constantly by differential creep and sapping. Large blocks of sandstone, dislodged from Hutchinson Rock, occur on the slopes below the knob. Their presence foreshadows the inevitable removal of the remaining cap of sandstone. When this has taken place, the rate of lowering of the divide between Thompson Valley and Burkes Garden will be greatly accelerated.

Crabtree Gap.—One of the most striking features of the skyline of Rich Mountain is a broad col located about 1½ miles southeast of Shawver Mill. One possible interpretation of Crabtree Gap is that it is a wind gap—an abandoned water gap through which the drainage of Burkes Garden and Little Creek Valley formerly passed. This interpretation presupposes that Wolf Creek then headed some distance east of the Bland-Tazewell county line. Headward erosion by Wolf Creek would have resulted in the intercision of the stream draining across Rich Mountain into Clear Fork Creek. One of the objections to this interpretation is that the gap is broad and flaring, in contrast to the V-shape of existing water gaps.

In the vicinity of Crabtree Gap, the Clinch and Juniata formations are cross-folded in a small anticline within which many fractures and possibly several small faults are present. The Clinch, which generally weathers in large blocks, is here found only in pieces at most a few inches in diameter, indicating that the rock is very closely jointed and fractured. This structural weakening of the ridge-making sandstones in the vicinity of Crabtree Gap accounts for the poor exposure of Clinch beds which normally make a bold outcrop. The broad, flaring saddle therefore appears to be the product of selective weathering in a local, weak zone. Tributaries of Clear Fork are now enlarging this gap by headward erosion. Further enlargement of the gap will result in the breaching of Rich Mountain by tributaries of Clear Fork and probably will result in the eventual intercision of Wolf Creek by those streams·

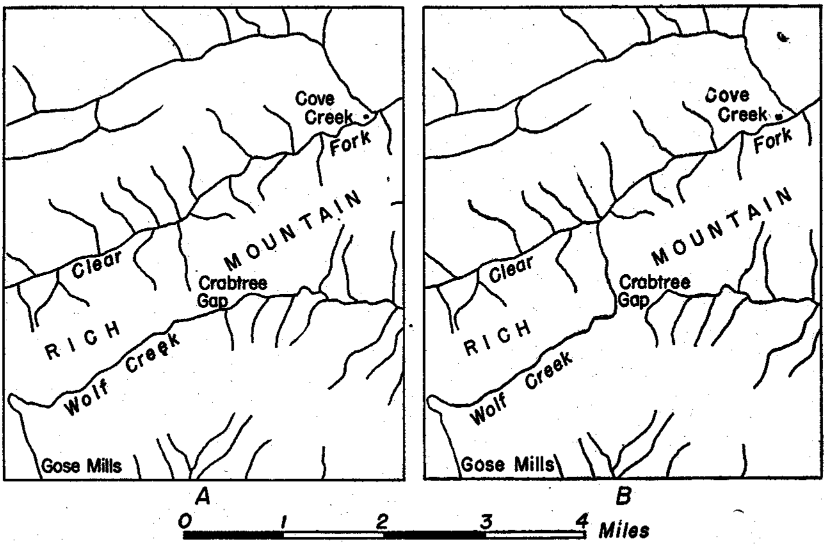

FIGURE 11.—Imminent piracy near Crabtree Gap, Bland and Tazewell counties, Virginia. A, Present drainage; B, probable drainage after predicted piracy of Wolf Creek by Clear Fork.

(Fig. 11). Thus Crabtree Gap may signify geologically imminent piracy rather than a past drainage diversion.

Dial Rock.—Dial Rock, one of the prominent landmarks of Tazewell County, is a projecting ledge of Clinch sandstone at the west end of East River Mountain (Pl. 18C). The south face of the ledge is a cliff about 175 feet high. The capping sandstones are broken into rectangular blocks by two sets of joints, one of which strikes N.5°W., and the other approximately N.30°E. The jagged face of the "rock" is maintained by sapping of the joint blocks. The sandstone "caves" in the south face result from differential creep of the sandstone blocks and the consequent widening of the joints.

Chimney Rock.—Chimney Rock is a conspicuous pinnacle of sandstone on the spur between Dark and Crag hollows, on the northwest slope of East River Mountain. It is marked on the Burkes Garden topographic map by the closed 4,250-foot contour line. The mountain crest about 100 feet above Chimney Rock is made by a narrow anticlinal fold of Clinch sandstone. The Clinch descends the northwest side of the mountain at a dip slightly greater than the slope. Streams flowing down Dark and Crag hollows have dissected the upper slope into flatirons. Chimney Rock is the projecting apex of one of these flatirons.

Abbs Valley.—Abbs Valley (Pl. 19B) differs from other valleys in this area in that it is wholly drained by subsurface streams. All of the runoff descending the slopes on either side of the valley enters sinks and sink-holes upon reaching the valley floor. The absence of large accumulations of slope wash on the valley floor is an indirect indication of the existence of a surface stream in Abbs Valley in the recent geologic past.

Natural Bridge.—At Natural Bridge Spring, one-fourth of a mile southeast of Marys Chapel, a thin narrow "bridge" in the Lincolnshire limestone has been formed by the collapse of a part of the roof of an underground channel. The top of the span is about 60 feet above the spring which issues from the cavern. The "bridge" seems to be of recent origin.

WATER RESOURCES

SPRINGS

The Burkes Garden area abounds in springs, many of which are good sources of domestic water. Nearly every farm has its own springs, which are more than adequate for local needs. Several springs have contributed to municipal water supplies. The largest springs (Table 2) are located in Burkes Garden. Blue Spring, discharging 3,900 gallons per minute, is one of the largest springs in the State.

The most common type of spring in this area is that which issues from limestone or dolomite. Such springs are fed by water entering sinks and sink-holes which lead into caverns in the underlying rock. Because of the open nature of the underground channels supplying these springs, the spring water is no less polluted than the surface-waters feeding the springs. The larger springs in the area, such as Blue, Station, and Fish springs in Burkes Garden, Natural Bridge Spring near Marys Chapel, and Dills Spring near Bluefield, Virginia, are points of emergence of "lost" surface streams. Consumption of untreated water from any of these springs is hazardous.

Next in abundance to springs issuing from limestone or dolomite are those in the Martinsburg shale, along the upper slopes of the limestone valleys. The general lack of human habitations in the catchment areas of these springs makes them less likely to be contaminated. The rates of discharge of springs in shale are relatively low, and movement of the water underground is accompanied by considerable natural filtering. The fluctuation in the flow of springs issuing from the Martinsburg shale is considerably less than is that of the limestone springs.

Small springs of the gravity type occur in moderate abundance in the synclinal shale valleys. Many of those flowing out of the Millboro black shale are charged with hydrogen sulphide. Several sulphur springs are located on the outcrop of this formation in the vicinity of Mt. Victory Church in Freestone Valley. Sulphur springs near the village of Mud Fork and at Sharon Springs are sites of former resorts. Moderate-sized hotels were operated at these localities but were abandoned long ago.

MUNICIPAL WATER SUPPLIES

Water for the town of Tazewell is obtained from springs and a surface stream in the Burkes Garden area. The springs are located in the Martinsburg shale along the northwest slope of Rich Mountain be-

TABLE 2.—*Data on springs in the Burkes Garden quadrangle, Virginia*[238]

Number	GEOLOGIC FORMATION[239]	Date examined	Flow, in gallons per minute	TEMPERATURES IN DEGREES FAHRENHEIT		APPROXIMATE PARTIAL ANALYSES (PARTS PER MILLION)								Total hardness as $CaCO_3$
				Water	Air	Dissolved solids	Iron (Fe)	Calcium (Ca) by turbidity	Sodium (Na) calculated	Bicarbonate (HCO_3)	Sulphate (SO_4) by turbidity	Chloride (Cl)	Nitrate (No_3)	
1	Cliffield	8- 3-28	760	54	74	104	......	30	6	110	5	.6	3.2	86
2	Cliffield	8- 7-28	1,800	52.7	64.4	83	......	24	7	89	5	.3	1.3	64
3	Beekmantown	8- 8-28	120	53.6	69.8	123	......	18	5	137	3	.5	2.4	117
4	Beekmantown	8- 3-28	240	54	74	102	......	20	5	113	3	.3	2.5	93
5	Honaker	8- 4-28	20	......	......	......	......	......	......	......	......	......	......	......
6	"Gasper"	8- 4-28	250	55	75	189	......	72	14	203	8	1.0	5.0	149
7	Copper Ridge	8- 3-28	190	55.5	75	150	......	36	9	156	13	.1	1.5	123
8	Copper Ridge	8- 4-28	770	54	70	104	......	36	8	118	3	.2	.93	83
9	Beekmantown	8- 3-28	980	53	74	100	......	26	5	111	3	.3	2.3	90
10	Beekmantown	8- 3-28	1,210	55	76	73	......	20	5	75	5	.7	1.4	58
11	Cliffield	8- 8-28	3,900	58.1	70.7	125	......	36	9	132	7	.4	3.0	99
12	Benbolt	8- 8-28	950	54.5	70.7	156	......	52	11	172	4	.5	4.2	126
13	Tonoloway (?)	8- 4-28	80	55.5	68	......	......	......	......	......	......	......	......	......
14	Copper Ridge	7-31-28	110	......	......	151	......	24	5	182	2	1	3.8	154
15	Copper Ridge-Honaker (fault)	7-31-28	50	......	......	......	......	......	......	......	......	......	......	......
16	Copper Ridge	7-31-28	500	......	......	113	......	22	5	131	2	.5	.22	111

1. W. C. Greever Spring, at Five Oaks, Virginia.
2. Natural Bridge Spring, one-third of a mile east of Mary's Chapel.
3. W. C. Yost Spring, 5½ miles east of Tazewell, at headwaters of the South Fork of Clinch River.
4. Phillip Ball Spring, a quarter of a mile northeast of the W. C. Yost Spring.
5. R. P. Harmon Spring, a mile northwest of Springville along the Tiptop Road.
6. Bailey Spring, near Bailey Station on the Norfolk and Western Railway.
7. John Carter Spring, about 3.7 miles northeast of Springville.
8. Wallace Spring, about 0.6 of a mile northeast of Springville.
9. Crabtree Spring, about 1 mile southwest of Shawver Mill.
10. H. S. Kinzer Spring, about half a mile southwest of Shawver Mill.
11. Blue Spring, western part of Burkes Garden.
12. Fish Spring, 1 mile east of Littletown in Burkes Garden.
13. Bluefield College Spring, about one-eighth of a mile north of State Highway 85, south of Bluefield, Virginia.
14. R. L. Horner Spring, about 1¼ miles southwest of Ceres on the South Fork of Holston River.
15. Boiling Spring, about one-third of a mile northeast of Ceres, along the North Fork of Holston River.
16. Sharon Springs, near State Highway 42.

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[238] Collins, W. D., and others, Springs of Virginia: Virginia Division of Water Resources and Power, Bull. 1, pp. 16-17, 1930.

[239] Stratrigraphic determinations by the writer.

low "The Peak." The principal source of water, however, is Cox Branch, one mile north of Gratton. Water from this stream and the springs is piped to a 150,000-gallon steel standpipe located along Road 648 at the eastern limits of the town and into a 200,000-gallon open concrete reservoir on Marion Avenue in the town.

Bluefield, Virginia, obtains its water from Dills Spring and Bluestone River. The spring water is filtered and treated with chlorine. The river water, obtained two miles southwest of the town, is treated with aluminum sulphate, lime, and chlorine. The filtration plant, located near Dills Spring, has a daily capacity of 500,000 gallons.

MINERAL RESOURCES

GENERAL STATEMENT

The Burkes Garden quadrangle contains a variety of mineral resources, most important of which are limestone, dolomite, and coal. A few resources may be worthy of development at the present time; others have only potential value.

Many factors, besides quality and quantity, must be considered in determining the value of a mineral deposit. These include: (1) possible competition with other mineral industries already utilizing the same or similar material; (2) accessibility to transportation routes and markets; (3) present and probable future demands for the material; and (4) quarrying, mining, and processing costs for the whole period of operation. The wise and profitable development of mineral resources depends largely upon preliminary consideration of these factors.

LIMESTONE AND DOLOMITE[240]

CHEMICAL AND LITHOLOGIC VARIETIES

Limestone and dolomite are widely used in agriculture and industry for their chemical ingredients. New industrial developments are constantly creating new uses for limestone and dolomite; consequently, their consumption is steadily increasing. In common parlance, the terms limestone and dolomite are loosely used, but in discussing their chemical uses the writer recognizes several varieties, namely:

High-calcium limestone—limestone containing more than 95 per cent calcium carbonate.

High-carbonate limestone—limestone containing more than 88 per cent calcium carbonate and sufficient magnesium carbonate to make the total carbonate content greater than 95 per cent.

Impure limestone—Limestone composed mainly of calcium carbonate, with not more than 10 per cent magnesium carbonate, and with small, variable amounts of silica, alumina, and iron oxide.

Magnesian limestone—a dolomitic limestone containing 10 to 40 per cent magesium carbonate.

High-magnesium dolomite—a dolomite containing more than 40 per cent magesium carbonate, more than 53 per cent calcium carbonate, and less than 7 per cent impurities.

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[240] Limestone and dolomite used for crushed stone and construction purposes are discussed on pages 270-273.

The only infallible method for identifying these chemical varieties of limestone and dolomite is by quantitative chemical analysis.

In the Burkes Garden quadrangle several lithologic varieties of limestone and dolomite have been found to have characteristic chemical compositions. The commonest variety of limestone in the area is dark bluish-gray, medium to fine grained, and medium to thin bedded, but is generally too high in silica content to qualify as high-calcium or high-carbonate limestone. In a few localities, limestones of this color and texture, but thicker bedded, contain slightly more than 95 per cent calcium carbonate. In this area, high-calcium limestones are almost invariably one of two distinct lithologic types. One is exceedingly fine grained, dense, and prevailingly dove-gray (calcilutyte); the other is coarse grained and light-gray to pinkish (calcarenyte). Thinner bedded limestones of these textures, as well as oolitic limestones, limestone-pebble conglomerates, and dark-gray crinoidal limestones, are generally near the border line between high-calcium and high-carbonate rocks.

The fine-grained, dark-gray, impure-looking dolomites in the Honaker formation are surprisingly high in magnesium carbonate. Coarse grained dolomites in the Copper Ridge and Beekmantown formations are also high-magnesium rocks, but they occur in thinner zones than do the high-magnesium dolomites of the Honaker.

USES

Table 3 shows the principal uses of various types of chemical limestone and dolomite. Almost half the annual production of chemical limestone in the United States is used as an iron-ore flux. Large amounts are also used in agriculture as a soil conditioner and acid neutralizer and in the manufacture of Portland cement and alkali products. Most of the remainder is used in the refining of sugar and in the manufacture of sodium carbonate, paper, and glass. Dolomite is less extensively used, but fairly large quantities are used in making dead-burned dolomite which is used as a refractory. In recent years the production of magnesium metal from dolomite[242] has been perfected, and this may become the principal use for this rock. Dolomite is being used more and more in agriculture as a soil conditioner and acid neutralizer and in the manufacture of

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[242] Singewald, J. T., Jr., Magnesia sources and the magnesium-metal problem: Pit and Quarry, vol. 35, pp. 45-48, 50, 1942.

TABLE 3.—*Important chemical uses of limestone and dolomite*[241]

USES	High-calcium limestone	High-carbonate limestone	Impure limestone	Magnesian limestone	High-magnesium dolomite
Agricultural limestone or "agstone"	x	x	x	x	x
Alkalies	x	x			
Ammonia (cyanamide process)	x	?			
Calcium carbide	x				
Dolomite refractories				?	x
Fluxing					
Open-hearth furnace	x	x			
Blast furnace	x	x		x	x
Nonferrous metals	x	x			
Glass manufacture	x	x			x
Lime					
High-calcium lime	x				
Low-magnesium lime		x		x	
High-magnesium lime				?	x
Hydraulic lime			x		
Magnesium metal manufacture					x
Mine dust (bituminous coal mines)	x	x		x	x
Natural cement			x		
Paper manufacture					
Sulphite pulp (Tower system)	x				x
Sulphite pulp (milk-of-lime system)					x
Soda pulp and sulphate pulp	x				
Plastics	x	?			
Portland cement	x	x	x		
Rock wool	x	x	x	x	x
Salt manufacture	x	?			
Sugar refining	x				
Whiting substitute	x	x		x	x

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[241] Data obtained mostly from Lamar, J. E., and Willman, H. B., A summary of the uses of limestone and dolomite: Illinois Geol. Survey Rept. Investig., No. 49, 50 pp., 1938.

magnesian plasters. Since most chemical uses demand a very pure type of limestone, high-calcium limestone is in greater demand and of greater immediate value than other varieties.

Impure limestones are of little importance for chemical uses, except in the manufacture of hydraulic lime and Portland cement. Limestones suitable for use in the manufacture of Portland cement may contain considerable silica, alumina, and iron oxide, but they should be relatively free of chert. Limestones containing partings and intercalations of shale, such as found in the lower part of the Martinsburg, can also be used, provided that the noncarbonate content does not exceed 25 per cent. In the manufacture of rock wool even greater latitude in chemical composition is permissible; limestone containing as little as 60 per cent calcium and magnesium carbonates has been used. Iron compounds, particularly iron sulphide, are objectionable. Hydraulic lime is made from impure limestone containing 10 to 20 per cent silica, with or without iron oxide and alumina[243]. Cherty and sandy limestones can not be used, because the contained silica is not evenly distributed in the rock.

STRATIGRAPHIC OCCURRENCE

High-calcium limestones.—High-calcium limestones, in the form of calcilutyte, occur in the Five Oaks and Peery members of the Cliffield formation, locally at other horizons in the Cliffield, and in the Gratton limestone. The Five Oaks limestone occurs in all the belts of Ordovician limestone in the quadrangle, but is thin and locally absent southwest of the Saltville-Bland fault. The Peery calcilutytes are developed mainly along the southeast base of Buckhorn Mountain southwest of Gratton and in Clinch and Bluestone valleys. In the vicinity of St. Clair and along the southwestern base of Buckhorn Mountain, about a mile north of Gratton, the Cliffield formation is abnormally thick and is composed principally of calcilutyte. In the locality north of Gratton, dark bluish-gray, cherty limestones, which are elsewhere characteristic of the Lincolnshire, Ward Cove, and Peery members, form only a few thin intercalations in a succession of 540 feet of dove-gray calcilutyte. At St. Clair also, calcilutytes almost entirely supplant cherty, dark-gray limestones.

High-calcium limestones in the form of coarse-grained, light-gray limestones (calcarenytes) occur principally at the base of the Ward Cove limestone member of the Cliffield formation and in equivalent beds in the Effna limestone, but a few zones of coarse-grained, crinoidal limestone in the Mississippian formations are pure enough to be included in this category. Locally, in the vicinity of Cave Spring, coarse-grained limestones largely supplant the dark-gray, cherty limestones which normally compose the greater part of the Lincolnshire and Ward Cove members. Here only a few beds of impure limestone are intercalated in a succession of 250 to 300 feet of coarse-grained limestone.

High-carbonate limestones.—The lowest zone of high-carbonate limestone in the Burkes Garden quadrangle is in the lower part of the

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[243] Eckel, E. C., Cements, limes and plasters, pp. 176-181, New York, John Wiley and Sons, 1928.

Beekmantown formation. The thickness in the belt southeast of the Saltville-Bland fault is 30 to 50 feet. This zone is not exposed in Burkes Garden and it is thin or absent in the upper end of Thompson Valley and in Clinch and Bluestone valleys. The thickest development of the limestone in the Beekmantown is one-fourth of a mile west of Mt. Olivet Church, near Gratton, where it is about 75 feet thick. Locally, in Clinch and Bluestone valleys, the Ward Cove member of the Cliffield contains no chert and averages above 95 per cent carbonate. Except for the few cherty beds at the top of the Benbolt limestone, the cross-bedded limestones in the upper part of this formation are high-carbonate rocks. At places in the valley of the South Fork of Clinch River, the crumbly limestones immediately beneath the cross-bedded limestones are high-carbonate rock. The Gratton formation locally contains intercalations of granular, dark-gray limestone which lower somewhat the calcium carbonate content of the formation as a whole. In Clinch and Bluestone valleys, particularly between Wittens Mills and Divide Church, these intercalated granular limestones are abundantly developed, and the formation is a high-carbonate limestone. Most of the calcilutytes, oolitic limestones, and coarse-grained limestones in the Mississippian formations are high-carbonate limestones, but intercalations of shale and shaly limestone, commonly poorly exposed, reduce greatly the thickness of quarriable zones. At St. Clair, near Cave Spring, and three-quarters of a mile north of Gratton, considerable thicknesses of high-carbonate limestone occur in association with locally thick zones of high-calcium limestone.

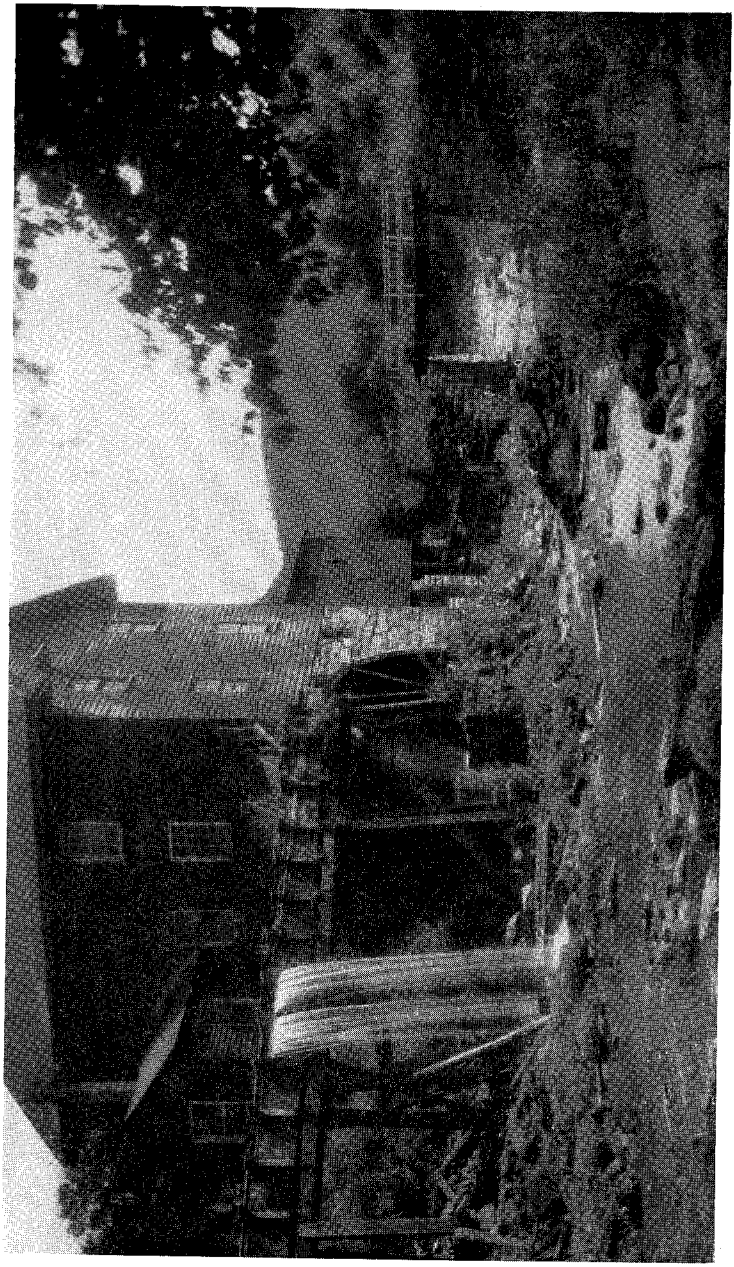
Impure limestones.—Most of the impure limestone in the Burkes Garden quadrangle is cherty and, because of this, it is unsuited for chemical uses, except possibly for agricultural purposes. Shaly limestones and nodular-weathering limestones containing considerable clay and silica occur in the Shannondale member of the Benbolt, in the Moccasin and Eggleston, and in the lower part of the Martinsburg formations. In the valley between Walker and Brushy mountains, the Athens limestone is the only distinctively argillaceous limestone below the Moccasin formation.

Magnesian limestones.—Most of the irregularly laminated, bluish-gray limestone of the Maryville type in the Honaker formation contains about 20 per cent magnesium carbonate. This limestone occurs only in belts of Honaker northwest of the Saltville fault. Most of the magnesian limestone in the quadrangle occurs in the Beekmantown and Copper Ridge formations in beds that are medium to fine grained, dense, and commonly cherty and sandy. Chert is not as abundant in the Copper Ridge as it is in the Beekmantown. Quarriable thicknesses of magnesian limestone, relatively free of chert and sand, do not exceed 50 feet in the Beekmantown and 100 feet in the Copper Ridge.

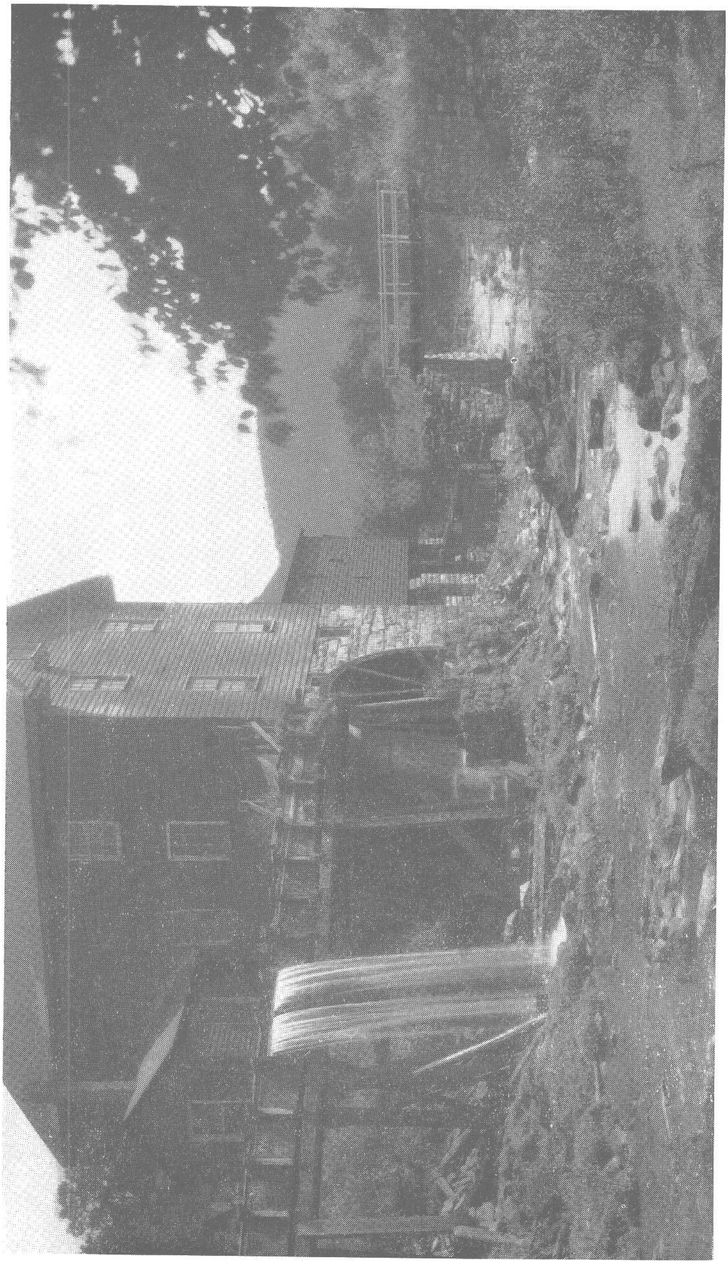
High-magnesium dolomites.—Dolomites containing over 40 per cent magnesium carbonate occur in the Beekmantown, Copper Ridge, and Honaker formations, but zones of quarriable thickness occur mainly in the Honaker. Most of the high-magnesium beds in the Beekmantown and Copper Ridge are coarse grained and relatively light-colored. Those in the Honaker are fine grained and relatively dark-gray. Both chert and sand are rare in the Honaker, so that the quarriable zones of high-magnesium rock are much thicker in this formation than those in the Copper Ridge and Beekmantown. The main body of high-grade dolomite in the Honaker is in the upper 400 feet of the formation, in the belt north of Wittens Mills. All the Honaker southeast of the Saltville-Bland fault is dolomite but because of its remote location was not sampled.

QUARRIES

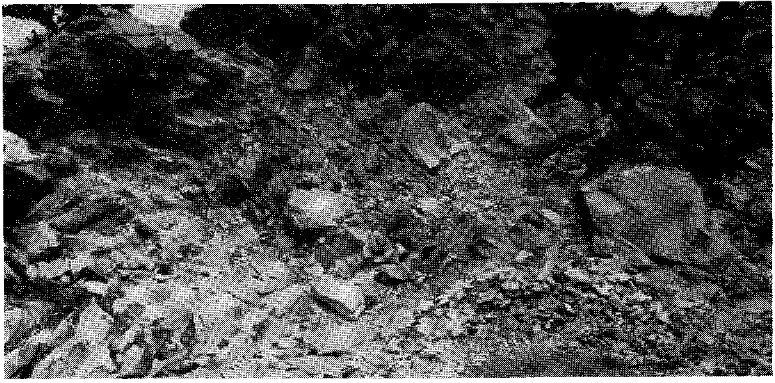
Five Oaks Lime Company.—The Five Oaks Lime Company's quarry (Pl. 21C), at Five Oaks is an open cut about 100 feet deep, about 100 feet wide, and about 175 feet long, in the Five Oaks limestone member of the Cliffield formation. The quarry floor is about 50 feet above stream level. Overhanging ledges of Lincolnshire limestone on the south side of the quarry are too cherty to be usable. The north wall of the quarry is composed of cherty limestone of the Blackford member of the Cliffield. Between the Blackford and Lincolnshire about 50 feet of high-calcium limestone occurs, but slumping of the overburden has concealed much of the quarry rock. Chemical and building lime was produced here, but the plant was not in operation when last visited in 1942.



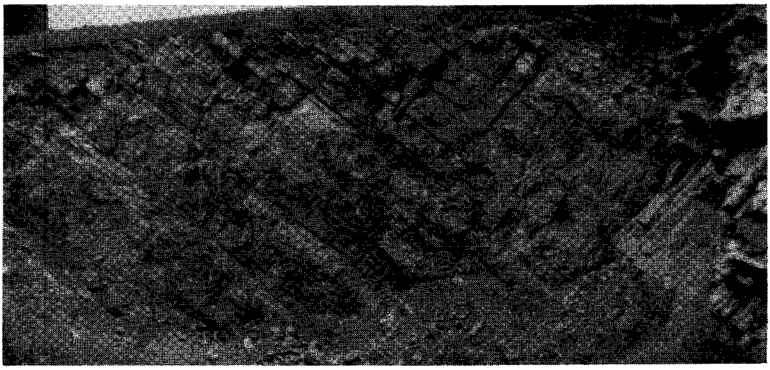
Wittens Mill on North Fork of Clinch River, Tazewell County, Virginia. (Photograph by J. O. Cammack.)



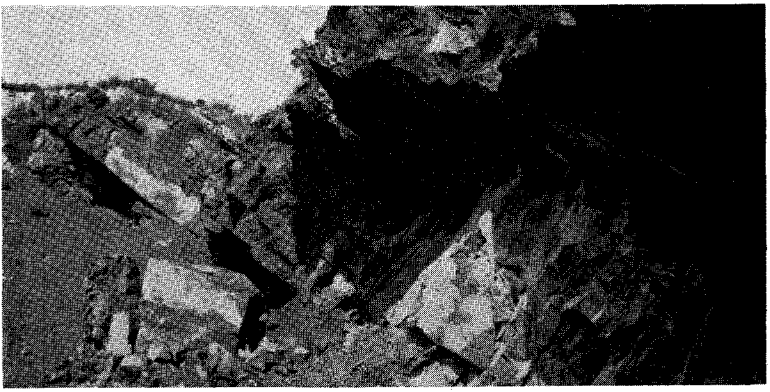
Wittens Mill on North Fork of Clinch River, Tazewell County, Virginia. (Photograph by J. O. Cammack.)



A.



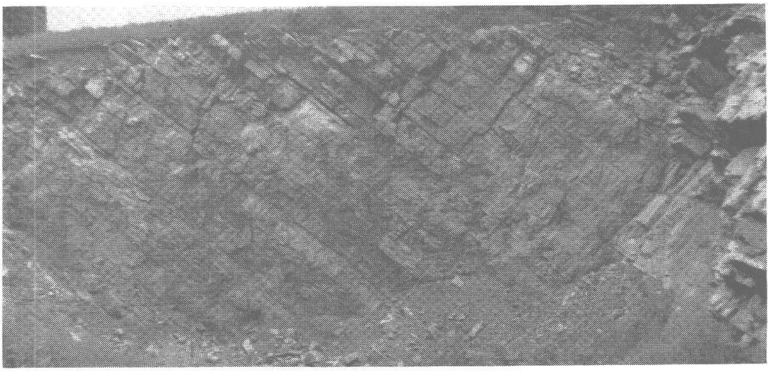
B.



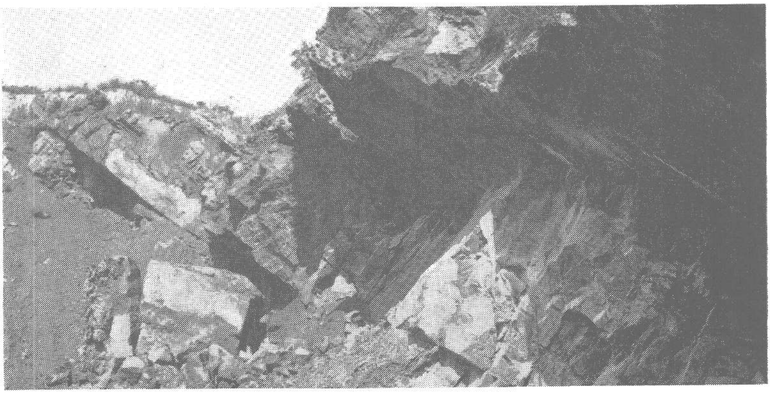
C.

A, McNutt quarry, in reefy part of the Effna limestone; near Sharon Springs. B, Quarry at Five Oaks; in upper part of the Beekmantown formation and lower part of the Blackford member. C, Quarry in Five Oaks limestone member at Five Oaks; overhanging ledge on right is cherty Lincolnshire limestone.

A.



B.



C.

A, McNutt quarry, in reefy part of the Effna limestone; near Sharon Springs. B, Quarry at Five Oaks; in upper part of the Beekmantown formation and lower part of the Blackford member. C, Quarry in Five Oaks limestone member at Five Oaks; overhanging ledge on right is cherty Lincolnshire limestone.

Geologic Section 50.—Quarry of the Five Oaks Lime Company, Five Oaks, Tazewell County, Virginia

	Thickness	
	Ft.	In.
Cliffield formation		
Lincolnshire limestone member (lower part)		
10. Limestone, dark bluish-gray, medium grained, dense, cherty	35±	
Five Oaks limestone member		
9. Calcilutyte, light dove-gray; deeply weathered at top of quarry	50	
Blackford member		
8. Calcilutyte, light-gray, cherty	1	3
7. Calcilutyte, dove-gray	1	2
6. Calcilutyte, cherty	1	5
5. Calcilutyte, gray	1	1
4. Calcilutyte, cherty	1	2
3. Limestone, light-gray, fine grained	4	2
2. Covered	2	6
1. Calcilutyte, argillaceous, thin bedded		9

McNutt quarry.—The McNutt quarry, 1¾ miles east-southeast of Sharon Springs (Pls. 1, 21A), is a small operation in Effna limestone which here contains more than 97 per cent calcium carbonate. All the rock is ground and sold locally for agricultural limestone. Reserves of limestone are more than ample for long production at the present rate. Units 2 and 3 of geologic section 50 are the quarried beds.

QUARRY SITES

General statement.—Sites where relatively small quantities of limestone or dolomite could be quarried for agricultural use are almost unlimited. The age and stratigraphic position of the various kinds of limestone and dolomite, previously given, together with the distribution of rock formations (Pl. 1), provide the information necessary for the location of small quarries for agricultural limestone. The quarry sites herein discussed in detail are possible sites for relatively large operations. Quantity and quality of a limestone or dolomite and its proximity to a railroad are the principal factors in determining the value of possible sites for shipping quarries. In a few instances, the great quantity and relatively high quality of rock available locally overshadow the more remote location of a limestone deposit. Impure limestones occur in such abundance throughout the Appalachian Valley in Virginia that only those occurrences adjacent to railroads can be considered to have any immediate value.

High-calcium limestone.—Relatively great thicknesses of high-calcium limestone occur in the Cliffield formation exposed along Road 650 south of St. Clair Station on the Norfolk and Western Railway. Butts'[244] detailed description of the limestones at this locality is given below. Analyses of samples collected by Butts from units 3 to 30 of geologic section 51 are shown in Table 4. The formation names used by Butts have been changed to conform to the stratigraphic nomenclature used in this report.

Geologic Section 51.—Cliffield formation south of St. Clair Station, along Road 650, Tazewell County, Virginia
(After Butts)

		Thickness Feet
Benbolt limestone		
Cliffield formation (1,222 feet)		
31.	Limestone, thick bedded, compact, calcite veins, dove-colored; with *Lophospira*	70
30.	Limestone, partly exposed	75
29.	Limestone, partly exposed, dark-colored, shaly; contains *"Rafinesquina"* sp., *Rhinidictya* sp., and *Isochilina* sp.	70
28.	Limestone, mainly thick bedded, compact, veined with calcite, dove-colored; contains *Lophospira, Maclurites,* or *Eotomaria*	105
27.	Limestone, thick bedded, mainly dark dove-colored; a little is pure, dove-colored, compact	85
26.	Limestone, thick bedded to medium thick bedded, mainly compact, dove-colored	55
25.	Limestone, mainly compact, dark dove-colored; a few argillaceous layers	40
24.	Limestone, dark dove-colored	50
23.	Limestone, compact or subcrystalline, dark dove-colored; slightly compact	20

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[244] Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. 1, pp. 123-124, 1940.

	Thickness Feet
22. Limestone, finely crystalline, thinly laminated	25
21. Not exposed	20
20. Limestone, finely crystalline, dark- to dove-colored; with bryozoa	22
19. Limestone, thick and thin bedded, some shaly; a little chert; dove-colored and dark dove-colored with *Helicotoma tennesseensis* Ulrich and Scofield	45
18. Limestone, thick bedded, mostly compact, dove-colored and dark dove-colored; with *Lophospira* and other gastropods	65
17. Limestone, variable, thick and thin bedded, dove-colored and dark dove-colored; argillaceous streaks; lower 2½ feet shaly; with *Tetradium syringoporoides* Ulrich	20
16. Limestone, medium thick bedded, mainly dark dove-colored; ostracodes abundant in some layers	16
15. Limestone, argillaceous	4
14. Limestone, medium bedded, mainly compact, dove-colored	14
13. Limestone, argillaceous	2
12. Limestone, medium bedded, compact, dove-colored	6
11. Limestone, fossiliferous; contains *Tetradium syringoporoides* Ulrich	4
10. Limestone, thick bedded, compact; light-gray with ostracodes	19
9. Limestone, as above with calcite eyes; *Zygospira*? cf. *Z. acutirostris* (Hall)	21
8. Limestone, as above, cherty below	20
7. Limestone, bluish-gray, finely striped; nodules and plates of black chert, with *Tetradium* sp.	8
6. Limestone, bluish-gray, finely striped, fine-grained	7
5. Limestone, thick bedded, light-colored, rather dense	13
4. Limestone, medium bedded, fine grained, dark drab-colored; a few fossils	40
3. Limestone, compact, pearl-gray	1
2. Limestone, partly exposed across low ground; apparently all fine grained	280
Beekmantown formation	
1. Dolomite	1,000

The principal zones of high-calcium limestone south of St. Clair are: (1) a zone 150 feet thick, at the top of the Cliffield, which crosses Road 650 south of St. Clair School; (2) a zone 180 feet thick, 250 feet stratigraphically below the top of the Cliffield, which crosses Road 650 immediately south of St. Clair School; and (3) a 100-foot zone crossing the same road midway between the schoolhouse and the intersection with U. S. Route 19. These zones can be traced half a mile northeast of Road 650 and slightly farther southwest of this road. In the area immediately east of the road, the available quantity of high-calcium limestone is estimated to be about 10 million tons. Southwest of the schoolhouse, the same zones of high-calcium limestone occur in a low ridge rising 100 to 200 feet above drainage. The amount of recoverable high-calcium stone here is several times that occurring east of Road 650. Considering the Cliffield formation as a whole, in the section south of St. Clair Station, the entire thickness is high-carbonate limestone. The upper half, which is free of chert, would be a suitable quarrying unit, particularly for obtaining large quantities of high-carbonate limestone. The tract should be test drilled to determine the depth of the water table, the amount of overburden, and the extent of solution channels.

Three-fourths of a mile north-northwest of Gratton, the Cliffield formation, which crops out on a gentle slope in a belt about 800 feet wide, contains a thickness of about 550 feet of calcilutyte, much of which is high-calcium limestone. The following section is exposed there:

Geologic Section 52.—Cliffield formation three-fourths of a mile north-northwest of Gratton, Tazewell County, Virginia

	Thickness Feet
Cliffield formation (830 feet)	
13. Calcilutyte, light- to medium-gray; with stringers of coarse-grained calcite	29
12. Calcilutyte, light-gray, thick bedded; with intercalations of dove-gray clastic limestone; abundant veins of cream-colored calcite	44
11. Calcilutyte, dove-gray, thick bedded; contains intercalations of coarse-grained clastic limestone	29

	Thickness Feet
10. Partly covered interval; all exposed beds are similar to those in unit 9	49
9. Calcilutyte, containing abundant vugs and veins of cream-colored calcite; rather thick bedded	38
8. Calcilutyte, dove-gray; clayey near top	50
7. Calcilutyte, with intersecting stringers and partings of clay; lower part slightly granular	48
6. Calcilutyte, dove-gray; contains yellowish vugs of calcite; beds burned locally for lime	50
5. Partly covered interval; all exposed beds are calcilutyte or very finely granular limestone; numerous partings of yellowish clay	95
4. Calcilutyte, not fully exposed, dove-gray, thick bedded	124
3. Limestone, medium-gray, granular, argillaceous	34
2. Limestone, coarse-grained, argillaceous, dark-gray; contains nodules of black chert	50
1. Covered interval; to approximate base of formation	190

The upper 200 feet of the Cliffield averages well above 95 per cent calcium carbonate. East of this locality the limestones are concealed by alluvium. The character of the limestones changes less than half a mile southwest of this locality, so that the locally thick development of calcilutyte probably does not extend more than one-fourth of a mile southwest of the location of geologic section 52. Within the local area of known occurrence of the abnormally thick development of calcilutyte, from 5 to 10 million tons of high-calcium limestone or from 10 to 20 million tons of high-carbonate limestone is estimated to be available for quarrying. These estimates are based partly on the assumption that it would be feasible to quarry the entire thickness to a depth of only 150 feet below the surface. Test drilling, particularly in the flat area containing relatively few exposures, should be done in order to determine the thickness of the overburden and the depth of the water table.

In the vicinity of Cave Spring, the Cliffield formation contains 250 to 300 feet of coarse-grained, clastic-textured limestone which is about 98 per cent calcium carbonate. The beds extend northeastward for one-fourth of a mile and southwestward but with slight diminution in thickness, for more than three-fourths of a mile. The coarse-grained limestones crop out mainly on the lower steep slopes at the base of Buckhorn Mountain. Several large springs issue from the coarse-grained beds, and it is not unlikely that considerable underground solution has taken place. Test drilling should be done to determine the extent of cavernous channels. Surface indications are that several million tons of high-calcium limestone could be quarried in this locality.

North of the end of Road 646, the Cliffield formation is exposed on a steep southeast slope of a hill which is about 300 feet high (Pl. 6A). The beds dip 55° to 90° N.W., and strike about N.75°E. In this hill about 40 million tons of stone, including considerable quantities of high-carbonate limestone and high-calcium limestone, could be quarried. The thickness and character of the various lithologic zones of the Cliffield and other Ordovician limestones are shown in the following section:

Geologic Section 53.—Cliffield and overlying limestone formations north of Road 646, near Concord Church, Tazewell County, Virginia

	Thickness Feet
Moccasin formation (50+ feet)	
34. Mostly red mudrock; thickness not determined....	
33. Limestone and mudrock, brick-red and pale green	50
Witten limestone (141 feet)	
32. Limestone, fine grained, golden-gray	72
31. Limestone, mostly coarse-grained, gray, shaly at base	17
30. Calcilutyte, dove-gray, medium bedded; contains argillaceous partings	40
29. Limestone, straticulate, dove-gray	12
Wardell (?) formation (8 feet)	
28. Limestone, nodular, contains lenses of coarse-grained limestone	8
Gratton limestone (65 feet)	
27. Calcilutyte, dove-gray, slightly granular near base	50
26. Limestone, slightly cherty, finely granular, straticulate	15

	Thickness Feet
Benbolt limestone (45 feet)	
25. Limestone, cross laminated, thin bedded, coarse grained	20
24. Limestone, argillaceous, nodular	25
Cliffield formation (673± feet)	
23. Calcilutyte, dove-gray; contains many intercalations of limestone of uneven texture	30
22. Limestone, coarse grained, granular; contains pebble-like inclusions of fine-grained limestone; weathers nodular because of wavy streaks of clay	68
21. Calcilutyte, light gray, somewhat cherty; partly covered	25
20. Calcilutyte, very cherty in lower part, upper part massively bedded	90
19. Limestone, gray, uneven grained	20
18. Calcilutyte, taupe-gray; in 6- to 8-inch beds	15
17. Limestone, coarse grained, gray	55
16. Limestone, light-gray, argillaceous, uneven texture	18
15. Limestone, uneven texture, dark-gray	29
14. Limestone, coarse grained, light-gray, clastic texture, partly cross laminated	40
13. Limestone, pseudo-conglomeratic, texture very irregular; inclusions of fine-grained limestones	32
12. Limestone, coarse grained, dark-gray; bedding uneven	7
11. Limestone, fine grained, dense, brownish-gray, mottled; bedding uneven	10
10. Limestone, dark-gray, dense, nodular, very cherty	14
9. Limestone, medium-gray, fine grained; texture uneven	14
8. Limestone, clastic texture; thin, wavy beds	67
7. Limestone, dark bluish-gray, with peculiar "worm-eaten" appearance	7
6. Limestone, dark bluish-gray, slightly cherty	10

	Thickness Feet
5. Limestone, dark bluish-gray, thin bedded, with a one-foot intercalation of calcilutyte two feet above the base	27
4. Calcilutyte, dark-gray, medium bedded	25
3. Chert, blocky, light-gray; fine-grained limestones intercalated in the chert	40
2. Shale, ash-gray; contains a few beds of shaly limestone	15
1. Partly covered; contains a few exposures of maroon-drab to brick-red silty dolomite and beds of chert conglomerate	5–15

Analyses of units 7, 8, 9, 13, 15, 16, 17, 18, 20, 21, and 25 are given in Table 4.

A considerable thickness of high-carbonate limestone occurs on the slopes south of the Norfolk and Western Railway about 1 mile west of Tiptop. The best quarry sites are mainly on the "Ste. Genevieve" limestone. (See geologic section 41.) Analyses of outcrops of the various lithologic types of limestone occurring in this locality are shown in Table 4. The area which could be developed is a narrow strip about half a mile long and 300 feet wide, on either side of a north-flowing tributary of Clinch River, which descends Valley Ridge. The hill on either side of this stream would yield about 1 million tons of high-carbonate rock. Some selective quarrying would have to be done to avoid intercalations of greenish-gray shale and shaly limestone. The beds are overturned and dip about 60° SE.

Impure limestone.—Favorable sites for quarrying impure limestone suitable for use in the manufacture of Portland cement and rock wool occur along the Norfolk and Western Railway about a mile southwest of Tiptop, and about half a mile south of Five Oaks. The locality southwest of Tiptop, previously referred to as a possible source of high-carbonate limestone, can furnish considerably greater quantities of argillaceous limestone if both high carbonate and clayey beds are quarried as a unit. These limestones do not contain sufficient silica and alumina to be natural cement-rocks or natural wool-rocks and would have to be mixed with shale. A suitable mix for the manufacture of either rock wool or Portland cement could be obtained by mixing various Mississippian limestones with the calcareous shales of the Bluefield formation, which are exposed along the northwest side of Wrights Valley. (See Table 4.)

The best quarry site for cement or rock-wool materials along the Norfolk and Western Railway half a mile southwest of Five Oaks is the hill between the railroad and Road 678. Formations occurring in this locality are described in the following section:

Geologic Section 54.—Middle Ordovician formations along the Norfolk and Western Railway, about one-fourth of a mile south-southwest of Five Oaks, Tazewell County, Virginia

	Thickness Feet
Martinsburg formation (lower part only)	
10. Limestone and shale, intricately folded; only partly exposed	200+
Eggleston formation (50 feet)	
9. Shale and limestone; partly exposed	50
Moccasin formation (325 feet)	
8. Mudrock, mostly maroon-drab; contains thin intercalations of dove-gray and variegated limestone; silty at top	325
Witten limestone (142 feet)	
7. Limestone, fine grained, thin bedded, weathers slabby	55
6. Limestone, coarse grained, thin bedded, shaly toward base	22
5. Calcilutyte, argillaceous, golden-gray to buff, medium to thin bedded	40
4. Limestone, fine grained, dense; finely straticulate	25
Gratton limestone (90+ feet)	
3. Calcilutyte, medium to thick bedded; contains few intercalations of dark-gray granular limestone	65
2. Limestone, slightly argillaceous, finely laminated	25+
Benbolt limestone (5± feet)	
1. Limestone, coarse-grained, nodular, argillaceous	5±

Analyses of limestone samples, collected by Bassler[245] from limestones exposed in this vicinity, are included in Table 4.

Dolomite.—Extensive deposits of magnesian limestone and lesser amounts of high-magnesium dolomite occur along the Norfolk and Western Railway in the immediate vicinity of Wittens Mills in the Copper Ridge and Beekmantown formations. The rock which could be quarried here lies on the south side of Lynn Hollow and east of the railroad in an area about 150 feet above drainage and is covered by a relatively thin overburden. The rocks are exposed along the Norfolk and Western Railway, where the following section was measured:

Geologic Section 55.—Magnesian limestone and dolomite exposed along the Norfolk and Western Railway, in the vicinity of Wittens Mills, Tazewell County, Virginia

	Thickness	
	Ft.	In.
Cliffield formation		
Beekmantown formation (787½ feet)		
57. Poorly exposed; contains fine-grained dolomite with pinkish blotches, with a few beds of dolomite conglomerate	78	
56. Dolomite, gray, medium grained, cherty	37	
55. Covered interval	386	
54. Dolomite, coarse grained, reddish blotches; with thin partings of red shale, cherty	34	
53. Dolomite and chert, interbedded; dolomite is gray; chert is gray and white banded	14	
52. Dolomite, gray, very cherty, medium grained	32	
51. Dolomite, coarse grained brownish-gray; vugs and stringers of dolomite and calcite	41	
50. Dolomite, light pearl-gray, fine grained	19	
49. Dolomite, fine grained, pearl-gray	21	
48. Dolomite, gray with pink streaks	15	
47. Dolomite, gray, fine grained	11	
46. Dolomite, dark gray, fine grained	3	
45. Dolomite, gray, medium grained; chert in thin layers	18	

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[245] Bassler, R. S., The cement resources of Virginia west of the Blue Ridge: Virginia Geol. Survey Bull. 2A, pp. 210-214, 1909.

		Thickness	
		Ft.	In.
44.	Dolomite, dark-gray, medium grained	30	
43.	Dolomite, gray, fine grained	7	3
42.	Dolomite, medium grained, gray; contains 1-inch chert beds and thin intersecting streaks of quartz sand	22	2
41.	Dolomite, light-gray, fine grained	12	
40.	Dolomite, buff-gray, with thin streaks of sand		7
39.	Dolomite, light-gray, fine grained	6	6
Copper Ridge formation[246] (465+ feet)			
38.	Dolomite, finely straticulate; contains thin sandy streaks	14	
37.	Dolomite, gray, medium grained; crinkly laminae	10	10
36.	Dolomite, light-gray, fine grained	24	
35.	Dolomite, medium-gray, medium grained	32	6
34.	Covered interval	14	
33.	Sandstone, dolomitic, buff-gray	1	2
32.	Dolomite, fine grained, light-gray	7	
31.	Dolomite, coarse grained, gray, cherty	5	
30.	Chert, gray		6
29.	Edgewise conglomerate; composed of dolomite pebbles set in matrix of coarse dolomite		8
28.	Dolomite, coarse grained, buff-gray; contains lenses of chert 1 to 5 inches thick	27	
27.	Dolomite, light-gray, medium grained	23	
26.	Dolomite, gray, medium grained	29	
25.	Covered interval	28	4
24.	Sandstone, buff-gray	7	4
23.	Dolomite, gray, fine grained; with thin beds of chert and a few sandy streaks	33	
22.	Dolomite, coarse grained, white to buff	14	
21.	Dolomite, fine grained, light-gray	15	
20.	Dolomite, very fine grained, light-gray; with crinkly laminae of fine-grained sandstone	19	
19.	Dolomite, fine grained, gray	23	
18.	Dolomite, very coarse grained light-gray	13	
17.	Dolomite, gray, medium grained	4	
16.	Sandstone, dolomitic, buff-gray	2	7

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[246] Boundary uncertain.

		Thickness Ft.	In.
15.	Dolomite, gray, coarse grained	3	
14.	Sandstone, buff-gray, dolomitic; contains a few thin beds of edgewise conglomerate	7	
13.	Dolomite, light-gray	12	
12.	Dolomite, gray, medium grained	3	
11.	Dolomite, light-gray	15	
10.	Shale		5
9.	Dolomite, medium grained, buff-gray	4	7
8.	Dolomite, brownish-gray; with thin siliceous crinkly laminae	9	
7.	Dolomite, pearl-gray, medium grained	4	
6.	Sandstone, buff	1	7
5.	Dolomite, gray, thick bedded	11	5
4.	Dolomite, gray, fine grained	1	
3.	Sandstone	3	8
2.	Dolomite, gray, medium grained, dense	14	
1.	Covered interval to base of section at south end of railroad bridge at Wittens Mills Station	28	

Extensive deposits of high-magnesium dolomite occur in the upper 375 feet of the Honaker formation along the Norfolk and Western Railway between Puckett Hollow and the highway underpass north of Wittens Mills Station. The analysis of a sample from this body of dolomite is given in Table 4.

ANALYSES

The chemical composition of 73 rock samples, mostly limestones and dolomites, is given in Table 4. The limestone samples from the Ward Cove, Witten, Moccasin, and Martinsburg, near Five Oaks, were collected by R. S. Bassler[246a]. The limestones south of St. Clair Station were sampled by Charles Butts of the Virginia Geological Survey and analyzed by John H. Yoe, chemist of the Survey. The other samples were collected by the writer and, with two exceptions, were analyzed by Doctor Yoe. The samples of Honaker dolomite, north of Wittens Mills, and of Cliffield limestone, north of Gratton, were analyzed by Froehling and Robert-

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[246a] Bassler, R. S., The cement resources of Virginia west of the Blue Ridge: Virginia Geol. Survey Bull. 2A, pp. 210-213, 1909.

son, Inc. The two analyses of the Lincolnshire limestone represent the composition of the rock exclusive of chert nodules which generally compose 5 to 10 per cent of the bulk of the rock.

TABLE 4.—*Analyses of various rocks in the Burkes Garden quadrangle, Virginia*

STRATIGRAPHIC NAME	ROCK TYPE	GEOLOGIC SECTION		SiO_2	R_2O_3	$CaCO_3$	$MgCO_3$	TOTAL	Thickness in feet of sampled interval	GENERAL LOCATION
		Number	Units							
Honaker	Dolomite	1	14–19	1.53	1.68	53.93	43.17	100.31	375	Along Norfolk and Western Railway, Wittens Mills.
Copper Ridge	Dolomite	55	36	9.36	1.10	50.67	39.45	100.58	24	Along Norfolk and Western Railway, Wittens Mills.
Copper Ridge	Dolomite	55	22	8.35	0.84	51.29	39.75	100.24	14	Along Norfolk and Western Railway, Wittens Mills.
Copper Ridge	Dolomite	55	19	11.92	2.36	48.92	37.11	100.31	23	Along Norfolk and Western Railway, Wittens Mills.
Copper Ridge	Dolomite	55	18	14.50	4.22	46.42	34.16	99.30	13	Along Norfolk and Western Railway, Wittens Mills.
Copper Ridge	Dolomite	55	17	7.27	1.55	51.73	39.51	100.06	4	Along Norfolk and Western Railway, Wittens Mills.
Copper Ridge	Dolomite	55	8	4.33	0.81	53.79	41.16	100.09	9	Along Norfolk and Western Railway, Wittens Mills.
Copper Ridge	Dolomite	55	5	1.59	0.50	56.17	42.20	100.46	11½	Along Norfolk and Western Railway, Wittens Mills.
Beekmantown	Dolomite	55	54	14.50	4.22	46.42	34.16	99.30	34	Along Norfolk and Western Railway, Wittens Mills.

Beekmantown	Dolomite	55	51	2.76	1.12	54.85	40.31	99.04	41	Along Norfolk and Western Railway, Wittens Mills.
Beekmantown	Dolomite	55	50	14.10	1.13	48.72	36.12	100.07	19	Along Norfolk and Western Railway, Wittens Mills.
Beekmantown	Limestone			3.47	0.56	94.36	2.35	100.74	60	Along State Highway 61, near Marys Chapel.
Blackford	Chert breccia	3	1–11	21.84	5.00	40.57	34.85	102.26	78½	East of stone quarry at Five Oaks.
Five Oaks	Limestone	6	base	0.66	0.22	94.62	3.47	98.97	35	Roadside quarry along Lincolnshire Branch.
Lincolnshire	Limestone	6	1– 7	1.37	0.43	97.77	2.43	102.00	102	Roadside quarry along Lincolnshire Branch.
Cliffield	Limestone	51	3	2.47	2.83	89.79	4.88	99.97	1	Along Road 650 south of St. Clair Station.
Cliffield	Limestone	51	4	2.12	1.66	93.34	3.49	100.61	40	Along Road 650 south of St. Clair Station.
Cliffield	Limestone	51	5	1.60	1.59	93.43	3.44	100.06	13	Along Road 650 south of St. Clair Station.
Cliffield	Limestone	51	6	1.51	2.63	90.26	4.83	99.23	7	Along Road 650 south of St. Clair Station.
Cliffield	Limestone	51	7	2.37	4.54	88.93	4.87	100.71	8	Along Road 650 south of St. Clair Station.
Cliffield	Limestone	51	8	2.30	2.74	90.57	3.98	99.59	20	Along Road 650 south of St. Clair Station.

TABLE 4.—*Analyses of various rocks in the Burkes Garden quadrangle, Virginia—Continued*

STRATIGRAPHIC NAME	ROCK TYPE	GEOLOGIC SECTION		SiO_2	R_2O_3	$CaCO_3$	$MgCO_3$	TOTAL	Thickness in feet of sampled interval	GENERAL LOCATION
		Number	Units							
Cliffield	Limestone	51	9	2.27	2.51	91.37	4.18	100.33	21	Along Road 650 south of St. Clair Station.
Cliffield	Limestone	51	10	1.70	2.76	92.52	3.44	100.42	19	Along Road 650 south of St. Clair Station.
Cliffield	Limestone	51	11	0.76	2.55	92.04	5.32	100.67	4	Along Road 650 south of St. Clair Station.
Cliffield	Limestone	51	12	1.04	3.55	93.41	2.50	100.50	6	Along Road 650 south of St. Clair Station.
Cliffield	Limestone	51	13	4.93	10.14	74.62	9.74	99.43	2	Along Road 650 south of St. Clair Station.
Cliffield	Limestone	51	15	0.97	11.29	84.06	2.80	99.12	4	Along Road 650 south of St. Clair Station.
Cliffield	Limestone	51	17	1.74	5.35	89.81	3.76	100.66	20	Along Road 650 south of St. Clair Station.
Cliffield	Limestone	51	18	0.39	1.95	95.09	2.51	99.94	65	Along Road 650 south of St. Clair Station.
Cliffield	Limestone	51	19	2.80	1.29	93.26	3.20	100.55	45	Along Road 650 south of St. Clair Station.

Cliffield	Limestone	51	20	0.67	0.52	96.11	2.99	100.29	22	Along Road 650 south of St. Clair Station.
Cliffield	Limestone	51	22	2.25	2.06	92.14	4.10	100.55	25	Along Road 650 south of St. Clair Station.
Cliffield	Limestone	51	23	1.56	0.18	95.21	2.37	99.32	20	Along Road 650 south of St. Clair Station.
Cliffield	Limestone	51	24	1.16	1.42	95.00	2.36	99.94	50	Along Road 650 south of St. Clair Station.
Cliffield	Limestone	51	25	trace	6.05	85.57	7.51	99.13	40	Along Road 650 south of St. Clair Station.
Cliffield	Limestone	51	26	trace	4.61	91.83	2.95	99.39	55	Along Road 650 south of St. Clair Station.
Cliffield	Limestone	51	27	trace	1.38	98.51	0.46	100.35	83	Along Road 650 south of St. Clair Station.
Cliffield	Limestone	51	28	trace	1.39	98.67	1.02	101.08	105	Along Road 650 south of St. Clair Station.
Cliffield	Limestone	51	29	trace	2.39	96.07	1.19	99.65	70	Along Road 650 south of St. Clair Station.
Cliffield	Limestone	51	30	3.02	5.86	87.50	3.05	99.43	75	Along Road 650 south of St. Clair Station.
Cliffield	Limestone	51	31	0.34	1.94	97.18	0.97	100.43	70	Along Road 650 south of St. Clair Station.
Cliffield	Limestone	53	4– 5	0.66	0.46	98.01	0.69	99.82	52	North of the end of Road 646, near Gratton.
Cliffield	Limestone	53	7	1.79	1.02	88.28	7.47	98.56	7	North of the end of Road 646, near Gratton.

TABLE 4.—*Analyses of various rocks in the Burkes Garden quadrangle, Virginia—Continued*

STRATIGRAPHIC NAME	ROCK TYPE	GEOLOGIC SECTION		SiO_2	R_2O_3	$CaCO_3$	$MgCO_3$	TOTAL	Thickness in feet of sampled interval	GENERAL LOCATION
		Number	Units							
Cliffield	Limestone	53	8	0.08	0.18	96.39	3.24	99.89	67	North of the end of Road 646, near Gratton.
Cliffield	Limestone	53	9	3.18	1.46	89.70	5.44	99.78	14	North of the end of Road 646, near Gratton.
Cliffield	Limestone	53	12–13	1.51	0.63	96.35	1.96	100.45	39	North of the end of Road 646, near Gratton.
Cliffield	Limestone	53	14–15	1.29	0.59	96.39	1.65	99.92	69	North of the end of Road 646, near Gratton.
Cliffield	Limestone	53	16	1.47	0.65	97.15	0.90	100.17	18	North of the end of Road 646, near Gratton.
Cliffield	Limestone	53	17	0.42	0.32	98.92	0.38	100.04	55	North of the end of Road 646, near Gratton.
Cliffield	Limestone	53	18	1.08	0.53	97.04	0.94	99.59	15	North of the end of Road 646, near Gratton.
Cliffield	Limestone	53	20	2.01	0.60	94.19	3.09	99.89	90	North of the end of Road 646, near Gratton.
Cliffield	Limestone	53	21	1.13	0.32	95.91	2.92	100.28	25	North of the end of Road 646, near Gratton.

Benbolt	Limestone	53	25	1.23	0.91	97.39	1.74	101.27	20	North of the end of Road 646, near Gratton.
Ward Cove	Limestone			5.94	1.46	91.68	0.70	99.78	60	Immediately south of Five Oaks limestone quarry.
Lincolnshire	Limestone	50	10	1.14	0.57	97.62	0.45	99.78	35	Five Oaks limestone quarry.
Cliffield	Limestone			0.60	0.38	97.26	0.46	98.70	250	Vicinity of Cave Spring.
Effna	Limestone	13	2- 7	0.08	0.26	97.13	2.49	99.96	105	McNutt quarry, near Sharon Springs.
Cliffield	Limestone	52	4-13	0.47	0.95	96.60	1.52	99.54	540	Three-fourths of a mile north of Gratton.
Benbolt	Limestone	16	1- 2	0.34	0.23	98.95	2.41	101.93	10	West of cattle barn at the Tazewell County Farm.
Benbolt	Limestone	16	3	7.10	2.15	87.40	2.93	99.58	33	West of cattle barn at the Tazewell County Farm.
Benbolt	Limestone	16	4- 5	4.61	1.13	92.51	3.34	101.59	39½	West of cattle barn at the Tazewell County Farm.
Gratton	Limestone			2.67	1.52	93.09	3.67	100.95	60	On U. S. Route 19, 500 feet east of intersection with Road 650, Wittens Mills.
Witten	Limestone	54	5	6.04	1.14	91.42	0.91	99.51	40	Along Norfolk and Western Railway, near Five Oaks.
Witten	Limestone	54	7	4.56	1.84	87.75	4.40	98.55	55	Along Norfolk and Western Railway, near Five Oaks.
Moccasin	Mudrock	54	8	24.72	3.94	68.71	1.35	98.72	300	Along Norfolk and Western Railway, near Five Oaks.

TABLE 4.—*Analyses of various rocks in the Burkes Garden quadrangle, Virginia—Continued*

STRATIGRAPHIC NAME	ROCK TYPE	GEOLOGIC SECTION		SiO_2	R_2O_3	$CaCO_3$	$MgCO_3$	TOTAL	Thickness in feet of sampled interval	GENERAL LOCATION
		Number	Units							
Moccasin	Limestone (intercalated in red mudrock)	54	8	13.20	2.66	81.07	1.83	98.76	20	Along Norfolk and Western Railway, near Five Oaks.
Martinsburg	Limestone			8.14	1.24	90.25	0.58	100.21		Along Norfolk and Western Railway, near Five Oaks.
Martinsburg	Limestone			22.50	2.34	73.82	0.11	98.77		Along Norfolk and Western Railway, near Five Oaks.
Martinsburg	Limestone			28.62	3.76	65.03	2.08	99.49		Along Norfolk and Western Railway, near Five Oaks.
"Ste. Genevieve"	Limestone	41	19–20	2.12	0.68	93.92	3.54	100.26	94	Along Norfolk and Western Railway, near Tiptop.
"Ste. Genevieve"	Limestone	41	21	1.98	0.71	92.92	3.18	98.79	5	Along Norfolk and Western Railway, near Tiptop.
"Gasper"	Limestone			1.16	0.60	96.10	3.28	101.14	25	Along Norfolk and Western Railway, near Tiptop.
Bluefield	Shale			42.11	15.40	36.16	4.00	97.67	100±	Along Norfolk and Western Railway, near Bailey.

COAL

Bland and Lick Creek fields.—Coal of Mississippian age crops out on Brushy Mountain, about 450 feet stratigraphically above the base of the Price formation. Three thin, sheared beds of coal occur near the top of a 25-foot zone of gray shale which contains numerous well-preserved plant fossils. Apparently the same zone occurs along the valley of Lynncamp Creek and in the line of low hills south of Brushy Mountain and east of Road 623. The coal beds of this district have been described by Campbell[247]. His report should be consulted for information concerning the various prospects. The thickest development of coal in this quadrangle is at the west end of a low ridge made by the Price formation, about one mile northeast of Sharon Springs. The following section was measured by Campbell[248] and Howell:

	Thickness	
	Ft.	In.
Coal, soft, flaky	1	6
Shale	1	
Coal, hard	2	
Shale	1	
Coal	2	6
Total thickness of beds	8	
Total thickness of coal	6	

The best coal in this locality, sampled by Campbell[249], contained about 63 per cent fixed carbon and 14.5 per cent ash.

Coal bloom was noted by the writer about 1¼ miles northeast of the Sharon Springs locality and 150 yards north of the Saltville-Bland fault. The old prospect pits here have caved in, so that the thickness of the coal beds could not be measured. The dip of the adjacent overturned sandstones is 60° SE. Another prospect is located a short distance north of the abrupt bend in the trace of the Saltville-Bland fault (Pl. 1), near the eastern border of the quadrangle. No coal was seen east of this prospect. So far as known, little if any coal has been mined from this belt.

Coal also occurs along the southeast slope of Brushy Mountain about 250 yards north of the Saltville-Bland fault. Several small ex-

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[247] Campbell, M. R., and others, The Valley coal fields of Virginia: Virginia Geol. Survey Bull. 25, pp. 255-270, 1925.

[248] Op. cit., p. 266.

[249] Op. cit., p. 266.

posures of coal were seen, but none appeared to have been prospected. All the showings of coal between Roads 623 and 625 on Brushy Mountain occur near the bottom of deep ravines and on the northwest flank of the Greendale syncline. The beds dip about 25° SE.

Campbell[250] described three coal prospects west of Road 623. The one nearest this road shows two benches of coal 12 to 18 inches thick, separated by 2 feet of black shale. A coal bed at the head of Lynncamp Creek is reported to be 5 feet thick, but the only exposure of coal in this general area showed about 2 feet of coal split by a 3-foot zone of black shale.

None of the known coal prospects on Brushy Mountain appear to be worthy of further exploration at the present time because the average thickness of the coal is not sufficient to be minable and the quality is inferior.

Coal on Stony Ridge.—A thin bed of coal in the Bluestone formation (Mississippian) crops out in two parallel belts on the northwest slope of Stony Ridge. The structure on the northwest side of this mountain is an overturned syncline. The coal outcrops are interpreted as being a single bed which is repeated in the fold. Showings of coal were seen at several places northeast of Road 656, but none was found southwest of this road. During 1940, an opening was driven into the slope along the coal bed (Pl. 1) by Rocco Pangallo and associates. At the time of the writer's field examination in August, 1941, a narrow entry had been excavated about 75 feet into the ridge. The thickness of coal averaged less than one foot, but one measurement across a local swell showed 22 inches of coal. Dense, black claystones heavily impregnated with iron sulphide overlie the coal. The underlying beds are variegated thin-bedded sandstone and grayish-buff, iron-stained shale, Shales associated with the coal contain well-preserved plant fossils. No coal had been shipped from this prospect, and considerably less than a ton of coal was seen at the mouth of the entry.

Another coal prospect, located half a mile to the east along the strike, shows a foot of coal. A third prospect about one-fourth of a mile east of the second one showed no coal, but blocks of black claystone were piled around the opening. The coal bed at the Stony Ridge "mine" dips about 55° SE., but the dip of the same coal bed in the northern belt is only 18° SE.

The prevailing thinness and relatively steep dips of the coal in the Bluestone formation and its remote location are unfavorable to development.

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[250] Op. cit., pp. 267-268.

Laurel Creek and Horsepen basins.—Coal of Pennsylvanian (Pottsville) age occurs in the Lee formation exposed in the northwest corner of the Burkes Garden quadrangle. Considerable prospecting has been done, but very little coal has been mined. At present, none of the outcropping coals is being mined or prospected, but deeper beds are being mined by the Boissevain Colliery of the Pocahontas Fuel Company, Inc.

The structure of the field is synclinal. Beds just north of the Boissevain fault dip 70° to 90° NW. Within a distance of 100 yards north of the fault the beds dip less than 7° SE. The trough of the syncline pitches about 70 feet per mile to the southwest. The steep dips along the southeast margin of the outcrop of Pennsylvanian rocks are the result of drag along the Boissevain fault.

Most of the valuable coal beds are below drainage. The famous Pocahontas No. 3 coal is about 1,700 feet above sea level. Considerable coal was mined from this bed during construction of the drainage tunnel[251] of the Pocahontas Fuel Company, Inc., which extends from Pocahontas, Virginia, southwestward to the Dry Fork of Sandy River in western Tazewell County. The construction of this drainage tunnel, having a total length of 18.6 miles, was a remarkable engineering feat providing gravity drainage for about 12,000 acres of valuable coal land, part of which is in the Burkes Garden quadrangle.

Owing to the limited area of occurrence of Pennsylvanian coal-bearing beds in the Burkes Garden quadrangle, the writer did not make a detailed study of coal in this area. Most of the information given here is from a report by Harnsberger[252].

The character and thickness of coal beds below the surface are known from diamond-drill borings (Fig. 5). A boring made on Horsepen Creek, in the Burkes Garden quadrangle, which encountered six coal beds in the lower part of the Lee formation, is as follows:

Geologic Section 56.—Boring near the 2,152-foot bench mark on Horsepen Creek, Tazewell County, Virginia
(After Harnsberger[253])

	Thickness		Depth	
	Ft.	In.	Ft.	In.
Sand, gravel, and boulders	21	0	21	0
Sandstone	18	0	39	0

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[251] Drainage tunnel of the Pocahontas Fuel Company, Incorporated (private publication), 23 pp., 1936.

[252] Harnsberger, T. K., The geology and coal resources of the coal-bearing portion of Tazewell County, Virginia: Virginia Geol. Survey Bull. 19, pp. 24, 29-95, 1919.

[253] Idem, p. 24.

	Thickness		Depth	
	Ft.	In.	Ft.	In.
Shale, sandy	28	0	67	0
Shale	6	0	73	0
Sandstone	200	0	273	0
Shale	25	4	298	4
Coal (Pocahontas No. 5)	2	8	301	0
Shale, sandy	1	0	302	0
Shale	5	1	307	1
Coal with shale bands, 11 in. Coal, 7 ft. 5 in. } Pocahontas No. 4 coal	8	4	315	5
Shale, sandy	39	7	355	0
Shale	6	0	361	0
Sandstone, shaly	2	0	363	0
Sandstone	10	0	373	0
Shale, sandy	18	1	391	1
Coal (Pocahontas No. 3)	7	1	398	2
Shale, sandy	7	10	406	0
Sandstone	60	0	466	0
Shale, sandy	19	2	485	2
Coal .... 4 in. Shale .... 5 ft. 11 in. Coal ....10 in. } Pocahontas No. 1 coal	7	1	492	3
Sandy shale to bottom	1	9	494	0

Two of the exposed coal beds, the Lower and Upper Horsepen coals, are thick enough to be mined profitably, but most probably neither will be mined as long as thicker beds are available. The outcropping belts of these two coals are shown on the geologic map (Pl. 1).

The Lower Horsepen coal occurs 150 to 175 feet above the lowest exposed beds of the Lee formation. It has an average thickness of about 30 inches and generally contains two clay partings. Harnsberger[254] describes the Lower Horsepen coal at several localities along Horsepen Creek, of which the following sections are representative:

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[254] Op. cit., pp. 84-88.

Lower Horsepen coal, one-fourth of a mile southeast of the 2,152-foot bench mark on Horsepen Creek

	Thickness	
	Ft.	In.
Sandstone	—	
Coal and tongues (pendants) of sandstone from roof	1	3
Coal		1½
Clay, very hard		5
Coal		4½
Rash		5
Coal	1	1
Rash		2
Coal		2
Total thickness	4	10
Total thickness of coal	3	10

Lower Horsepen coal, half a mile southeast of the 2,152-foot bench mark on Horsepen Creek

	Thickness	
	Ft.	In.
Shale		
Coal	1	0
Clay		3
Coal	1	10
Clay and rash		5
Coal		1
Total thickness	3	7
Total thickness of coal	2	11

Another coal bed 40 to 110 feet below the Upper Horsepen coal crops out on the north and northeast slopes of Horsepen Creek valley. According to Harnsberger[255] this bed is 38 to 52 inches thick in the valley of Yokel Branch. The coal appears to thin to the south and west from the head of this creek.

The Upper Horsepen coal is the thickest coal exposed in the Burkes Garden quadrangle, but the character and thickness vary considerably. In the valleys of Yokel Branch and Horsepen Creek below the junction of these two streams, the Upper Horsepen coal is 2½ to 5 feet thick. In Horsepen Creek valley, the Upper Horsepen coal

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[255] Op. cit., p. 91.

thickens toward the Boissevain fault. At a prospect about one-eighth of a mile northwest of this fault, the coal is 9½ feet thick, including an 8-inch parting of shale. This is probably the best coal prospect in the Pennsylvanian coal-bearing area of the Burkes Garden quadrangle. About one-tenth of a mile southwest of Laurel School, the upturned coal is severely contorted and locally thickened by faulting or shearing. The coal here is at least 7 feet thick. Less than half a mile southwest of Laurel School, the Upper Horsepen coal, according to Harnsberger[256], is between 6 and 7 feet thick and is overturned, dipping 60° SE. No information is available on the thickness of the Upper Horsepen coal exposed along the stream north of Yokel Ridge.

No analyses of the above-mentioned coals are available. Mining experience in Tazewell County shows that the mining of coal from beds less than 40 inches thick is unprofitable. The amount of coal which could be mined from the exposed beds is small because of deep dissection by streams.

CLAY

Residual clay and shale suitable for use as low-grade refractory clays and brick clays occur in relatively large quantities. The upper 200 feet of the Millboro formation and the lower 250 feet of the Brallier shale are predominantly clay shales which, when properly treated, have high plasticity. These clays contain small amounts of pyrite (iron sulphide) and limonite (hydrous iron oxide), but generally the quantity of these impurities is not enough to be objectionable. The quartz and carbonate content of the shales is low, but intercalations of sandstone are highly siliceous. The principal areas of outcrop of these shales are the valleys of Huntingcamp, Lick, Laurel, Wolf, and Cove creeks, all of which are remote from railroads and main highways with the exception of the belt of Brallier-Millboro along the St. Clair fault in the vicinity of Bluefield, Virginia. Southwest of St. Clair Station, clay shales near the top of the Brallier crop out in a narrow belt about 200 feet wide and dip 45° to 60° SE. (overturned).

Shales in the lower part of the Bluefield formation and in the upper part of the Gasper were formerly utilized for the manufacture of red building brick. The clay was obtained from weathered rock along the north side of the Norfolk and Western Railway half a mile west of Tiptop. Laboratory tests on three samples of this

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[256] Op. cit., p. 82.

clay, then being utilized by the Tiptop Brick Co., are reported by Ries and Somers[257] as follows:

TABLE 5.—*Properties of three samples of Bluefield shale, near Tiptop, Tazewell County, Virginia*[258]

PROPERTIES	SAMPLE 2339	SAMPLE 2340	SAMPLE 2378
Water of plasticity	37	31	25
Plasticity	High	Good	Good
Air shrinkage	5%	4%	4%
Tensile strength (pounds per square inch)	60	40	70
Cone 010			
Fire shrinkage	2	0	0
Absorption	28.5	25.7	27.9
Cone 1			
Fire shrinkage	5	3.3	2.6
Absorption	3.0	3.7	9.6
Cone 3			
Fire shrinkage	10.6	3.6	11.6
Absorption	.9	1.1	.2

The description of the samples is as follows[259]:

"Lab. No. 2339. The clay fires to a red color. At Cone 05 it has a good hard body. Shrinkage too high at Cone 1 to use clay alone at this temperature. Nearly steel hard at 010, and fully so at 05. Works well dry press and at Cone 05 had 3.0 per cent fire shrinkage, and 16.9 per cent absorption. It is overfired at Cone 3.

"Lab. No. 2340. Barely hard enough at Cone 010, but has a good hard body at 05. Shrinkage somewhat high at Cone 1. Fires to red color.

"Lab. No. 2378. Excellent hard body at Cone 05, but absorption somewhat high. Fires to a red color. Mixing the shale and clay tends to reduce the fire shrinkage. A good brick material, which could probably be used also for hollow brick."

Considerable quantities of weathered clay shale occur in the Pennington and Bluestone formations in exposures in Mud Fork valley. The same shales, together with clay shales of the Bluefield formation, are also exposed in Abbs Valley. Most of the red and buff shales in the Pennington and Bluestone could be used for the manufacture of brick, but no data on tests are available.

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[257] Ries, H., and Somers, R. E., The clays and shales of Virginia west of the Blue Ridge: Virginia Geol. Survey Bull. 20, p. 102, 1920.

[258] Ries, H., and Somers, R. E., op. cit., p. 102.

[259] Idem.

It is very doubtful whether any of these clay or shale deposits will be utilized in the near future. The same beds are exposed along the Norfolk and Western Railway north of Bluefield, Virginia, where any future developments in these beds most likely would be made.

SAND

Large supplies of sand are scarce in the Appalachian Valley of Virginia, and the few deposits now being utilized are insufficient for the needs of the region. Most of the sand used in the Burkes Garden quadrangle is shipped in from Fort Chiswell, Wythe County, but some comes from the Coastal Plain region of eastern Virginia. Besides construction sand, much sand is used by the railroads as engine sand. Either round or angular sand can be used, but angular grains seem to be preferred. The size which is most desirable is 20- to 80-mesh.

Sand suitable for construction work and engine sand is found in the Burkes Garden quadrangle in the Rocky Gap, Clinch, and Rose Hill formations. All of the occurrences are rather remote from railroads, but some places are close to through highways.

The Rocky Gap sandstone, which is the chief potential source of sand in this area, is a firm sandstone in the fresh state. Weathering leaches out the calcium carbonate cement and frees the sand grains, so that the rock is thoroughly disintegrated in much of the area. Three samples of sand, obtained from exposures of the Rocky Gap formation along Wolf Creek 1½ miles west of Grapefield School, showed about 80 per cent of the material to be composed of grains 0.5 to 2 mm. in diameter. At this locality, the sand is relatively free of fine particles and clay but contains enough iron to color the sand light buff. The beds dip 20° NW., in a bluff about 50 feet high. The dip steepens a few yards north of the bluff, so that very little sand could be obtained above drainage.

Occurrences of weathered Rocky Gap sandstone occur on the southeast slopes of East River Mountain. The character of the sand is shown in several small pits which have been opened along Road 662. Prevailing dips are 5° to 30° SE., but local flexures reverse the direction of dip and broaden the outcrop of the sandstone. Most of the sand on East River Mountain is considerably finer than that along Wolf Creek; about 75 per cent will pass a 40-mesh sieve. The East River Mountain sand deposits are streaked with manganese, but the amount is so small that the sand, after washing and sieving, is almost as light colored as that along Wolf Creek. By quarrying along the strike west of the road, considerable sand could be obtained without the removal of much overburden. The depth to which the sandstone has been thoroughly leached of its cement is not known, but this should be determined prior to quarrying. If this deposit were worked, it probably would be necessary to locate the washing plant at Cove Creek or in Bluestone Valley, where a good supply of water is available.

During 1941 a small quantity of buff sand was obtained from exposures of sugary sandstone along the West Fork of Cove Creek, about 2 miles west of Road 662. The sand was washed with water obtained from the adjacent creek but was not sieved. The dip of the sandstone beds in this locality is about 15°NW., so that the sandstone passes below creek level a few yards west of the prospect pit. The sandstone was traced northeastward to Cove Creek, where larger bodies of sand are available. According to H. A. Bowen of Tazewell, who operated the prospect on the West Fork of Cove Creek, the sand grains are too round to be suitable for engine sand.

Probably the best locality for obtaining sand in Nye Cove is the conspicuous hill about half a mile north of the junction of the forks of Cove Creek. The hill is capped with Huntersville chert, but as shown in the east-facing bluff most of the hill is composed of sandstone which appears deeply weathered. About 60 per cent of the sand grains pass a 20-mesh sieve but are larger than 40-mesh. The sand on the face of the bluff is stained with limonite, but the rock a few inches beneath the exposed surface is light-buff. Before any development is made, the hill should be core drilled some distance back from the face of the bluff to determine the depth of disintegration of the sand and the amount of cherty overburden. Cove Creek offers adequate supplies of water for a crushing and washing plant. The East River Mountain road (Road 662) is within 200 yards of the hill. No electric power is directly available, but there is an electric line in Clear Fork Valley, half a mile away.

Some of the white sandstones in the upper part of the Rose Hill formation, exposed on the spur of Big Ridge near the Bland-Tazewell county line, are sufficiently weathered to be workable for sand. Most of the sand grains are less than 0.5 mm. in diameter and are angular. The sand is also relatively free of iron oxides and other discolorations. The locality is too remote from an all-weather highway to be developed at the present time.

Part of the south slope of Garden Mountain below Walker Gap is a dip slope made by the Clinch sandstone which has weathered by granular disintegration to a depth of several feet. The major grade of the sand is 0.5 to 1 mm. in diameter. A small quantity of clean, white sand was obtained from a prospect pit half a mile below Walker Gap. At this locality, the sand appears to be disintegrated to a depth of about 20 feet. Although it is possible that considerable supplies of high-grade sand are available in this immediate area, its remoteness is a serious obstacle to commercial development.

CRUSHED STONE

In southwestern Virginia, large quantities of crushed limestone and dolomite are used in the construction of macadam and bituminous macadam roads, as railroad ballast, and as concrete aggregate. In recent years the "fines" obtained in the crushing of limestone and dolomite have been processed into rock dust which is used to reduce the hazard of explosion in bituminous coal mines and as agricultural limestone. Specifications for agricultural limestone are sufficiently flexible for practically all of the limestones and dolomites in the region to be used for this purpose. Specifications for rock dust used in coal mines call for stone low in silica and light in color. The Burkes Garden quadrangle contains abundant supplies of limestone and dolomite suitable for use as crushed stone. At the present time, no stone quarries are operating in the area.

The State Department of Highways has obtained crushed stone from several temporary quarries and from the stone quarry at Five Oaks, which is no longer being operated. Five quarries were opened adjacent to U. S. Route 19, and the stone used in the construction of the new highway during 1933-1936. The roadside quarry about 150 yards east of the intersection of U. S. Route 19 and Road 650, near Wittens Mills, is in the pure limestone beds of the Peery member of the Cliffield formation. The largest of the temporary quarries along U. S. Route 19 was in the upper part of the Beekmantown dolomite west of Divide Church. Two small quarries were opened in the vicinity of Springville in the Copper Ridge formation. Just south of St. Clair Station a quarry was opened in the cherty limestones at the base of the Lincolnshire limestone. A quarry was operated in the Benbolt and Gratton formations north of U. S. Route 19 at the west edge of the quadrangle. This quarry also furnished a small quantity of dimension stone. In Clear Fork Valley, the State Department of Highways opened three quarries: one in the limestone at the base of the Beekmantown, about one-fourth of a mile west of Mt. Olivet Church at Gratton; another in the Beekmantown dolomite about a mile east of Gratton; and one in the Lincolnshire member of the Cliffield formation, about 1 mile southwest of Kinzer Church. The stone obtained from these quarries was used in the hard-surfacing of State Highways 61 and 78.

Road 650 in Wrights Valley was hard surfaced with stone obtained in part from a small quarry in the Hillsdale and Little Valley limestones immediately south of Bailey Church. Near Sam, the Price sandstone was quarried for crushed stone which was used in surfacing this road to St. Clair Station.

Crushed stone obtained from the "Chemung," Price, and Brallier formations along the Burkes Garden-Sharon Springs road has been used in grading and surfacing State Highway 42 between Effna and Ceres.

The distribution of limestone and dolomite, suitable for use as crushed stone, is shown on the accompanying geologic map (Pl. 1). Temporary quarry sites for road stone are almost unlimited. None of the rocks in the quadrangle have been tested for use as stone sand, but the same rock formations used elsewhere in southwestern Virginia for stone sand crop out along the Norfolk and Western Railway between Five Oaks and the north side of Puckett Hollow.

The Five Oaks Lime Company formerly operated a small quarry in the uppermost beds of the Beekmantown formation and the lower beds of the Blackford member of the Cliffield formation (Pls. 1, 21B). These beds contain considerable chert and, therefore, would be too siliceous to use for rock dusting. All of the stone obtained from this quarry was used in highway construction.

Proximity to large, active stone quarries makes it unlikely that any large stone quarry will be opened in the Burkes Garden quadrangle until the local demands in the area increase greatly. Possibly crushed stone could be made as a byproduct in connection with the utilization of limestone and dolomite for other purposes.

DIMENSION STONE

Some of the rocks exposed in the quadrangle are being used on a small scale as dimension stone. Mississippian sandstones were used in building tunnel facings, bridge abutments, and culverts along the Norfolk and Western Railway in Wrights and Clinch valleys. Most of this material came from the Stony Gap sandstone in the vicinity of Bluefield, Virginia. Medium-bedded, drab-gray sandstones of the Price formation have been used locally for the construction of stone fences and retaining walls in the town of Bluefield, Virginia. The stone was obtained from several small quarries in the south environs of the town. Large quantities of similar sandstone are available along the Norfolk and Western Railway in the vicinity of St. Clair Station.

Sandstones of the "Chemung" and Brallier formations have been used in fills and bridge abutments along the Burkes Garden-Sharon Springs road and along State Highway 42 southwest of Sharon Springs. Most of the material was obtained from a roadside quarry on the northwest slope of Brushy Mountain.

The Stony Gap sandstone, on Stony Ridge north of Tiptop (Pl. 16B), offers possibilities as a source of building stone. Because of the even bedding, sandstone blocks obtained from this locality would require relatively little shaping. The prevailingly light color and uniform texture of the Stony Gap sandstone are desirable characteristics. Blocks of this sandstone would also be suitable for use as refractory lining material.

Limestones and dolomites suitable for use as dimension stone occur widely throughout the quadrangle. The most desirable type of stone for this purpose is a dense, exceedingly fine-grained, dove-gray to golden-gray limestone known as vaughanite[260] or calcilutyte. Because of the fine grain and compactness of the rock, exposed surfaces collect little dirt and are easily cleaned. Fine-grained limestones in the Gratton formation have been used to a small extent for building stone in the vicinity of Tazewell. Some of the stone so used came from quarries along U. S. Route 19 near Benbolt. Other localities where relatively large quantities of similar fine-grained limestone occur are: (1) southeast of the intersection of U. S. Route 19 and Road 650, near St. Clair Station; (2) along the Norfolk and Western Railway half a mile southeast of Five Oaks; (3) along the south side of Wrights Valley about a mile west of

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[260] Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. 1. pp. 106, 107, 109, 122, 136, 1940.

Tiptop; (4) about one-fourth of a mile south of State Highway 61 and half a mile west of Marys Chapel; and (5) three-fourths of a mile north of Gratton.

Dolomites are equally abundant but are somewhat less desirable for dimension stone. They are expensive to quarry and the blocks are difficult to shape. Impurities invariably present produce discolorations on weathered surfaces. Dolomites used for foundation stone seem to be less durable than fine-grained limestones similarly used.

It should be pointed out that the general abundance of rocks suitable for dimension stone in the southern Appalachian region more or less predetermines the limited extent to which individual workings can be developed profitably. Local needs are not likely to warrant quarrying of much building stone.

BARITE

The barite deposits of Virginia have been described by Edmundson[261]. One of the principal belts extends along Kent Ridge in Tazewell and Russell counties northeastward to a point near Wittens Mills. Small concentrations of residual barite were found by the writer near the top of the Beekmantown formation north of Drytown, at Five Oaks, and at Wittens Mills. Barite was also noted in the lower 200 feet of the Beekmantown formation about 1 mile east of Wittens Mills, where it occurs in fossiliferous chert atop the hill north of U. S. Route 19. The amount of barite seen in any one place in the Burkes Garden quadrangle is very small, which suggests that little barite is present in the underlying rock.

IRON

General statement.—Local concentrations of iron oxide are numerous in this area as well as in other sections of the Appalachian Valley. Some of the deposits in the Burkes Garden quadrangle may be minable in the future, but probably none will be developed as long as the larger and richer iron deposits of other parts of the United States can supply the demand at lower costs. The types of iron deposits in the Burkes Garden area consist of bedded deposits, chiefly hematite and limonite, and deposits along fault zones, mainly

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[261] Edmundson, R. S., Barite deposits of Virginia: Virginia Geol. Survey Bull. 53, 5 pp., 1938.

limonite. The thickest deposits appear to be present where bedded deposits occur along faults.

Bedded deposits.—Beds of hematite generally less than two feet thick occur near the base of the white quartzitic sandstone in the upper part of the Rose Hill formation. The character of the hematite varies considerably. In a few places it is soft, powdery, and relatively porous, but commonly it is rather firm and hard and of dark reddish-black color. Fossil fragments, mostly of bryozoans, show concentric crusts of iron oxide; some shells seem to have been wholly replaced by iron oxide. Hematitic oolites and small flattened pellets of iron oxide are especially characteristic of the Rose Hill hematites in the Burkes Garden area. Beds of hematite in the Rose Hill are well exposed along the road at the south end of the gorge of Cove Creek through Buckhorn Mountain, along the southeast slope of East River Mountain in Nye Cove, along State Highway 78 in Mill Gap, and on the north side and east end of Chestnut Ridge adjacent to Oneida Branch. The hematite zone in the Rose Hill makes a conspicuous dark-red streak across the road up East River Mountain, above the first outcrop of the white sandstone in the upper part of the formation. The Rose Hill hematites are believed to be primary deposits formed principally by the precipitation of hematite around sand grains and fragments of fossils.

Locally, on the southeast slope of Big Ridge, the position of the Huntersville chert is occupied by 50 to 75 feet of siliceous limonite. The iron bed is well exposed along the CCC road about 1 mile east of the Bland-Tazewell county line. The same bed crops out in several places for a distance of 500 yards southwestward along the strike but was not identified elsewhere. The iron is presumably of secondary origin, but its source is not known. Occurrences of iron at this stratigraphic horizon are uncommon, although considerable iron concentrations are known to occur in the immediately underlying sandstones in other parts of the Appalachian Valley in Virginia.

Bedded limonite also occurs in the Copper Ridge formation on Big Ridge between Redoak School and Ceres. The mineralized zone is stratigraphically about 150 feet above the Nolichucky shale. A few large blocks of almost pure limonite were found at the crest of this ridge less than half a mile east of Ceres, but blocks seen elsewhere along this belt contained considerable silica and clay.

Mineralized zones along faults.—Brown limonite occurs along two principal overthrusts—the Narrows and St. Clair faults. The main concentration is along the St. Clair fault in the vicinity of Bell Hill, where iron oxides occur in residual clays derived from the Honaker formation. Most of the ore which was mined and shipped[262] was in the form of lumps. Two mines, the Bell Hill (Pl. 1) and May, were worked, but operations ceased many years ago. At the time the mines were operating, the ore was transported to Tiptop on a narrow gauge railroad and there smelted in a local forge.

Conspicuous deposits of limonite and hematite occur along the Narrows fault on the southeast slope of Buckhorn Mountain, from the east end of Pine Spur to the west end of the mountain. The Ordovician limestones forming the hanging wall of the overthrust block have been impregnated and partly replaced by iron oxides. The belt is widest where the overridden beds are ferruginous sandstones of the Rose Hill formation. For this reason, it appears likely that the iron concentrations along the fault resulted from the leaching of iron out of the Rose Hill and deposition in the overthrust limestones.

MANGANESE

General statement.—During the first World War the manganese deposits in the Burkes Garden quadrangle were prospected and several carloads of ore were mined. At the close of the war, the market price of manganese declined so greatly that all local operations were abandoned. Up to the close of 1940, none of the old workings had been reopened and no additional prospecting had been done. During the short period of mining activity, the various prospects and mines were visited by Stose and Miser,[263] and others. The report of Stose and Miser includes descriptions of about 20 prospects in the Burkes Garden quadrangle. The location of these is shown on the accompanying geologic map (Pl. 1). During 1940 and 1941, Harry S. Ladd of the United States Geological Survey, visited several of the manganese prospects in Nye Cove and Wolf Creek Valley, in connection with a detailed study of the Round Mountain and Flattop Mountain manganese mines in Bland and Giles counties. The reports by Stose and Miser and by Ladd[264] should be consulted for information concerning details of occurrence and character of the manganese deposits.

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[262] Holden, R. J., Iron, *in* Watson, T. L., Mineral resources of Virginia, pp. 462-463, Lynchburg, Virginia, Virginia Jamestown Exposition Commission, 1907.

[263] Stose, G. W., and Miser, H. D., Manganese deposits of western Virginia: Virginia Geol. Survey Bull. 23, pp. 152-193, 1922.

[264] Ladd, H. S., unpublished manuscript.

Occurrence and origin.—Psilomelane and manganite form the interstitial material of fault breccia along the St. Clair overthrust from St. Clair Station southwestward to a point midway between Tiptop and Wittens Mills. The fragments in the breccia, which are mostly chert, have been partly replaced by the manganese minerals. Many blocks of manganite-bearing fault breccia occur in the fields about 1 mile east of Bailey and near Road 656. Here and at the Tiptop prospect (Pl. 1), the manganiferous fault breccia occurs between the main fault and a branch fault.

Northeast of Wittens Mills lumps of manganese and manganiferous chert occur in the Copper Ridge dolomite stratigraphically about 175 feet above the Nolichucky shale. The best showing of manganese in the quadrangle is at this horizon in Lynn Hollow, especially in the vicinity of the Pocahontas mine. Smaller concentrations of manganese occur near the top of the Copper Ridge in the vicinity of Divide Church.

According to Stose and Miser[265] the manganese in the Cambrian and Ordovician dolomites was originally disseminated mainly in the lower part of the Copper Ridge (lower Knox) dolomite. The dolomite was brecciated during folding and faulting, and the disseminated manganese, probably in the carbonate form, was dissolved and redeposited as interstitial material in brecciated rock.

Manganese oxides are also present in the Rocky Gap sandstone and in associated clays derived by weathering of the underlying Tonoloway limestone. That in the sandstone is chiefly in the form of bedding stringers, veins, and as interstitial cement of sandstone breccia. Bedding stringers of manganese are well shown in sand pits along Road 662 on the north side of Nye Cove. Veins of manganese, chiefly pyrolusite, occur in the Rocky Gap sandstone at the Adz Ridge and Nye Cove manganese prospects (Pl. 1). At the Gose mine (Pl. 1) some of the manganese lumps have the texture of sandstone and presumably were formed by replacement.

Manganese in clays derived from the Tonoloway limestone occurs chiefly in the form of irregular masses and stringers of wad and impure pyrolusite. Most of the occurrences of manganese in the Tonoloway are at the apexes of flatirons on dip slopes, as for example, the Shott, Donahue, and Leckie-Moss prospects (Pl. 1); but the Adz Ridge and Big Ridge prospects are on the crests of anticlinal ridges.

According to Stose and Miser[266] the manganese occurring in the Upper Silurian and contiguous Devonian sandstones was originally dis-

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[265] Op. cit., pp. 52-53.
[266] Op. cit., p. 53.

seminated in the sandstones, probably in the form of manganese carbonate. The manganese was leached out of the rock after folding, carried downward by percolating waters and deposited as oxides in fissures and interstices in the subjacent beds. Stose and Miser believe that most of the manganese at this general horizon was concentrated when the Appalachian area was reduced to a peneplain.

LEAD AND ZINC

A float block of Maryville-type limestone impregnated with small crystals of sphalerite (zinc sulphide) and galena (lead sulphide) was found on the north slope of a small hill, half a mile south of the 2,954-foot bench mark on Valley Ridge. No mineralized rock was found in place, but the occurrence of lead and zinc in this general vicinity was reported by Boyd[267]. In Russell County[268], lead and zinc occur in Maryville-type limestones near the top of the Honaker formation.

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[267] Boyd, C. R., Resources of South-west Virginia: p. 180, New York, John Wiley and Sons, 1881.

[268] Woodward, H. P., Outline of the geology and mineral resources of Russell County, Virginia: Virginia Geol. Survey Bull. 49, pp. 66-69, 1938.

GEOLOGIC HISTORY

GENERAL STATEMENT

The interpretation of the geologic history of an area is based upon the records of the past events, which are found in the rocks and in the land features. Together, these records cover an immense span of time and a variety of changes. The length of geologic time and other aspects of geologic history are not speculative guesses. Geologic history has been deciphered from the rock record in terms of certain basic and fully validated concepts. However, the evidence upon which the inferred history is based is, at best, only fragmentary. Also, it is known that similar impressions on the geologic record may have been made by different processes.

One of the fundamental concepts by which geologic history is synthesized is known as the Doctrine of Uniformitarianism. According to this principle, the events of the geologic past represent the activity of the same geologic processes and agencies observed to be working at the present time. "The present is the key to the past." Thus by studying deposition in rivers, lakes, oceans, glacial areas, and deserts it is possible to recognize the various origins of ancient sediments.

Since 1900, accurate, quantititative measurement of the disintegration products of uranium, radium, and other radioactive elements found in igneous rocks has made it possible to determine within rather narrow limits of accuracy the age of the containing rock. Extension of this work has led to a proper realization of the antiquity of the earth. Some rocks have been found to be about two billion years old, and none of these ancient rocks is believed to represent the primal crust of the earth. It is the order of magnitude of the age rather than the age in terms of years which is significant. Suffice it to say that geologic time is inconceivably long in terms of human experience.

The study of present geologic processes is accomplished only with great difficulty. The rates at which the processes work are so slow as to seem of negligible importance. The "eternal mountains" and "everlasting hills" scarcely seem to be overstatements. However, the slowest geologic process takes on real significance when gauged by the great length of geologic time. Gaining the proper perspective of the geologic past presupposes awareness to the slow but inexorable action of erosion, deposition, crustal movement, and numerous other processes.

Deciphering past events from records in the rocks would be of slight historic value if the chronology of those events could not be established. Chronology is mainly related to the concept of superposition. Successive layers of sediment or rock are the products of successive events. Of the sediment deposited in a certain place, the lowest layer must be the oldest. If crustal upheaval should invert the succession of strata, the series of inferred geologic events would be in reverse, unless it were discovered that the layers were upside down. Such actual inversions are rather common in the Appalachian region, but they are easily detected.

All of the rocks exposed in the Burkes Garden quadrangle accumulated as particles of sediment, chiefly on sea floors, but some possibly along river channels or on tidal flats. Thus they are in beds or layers, which originally were more or less flat lying. Deposition of sediment resulted in the entombment of contemporaneous life, chiefly shells and plant remains. Some of the material composing these sedimentary rocks was probably derived from the crystalline rocks of the Piedmont region and higher land areas still farther east, which existed during the Paleozoic era. The total measurable thickness of the exposed Paleozoic rocks in the Burkes Garden area is about 17,000 feet. The oldest rock, the Rome formation of Middle Cambrian age, was deposited early in Paleozoic time. It is exposed north of Wittens Mills. The youngest rock, which is in the early Pennsylvanian Lee formation, was deposited relatively late in the Paleozoic era. It is exposed on the divides above Horsepen Creek. During the closing stages of this era, all the rocks were uplifted, folded, fractured, and faulted. During and since this great period of deformation all of the exposed rocks have been deeply eroded. All parts of the region are being eroded today, though at different rates.

The record of the geologic history of the Burkes Garden area is far from complete. No information is available concerning early Cambrian and pre-Cambrian time—covering a span of more than 1½ billion years—because erosion has not yet cut sufficiently deep in the earth's crust to expose Lower Cambrian and pre-Cambrian rocks. The decipherable history deals with the origin of the exposed rocks, their subsequent deformation, and their sculpture into mountains and valleys. It is evident that a revolutionary change in geography must have taken place in order to transform an area of principally marine deposition into a mountainous area undergoing vigorous erosion.

ORIGIN OF THE ROCKS

GENERAL CONDITIONS

Prior to the Paleozoic era, the eastern coastal part of the United States was a land mass, composed of igneous, sedimentary, and metamorphic rocks. Toward the close of pre-Cambrian time, this region was worn down to an essentially base-leveled surface. A long strip of this region, occupying the general position of the present Appalachian Mountains, but somewhat wider than the present chain, was downwarped sufficiently to allow marine waters to advance over the sinking land. The structural feature thus formed is commonly referred to as the Appalachian geosyncline. The downwarped trough was bordered on the east by a land mass which probably extended a considerable distance east of the present Atlantic coast line. This land mass, known as Appalachia, was composed of a variety of rocks. Sediments eroded off of Appalachia were transported by rivers to the inland sea on the west. Removal of great quantities of rock from Appalachia was accompanied by the rise of that land mass—a rise which further accelerated its degradation. Deposition of this material in the sea-covered Appalachian geosyncline caused that area to subside. This condition must have prevailed throughout the time required to deposit the Paleozoic sediments exposed in the Burkes Garden quadrangle.

Such features as ripple marks, mudcracks, cross-bedding, current markings (Pls. 3A, B), and many types of fossil remains, which are preserved in the rocks, indicate that the depth of water in the geosyncline was never very great, probably considerably less than 600 feet. The fact that thousands of feet of sediment were deposited in shallow water is proof that the sea floor subsided as deposition took place.

CAMBRIAN PERIOD

Although the Rome shale north of Wittens Mills is the oldest exposed rock in the quadrangle, it is not the oldest rock deposited in the ancient sea. In the eastern part of the Appalachian Valley, the Rome is underlain by 1,000 to 1,800 feet of dolomite and limestone of the Shady formation which in turn overlies several thousand feet of coarse sandstone and conglomerate of the Chilhowee group. These Lower Cambrian rocks presumably underlie the Rome in this quadrangle, but they are far below the surface.

In Middle Cambrian time a great thickness of variegated muds and silts was deposited, and, as shown by the general sparsity of fossils, conditions of deposition were favorable only to mud-loving forms of marine life, such as the trilobites. Following deposition of the Rome, great thicknesses of calcareous sediment, mainly dolomitic, accumulated up to the close of Cambrian time, except for one interval when the Nolichucky muds and silts were deposited. The Honaker, Nolichucky, and Copper Ridge formations, with an aggregate thickness of more than 3,000 feet, were deposited in very shallow water and in an environment where currents were very active. Many of the limestone and dolomite layers are mechanical deposits, resulting from the transportation and deposition of carbonate grains. The Copper Ridge dolomites, bearing current ripple marks (Pl. 3A), east of Cove Creek, were evidently formed in this way. The carbonate particles, although probably formed by chemical precipitation from sea water, were deposited mechanically as sand, under conditions no different than existed during the intervals when quartz grains were deposited over parts of the sea floor. Shallow water conditions are also indicated by the numerous mud-cracked bedding surfaces (Pl. 3B). The shallow waters withdrew before the layers had consolidated. Exposure of the water-laden sediment to the air resulted in its desiccation, contraction, and cracking into polygonal columns. Possibly some of the edgewise conglomerates in the Nolichucky and Copper Ridge are composed of reworked slivers of desiccated mud-cracked sediment: In this area, during most of Cambrian time, conditions were not very favorable for the existence of marine invertebrates, except during early Honaker (Rogersville) and Nolichucky times, when trilobites seemed to have existed in abundance.

From age determinations of early and late Cambrian igneous rocks, the Cambrian period is believed to have lasted about 100 million years. Considering that 7,000 to 10,000 feet of sediment was laid down in the Appalachian trough during this time, the average rate of deposition was about 1 foot of rock every 10,000 years.

ORDOVICIAN PERIOD

The oldest Ordovician formation in the Appalachian Valley, the Chepultepec limestone, has not been identified anywhere in the Burkes Garden quadrangle and is presumed to be absent because of nondeposition. If this is correct, then the sea withdrew temporarily from the area at the beginning of Ordovician time. During the Nittany and Bellefonte divisions of Beekmantown time, the area was submerged and depositional conditions, essentially the same as had existed during Copper Ridge time, again prevailed. The origin of the abundant chert in the

Beekmantown dolomite is obscure. Some of it is bedded and appears to have been deposited on the sea floor, but much of the chert, particularly the spongy varieties occurring in large masses on the surface, may have been formed by the silification of carbonate rock. Originally the silica may have been disseminated in the limestone and dolomite and later dissolved out and deposited by replacement of carbonate minerals.

Following deposition of the Beekmantown, the area was uplifted above sea level and subjected to erosion. Locally, valleys of considerable depth were cut into the previously deposited sediment. The irregular erosion of the Beekmantown during this interval accounts for the variation in thickness of the formation. Similar evidences of post-Beekmantown erosion have been noted in many other parts of the United States, and the withdrawal of the sea from the Burkes Garden area is therefore believed to have been part of a regional emergence. A depositional record of the post-Beekmantown interval is found in only a few areas, particularly in southern Missouri and northern Arkansas.

At the beginning of Cliffield time the sea again advanced over the area and the first deposits, mainly fragments of chert and dolomite eroded from the Beekmantown, were deposited in the low places of the submerged erosion surface. During accumulation of the ash-gray shale and blocky chert, conditions gradually changed from clastic to chemical deposition. The Five Oaks limestone and similar calcilutytes were probably formed by the chemical precipitation of finely divided calcium carbonate. Turbid conditions prevailed during precipitation of the "lime" mud, as is shown by the predominance of mud-loving forms in the faunas of the Five Oaks and younger Ordovician calcilutytes.

In Lincolnshire time, both chemically precipitated and organically secreted calcium carbonate accumulated over the entire area under marine conditions favorable to the existence of a variety of invertebrates. The dominant forms were large gastropods and cephalopods, some of which were considerably over a foot long. The coarse-grained limestones of the Effna and the similar and supposedly equivalent limestones at the base of the Ward Cove member probably accumulated as shell sands in an environment teeming with trilobites, brachiopods, and bryozoans. Current and wave action were sufficiently active locally to grind up the shells as fast as they accumulated.

During or soon after Effna time the sea, which covered the southern Appalachian trough, was split into two rather distinct basins of deposition by a rising of an area of sea bottom located between the present site of Clinch Mountain and the northwest edge of the Saltville-Bland overthrust block. This barrier probably was most strongly developed during Whitesburg time, since none of this formation appears to have been deposited northwest of the position of Clinch Mountain. During Athens time the barrier continued to exist, but very probably was a submarine ridge rather than a neck of land. This conclusion is based upon the fact that many of the same organisms inhabited both the Athens trough and the basin in which the *Nidulites* beds of the Ward Cove limestone were deposited. Although the barrier was not prominent enough to prevent faunal interchanges, it did restrict the black muds accumulating in the southeastern basin from being washed into the northwestern trough. In the latter basin, limestone accumulated under conditions similar to those of Lincolnshire time.

The two distinct depositional troughs disappeared at the close of Athens time and the cherty Peery limestones were deposited in a single basin covering the whole area. However, before the close of Peery time, deposition was restricted to a relatively small area, as shown by the absence of Peery calcilutytes southeast of Gratton and Thompson Valley. The cross-bedded calcarenytes intercalated in the Peery calcilutytes indicate that wave and current action locally interrupted chemical precipitation of "lime" mud and reworked some of the chemically deposited material. Possibly the currents were strong enough to prevent the accumulation of any sediment in the southeastern half of the area during late Cliffield time.

The abnormally thick succession of calcilutytes in the Cliffield at St. Clair and north of Gratton is believed to indicate that in a few places in the Cliffield sea, conditions of deposition favored the accumulation of chemically precipitated "lime" muds to the almost complete exclusion of other types of limestone accumulating on near-by parts of the sea floor. In a few other places, notably at Cave Spring, local conditions must have favored accumulation of shell sands during part of Lincolnshire and all of Ward Cove time.

Except for a small tract in the vicinity of Five Oaks, the Benbolt formation was deposited over the entire area of the quadrangle. Lime-secreting organisms were very abundant, both in number and variety. Calcareous algae, sponges, bryozoans, and brachiopods were important rock-makers of this time. During late Benbolt time, currents were active, and the organically secreted material was ground into shell sand.

At the beginning of Gratton time, the area southeast of Clinch Mountain was above water and remained so until late Witten or early Moccasin time. During Gratton time, mostly chemically precipitated "lime" muds accumulated in very shallow water. The sea withdrew at times, and the muds on the sea bottom dried and cracked. Some of the desiccated "lime" muds were locally disrupted by readvancing waters and laid down as calcarenytes and limestone conglomerates. The characteristic fauna of calcilutytes, numerically dominated by *Tetradium* corals, molluscans, and crustaceans, inhabited the Gratton sea. During Wardell time, the sea was restricted to a narrow embayment reaching no farther north than Five Oaks and no farther east than the west end of Burkes Garden. The main area of Wardell deposition was southwest of Burkes Garden quadrangle. The variety of sediments in the Wardell formation indicates changing conditions of deposition. A considerable part of the calcareous material is the product of secretion of calcium carbonate by stromatoporoids, corals, calcareous algae, and bryozoans. Echinoderms were rather common for the first time. During late Wardell and Bowen times muds accumulated in the embayment.

At the beginning of Witten time, all the area northwest of Clinch Mountain was covered by the sea, and probably also a part of the area southeast of the Saltville-Bland fault. Remarkably uniform conditions of deposition prevailed throughout the Witten sea, as is shown by the uniformity in character and thickness of the formation north of Clinch Mountain. The abundance and variety of invertebrates were probably greater than at any other time in the Ordovician.

The local areas of land which existed during Gratton, Wardell, Bowen, and Witten times were not appreciably eroded during their exposure. The sediments deposited in the Moccasin sea covered the whole area.

During deposition of the Moccasin, conditions were distinctly unfavorable to marine life. At several times, volcanic ash, ejected from relatively distant volcanoes, settled on the sea floor. Considerably greater thicknesses of this material accumulated during Eggleston and early Martinsburg time. Later, the chemically unstable ash was altered to bentonite, and the free silica released by the alteration permeated contiguous mudrocks and silicified them.

Marine life, particularly brachiopods and bryozoans, was very abundant during Trenton time. Most of the limestone layers in the Martinsburg are almost wholly composed of their remains. Later in the Martinsburg epoch, more mud and silt accumulated. The changing environment is reflected by numerical increase in mud-loving forms, particularly pelecypods.

Although material very similar to Maysville deposits accumulated during Juniata time, the environment was wholly unsuited to marine organisms. Butts[269] believes that the absence of marine fossils in the Juniata is evidence that the formation was deposited in fresh water. The relative uniformity in distribution and thickness of the Juniata in the Appalachian area would be most easily explained by assuming that the beds accumulated in a single body of water. The absence of fossils in the Juniata does not necessarily mean that the formation was deposited where marine organisms did not exist. Their absence may only indicate that conditions favoring their entombment and preservation did not exist.

The Ordovician period was approximately 70 million years long, and in that time about 4,000 feet of sediment accumulated in the Burkes Garden quadrangle. Thus the average rate of deposition was about 1 foot in 17,000 to 18,000 years. Late in Ordovician time the northern part of the Appalachian geosyncline was subjected to folding and faulting, and was uplifted along with the land area east of the Appalachian trough. The mountain-making disturbance which terminated Ordovician marine sedimentation in the northeastern part of the Appalachian trough affected the southern part of that area only indirectly. The sea continued to exist but coarser sediments, derived from the uplifted landmass to the east, were deposited.

SILURIAN PERIOD

The Silurian period began with the deposition of coarse sands and gravels during Clinch time. Waves and currents were active, as shown by the lenticularity of the beds, cross bedding, and ripple marks. Butts[270] believes that the Clinch was laid down in fresh water. The conditions in which sands and gravels accumulate, even in the sea, are not very favorable for preservation of organic remains. Their scarcity or absence in the Clinch is not a conclusive indication that the Clinch sands and gravels accumulated in fresh water. The Rose Hill formations accumulated under somewhat

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[269] Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. 1, p. 487, 1940.

[270] Idem.

less turbulent conditions. Muds, silts, and sands, but relatively little gravel, were deposited during Rose Hill time. Depositional conditions were not very favorable to most kinds of invertebrate life, but crustaceans, particularly ostracodes, seemed to thrive. At one time during the deposition of the Rose Hill considerable iron, probably as iron carbonate, was washed into the sea, and was oxidized and deposited as hematite.

Before the close of Clinton time, the sea withdrew from this part of the Appalachian trough, so that the Rochester shale (upper Clinton) and early Cayugan (McKenzie and Bloomsburg) beds were not deposited. Before the close of Silurian time the sea again advanced, but it probably did not flood the area southwest of the Saltville fault. In the northern part of the quadrangle the Wills Creek sandstone and Tonoloway limestone were laid down.

The Silurian period, which was about 27 million years long, witnessed locally the accumulation of only 500 to 750 feet of mostly clastic sediment. Assuming that deposition took place during three-fourths of Silurian time, the average rate of deposition in this area was about one foot in 30,000 to 40,000 years.

DEVONIAN PERIOD

After Tonoloway time the sea withdrew and the entire area of the quadrangle was exposed during late Silurian and early Devonian time. After the Keyser and Coeymans limestones had been deposited in northern Virginia, the sea again advanced over the Burkes Garden area, but, by the close of New Scotland time, only a small sector in the northeastern corner of the quadrangle had been submerged. During Rocky Gap time the sea spread southeastward. The absence of the Rocky Gap sandstone southeast of the Saltville-Bland fault indicates that the sea probably did not advance that far southeast before the close of Rocky Gap time. The patchy distribution of the Ridgeley northeast of Walker Mountain probably indicates that the sands of this formation were laid down in shallow embayments which covered only a part of the area. The belt of Ridgeley along Walker Mountain appears to have been deposited in the main basin of Oriskany deposition. During Huntersville time the sea covered the whole area and rather uniform depositional conditions must have prevailed. Although the Huntersville is almost wholly chert, it is not likely that the original deposit was siliceous. The Huntersville contains a profusion of fossils, most of which are impressions of lime-secreting organisms. It is likely that the original rock was shell limestone which was later almost completely altered to chert.

During the rest of Devonian marine sedimentation in this area, great thicknesses of mud, silt, and sand were deposited. The general sparsity and diminutive character of fossils in the Brallier and Millboro formations suggest that depositional conditions were not very favorable to marine life. However, during "Chemung" time, sediments similar to those composing the unfossiliferous Brallier were accumulating. Before the close of Devonian time, the sea withdrew from the entire area and it remained above water until after the beginning of Mississippian time. The Devonian period lasted for about 45 million years, and with the exception of relatively short intervals at the beginning and at the close of the period the Burkes Garden area was submerged and was receiving sediment. In other words, the Devonian sediments accumulated at the average rate of about one foot in 15,000 years.

MISSISSIPPIAN PERIOD

The southeastern part of the Burkes Garden quadrangle remained above water during all of Kinderhook time, but the area north of the St. Clair fault was submerged before the close of that epoch, as shown by the occurrence there of Big Stone Gap shale. The Price formation was deposited over the entire area. A normal marine environment appears to have prevailed during most of Mississippian time, as indicated by the many fossiliferous sandstones and shales. A similar origin is very probable for the cross-bedded sandstones and conglomerates[271]. On the other hand the coal beds found in the southeastern belt of the Price indicate that locally swampy conditions prevailed. The fact that the coal beds are intercalated in marine layers suggests that the coal swamps were close to the sea. The last formation known to have been deposited both in the northern and southern parts of the quadrangle is the Maccrady. The general sparsity of fossils indicates that the environment of Maccrady time was not very favorable to marine organisms.

In Middle Mississippian time, several hundred feet of limestone accumulated in seas that covered at least the northern part of the area. Some of the beds were precipitated as fine "lime" muds, but

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[271] Cooper, B. N., The Price formation in the Draper Mountain area, Virginia: Jour. Geology, vol. 45, pp. 414-431.

many layers were formed by the gradual accumulation of shells and other biologically secreted material. The most common type of Mississippian limestone—the crinoidal, oolitic layers—was deposited as shell sands which resulted from the mechanical disruptions of invertebrate skeletons, chiefly those of echinoderms and bryozoans. During late "Gasper" and early Bluefield times, conditions gradually changed from deposition of calcium carbonate to accumulation of muds and silts. During the Chester epoch more than 3,000 feet of clastic sediment was laid down in this part of the Appalachian trough. At several times during this epoch, coal-forming swamps existed locally, but Chester time was mainly one of marine deposition. The Bluestone formation represents a gradual transition from mainly marine conditions of late Mississippian to alternating marine and nonmarine conditions of early Pennsylvanian time.

The best estimate of the length of Mississippian time is 38 million years. Since about 5,000 feet of rocks accumulated during this time in the Burkes Garden quadrangle, the rate of Mississippian sedimentation was, on the average, considerably more rapid than that of any previously recorded time—about one foot in 7,600 years.

PENNSYLVANIAN PERIOD

Only earliest Pottsville time is recorded in the rocks of the Burkes Garden quadrangle. Judging from the abundance of fossil land plants in the sandstones, shales, and coals of the Lee formation, much of the deposition must have taken place on the land, probably on tidal flats fringed with coastal swamps. The coal beds were formed by the accumulation of vegetation under water in conditions inhibiting the oxidation of the accumulating plant material. From what is known of the rate of accumulation of peat in existing swamps[272], it seems safe to infer that the thick coal beds, such as the Pocahontas No. 3 coal, must have required thousands of years to form. The repetition of conglomerate, sandstone, shale, and coal beds, suggests that cyclical conditions of deposition prevailed. The great thickness of coarse, arkosic sandstones indicates that the continent of Appalachia, to the east, was being vigorously eroded and that deposition was rapid.

The record of Pennsylvanian deposition in the Burkes Garden area has been largely effaced by erosion and removal of Pennsylvanian rocks.

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[272] Twenhofel, W. H., Treatise on sedimentation, 2nd ed., pp. 387-388, Baltimore, The Williams & Wilkins Co., 1932.

In neighboring parts of the coal-bearing portion of southwestern Virginia additional thousands of feet of Pennsylvanian rocks were deposited, and it is only reasonable to assume that all, or at least a large part, of the additional Pennsylvanian strata accumulated in this area. The youngest rocks in the quadrangle, which cap the divides above Horsepen Creek, were deposited 250 to 275 million years ago. Since Pennsylvanian time the Burkes Garden area has been undergoing erosion.

DEFORMATION OF THE ROCKS

Toward the close of Paleozoic time, probably in the Permian period, a profound change in the geography of eastern North America was initiated by great earth movements. The Appalachian geosyncline, in which sedimentary layers had accumulated to a total thickness of several miles, was subjected to tremendous stresses directed laterally from a southeasterly direction. The sedimentary beds were folded, broken, and sliced by faults. Great segments of the strata deposited in the geosyncline were thrust many miles to the northwest. Shortening of the width of the geosynclinal tract was accompanied by vertical movements which resulted in the gradual emergence of the geosynclinal deposits. Thus the Appalachian trough, which had received sediment for about 250 million years, became a rising land area.

The movements attending this crustal upheaval were by no means catastrophic. It is probable that the stresses which produced the folding, fracturing, and faulting of the strata acted over long periods of time—probably millions of years. For example, the movements along the St. Clair fault and other great thrusts may have extended over such a long period of time that the average total movement in a single year was but a small fraction of an inch. This is emphasized because the Appalachian Revolution most probably did not result in the formation of mountains any more rugged than those of today. As soon as the folded strata were pushed above the sea, they began to be eroded and in all probability have continued to be eroded in the ensuing 250 million years up to the present time.

LAND SCULPTURE

Erosion during Mesozoic and Cenozoic time must have been attended by additional uplifts of the land, or long ago the area would have been worn down to sea level. The nature and frequency of the rejuvenative movements are obscure. Most geologists believe that vertical uplifts occurred at periodic intervals following relatively prolonged intervals of crustal stability during which the land areas tended to be worn down to a common level. It is possible that the Burkes Garden area, along with the rest of the Appalachian region, may have been worn down to a peneplain one or more times in the geologic past. The evidence for postulating the existence of one or more ancient peneplains is, however, far from conclusive. Some of the topographic features commonly interpreted as remnants of peneplains, particularly even-crested ridges, seem to be the result of presently active erosion and to reflect only the differences in structure and relative resistance of different kinds of rock.

The existing topographic features of the Burkes Garden quadrangle are temporary ones which are being constantly reshaped and modified by erosion. It is only by noting the changes that are now taking place that the evolution of existing land forms can be truly appreciated.

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VIRGINIA CONSERVATION COMMISSION

VIRGINIA GEOLOGICAL SURVEY

ARTHUR BEVAN, STATE GEOLOGIST

BULLETIN 60, PLATE 1

19 Federal highway

78 State highway

600 State secondary road

Overthrust fault

U D Normal fault

Probable fault

25 Strike and dip of beds

55 Strike and dip of overturned beds

Strike of vertical beds

Horizontal beds

Active quarry

Abandoned quarry

14 Prospect

Boring

ECONOMIC DATA

PROSPECTS

MANGANESE [a]

1. Chestnut Ridge
2. Donahue
3. Big Ridge
4. Adz Ridge
5. Buckhorn Mountain
6, 7. East River Mountain
8a, 8b, 8c. Nye Cove
9. Leckie-Moss
10. Gose
11. Pocahontas
12. Dill
13a, 13b. Harmon
14. Tiptop
20. Yost

IRON

21. Bell Hill [b]
22. Big Ridge
24. Shott [a]

SAND

23. Bowen

COAL

15.
16.
17.
18.
19. Bland and Lick Creek fields [c]
25. Stony Ridge
73.
82.
84. Laurel Fork basin [d]
90.
97.
98.
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126.
136.
137.
138.
139.
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141.
142.
143.
144.
145. Horsepen Creek basin [d]

LIMESTONE

"GASPER" AND "STE. GENEVIEVE" LIMESTONES

(Contain several zones of high-calcium and high-carbonate limestone, most of which are less than 50 feet thick; several quarry sites along southeast side of Wrights Valley)

GRATTON LIMESTONE

(Chiefly fine-grained, high-calcium limestone; in Clinch and Bluestone valleys, quarriable thicknesses of high-calcium limestone occur locally)

CLIFFIELD FORMATION

(NORTHWEST OF CLINCH MOUNTAIN)

(Five Oaks limestone, burned for lime at Five Oaks, averages 35 to 50 feet thick; in Clinch and Bluestone valleys, a similar limestone occurs at the top of the formation. In the vicinity of Cave Spring 250 feet of coarse-grained, high-calcium limestone occurs locally; three-fourths of a mile north of Gratton, a zone of fine-grained, high-calcium limestone several hundred feet thick occurs locally; south of the intersection of U. S. Route 19 and Road 650, near St. Clair, zones of fine-grained, high-calcium limestone, some upwards of 100 feet thick, occur locally).

EFFNA LIMESTONE

(Mainly composed of very coarse-grained, high-calcium limestone; thickness varies greatly in short distances along the strike; ground on a small scale for agricultural limestone at McNutt quarry, near Sharon Springs)

DOLOMITE

BEEKMANTOWN FORMATION

(Mainly composed of fine- to coarse-grained dolomite; average $MgCO_3$ content less than 40 per cent; contains much chert and some disseminated sand; suitable for use as crushed stone)

COPPER RIDGE FORMATION

(Mainly composed of medium-grained dolomite, with many intercalations of quartz sandstone and some chert; suitable for use as crushed stone)

HONAKER FORMATION

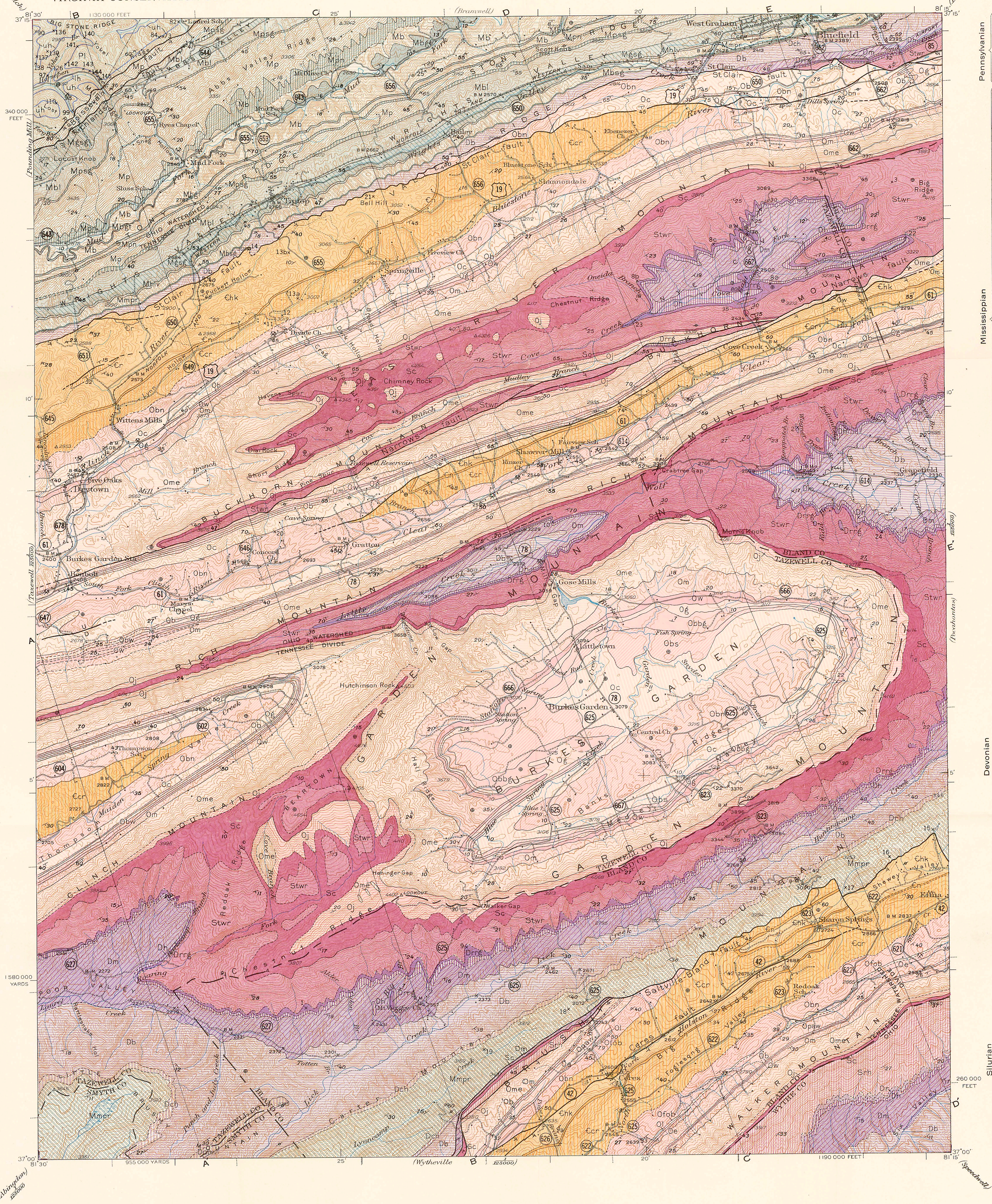
(Mainly dolomite; north of Wittens Mills several hundred feet of beds in the upper part of the formation average more than 40 per cent $MgCO_3$; these beds suitable for chemical uses; formation as a whole suitable for crushed stone)

[a] Prospects fully described in Stose, G. W.; and Miser, H. D., Manganese deposits of western Virginia: Virginia Geol. Survey Bull. 23, 1922.

[b] Described in Holden, R. J., Iron, in Mineral resources of Virginia: Virginia Jamestown Exposition Commission, 1907.

[c] Prospects described under same numbers in Campbell, M. R., Valley coal fields of Virginia: Virginia Geol. Survey Bull. 25, 1925.

[d] Prospects described under same numbers in Harnsberger, T. K., Geology and coal resources of the coal-bearing portion of Tazewell County, Virginia: Virginia Geol. Survey Bull. 19, 1919.



EXPLANATION

Pennsylvanian

Pottsville series

Pl (uh, lh) **Lee formation**
(Sandstone, shale, conglomerate, and intercalated coal beds; uh, Upper Horsepen coal; lh, Lower Horsepen coal; several minable coals, including Pocahontas No. 3, occur at depth)

Mississippian

Chester series ?

Mb (Mbgf) **Bluestone formation**
(Mudrock, shale, sandstone, and thin coal beds; Glady Fork sandstone member, Mbgf)

Mpn **Princeton sandstone**
(Sandstone, locally quartzitic and conglomeratic)

Mp (Mpsg) **Pennington formation**
(Mainly sandstone and shale; ridge-making beds at base, Stony Gap sandstone member, Mpsg)

Mbl **Bluefield shale**
(Mainly calcareous shale; a few limestone layers near the base; several sandstone beds in the upper half)

Mgsg **"Gasper" and "Ste. Genevieve" limestones**
(Limestone, fossiliferous, cherty, clayey; contains a few thin zones of relatively pure limestone)

Meramec series

Mhlv **Hillsdale limestone and Little Valley formation**
(Cherty, clayey limestone, fossiliferous throughout)

Osage series

Mmpr **Maccrady and Price formations**
(Maccrady mostly reddish-brown mudrock and shale; Price consists of sandstone, shale, and lenses of quartz-pebble conglomerate; Price on Brushy Mountain contains thin beds of coal)

Kinderhook series

Mbsg **Big Stone Gap shale**
(Thin zone of black shale; apparently absent southeast of the St. Clair fault)

Devonian

Senecan and Chautauquan series

Dch **"Chemung" formation**
(Sandstone and shale, very fossiliferous; thin or absent north of the St. Clair fault)

Db **Brallier formation**
(Alternating sandstone and shale; sparsely fossiliferous)

Erian series

Dm **Millboro shale**
(Black fissile shale below, "Marcellus" member; greenish-gray and buff shale above, "Naples" member)

Ulsterian series

Dh **Huntersville chert**
(White to dark-greenish-gray chert; fossils locally abundant; contains glauconitic layers near the base and top)

Drrg **Ridgeley and Rocky Gap sandstones**
(Quartz sandstone, locally very fossiliferous; Ridgeley thin and locally absent)

Dr **Ridgeley sandstone**
(Glauconitic sandstone, moderately fossiliferous; mapped separately only on Walker Mountain)

Dns **"New Scotland" formation**
(Quartz sandstone at base possibly Healing Springs sandstone member; middle part very cherty; upper beds coarse grained and fossiliferous; absent south of the St. Clair fault)

Silurian

Niagaran and Cayugan series

Stwr **Tonoloway limestone, Wills Creek sandstone and Rose Hill formation**
(Tonoloway is thin-bedded clayey limestone, at top; Wills Creek is thin, coarse-grained sandstone, only locally developed; Rose Hill is mainly shale and sandstone with a few very thin beds of hematite)

Srh **Rose Hill formation**
(Sandstone and shale, with one or more thin beds of hematite; mapped separately only on Walker Mountain, where the Wills Creek and Tonoloway are absent)

Lower Silurian series

Sc **Clinch sandstone**
(Very resistant sandstone, locally conglomeratic; upholds most of the higher ridges)

Ordovician

Upper Ordovician series

Oj **Juniata formation**
(Reddish-brown shale and sandstone; unfossiliferous)

Ome **Martinsburg and Eggleston formations**
(Maysville division, at top of Martinsburg is shale and concretionary siltstone; Eden division is mostly shale and siltstone; Trenton divison, at base of Martinsburg is fossiliferous limestone and shale; Eggleston formation is clayey, siliceous limestone and shale; Eggleston and basal Martinsburg contain metabentonites)

Middle Ordovician series

Om **Moccasin formation**
(Mostly red mudrock, with thin intercalations of limestone; contains thin, red metabentonites)

Ow **Witten limestone**
(Very fossiliferous limestone, characteristically thin bedded; thin or absent southeast of Clinch Mountain)

Obw **Bowen and Wardell formations**
(Bowen is red mudrock; Wardell fossiliferous limestone below and buff shale above; both formations confined to small area in west-central part of quadrangle)

Og **Gratton limestone**
(Most pure, fine-grained limestone; absent southeast of Clinch Mountain)

Ob (Obbg, Obs) **Benbolt limestone**
(Argillaceous limestone below, cross-bedded limestone above; mapped as two members in Burkes Garden; lower nodular beds, Shannondale limestone member, Obs; upper nodular beds and cross-bedded limestone, Burkes Garden limestone member, Obbg).

Cliffield group (southeast of Clinch Mountain)

Opaw **Peery limestone, Athens formation, and Whitesburg limestone**
(Peery is thin cherty limestone at top; Athens is mostly black clayey limestone with some intercalated shales; Whitesburg is thin fossiliferous limestone at base)

Oe **Effna limestone**
(Coarse-grained, high-calcium limestone; reefy in lower part)

Ol **Lincolnshire limestone**
(Dark, cherty limestone; thin or locally absent)

Ofob **Five Oaks limestone and Blackford formation**
(Five Oaks is fine-grained limestone; Blackford is mainly chert- and dolomite-pebble conglomerate; both are locally absent).

Oc **Cliffield formation**
(Chert conglomerate at the base; mostly cherty, dark-gray limestone, but contains two zones of high-calcium limestone; locally, cherty beds supplanted by fine-grained pure limestone several hundred feet thick; includes representatives of all the formations assigned to the Cliffield group southeast of Clinch Mountain)

MAJOR DISCONFORMITY

Lower Ordovician series

Obn **Beekmantown formation**
(Chiefly dolomite, with several intercalations of fine grained limestone)

Cambrian

Upper Cambrian series

Ꞓcr **Copper Ridge dolomite**
(Chiefly dolomite, with intercalations of quartz sandstone; 75-foot sandstone at base of formation between Brushy and Walker Mountains)

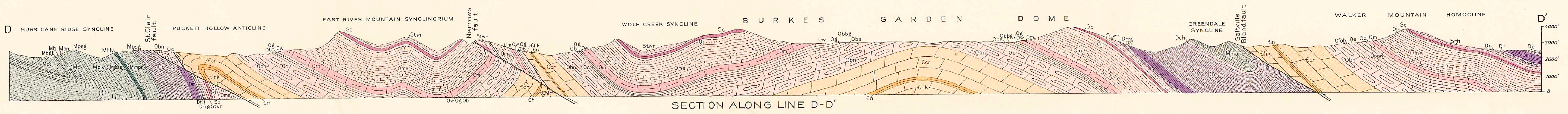
Ꞓn **Nolichucky shale**
(Chiefly shale, with few thin intercalations of limestone)

Middle Cambrian series

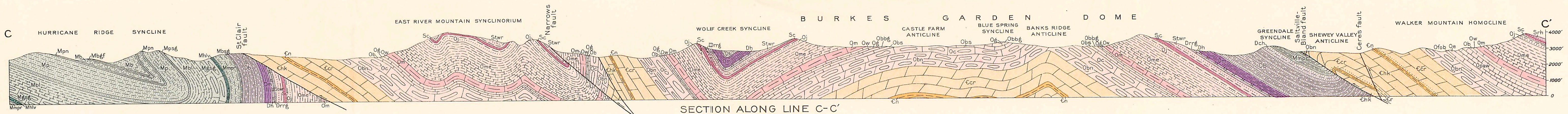
Ꞓhk **Honaker formation**
(Chiefly dolomite, with intercalations of shale and limestone in the belts northwest of the Saltville-Bland fault)

Lower Cambrian series

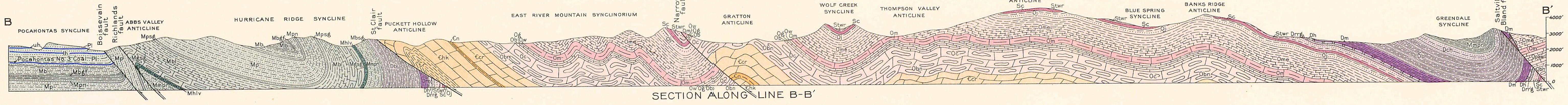
Ꞓr **Rome formation**
(Mostly red, green, and yellow shales; only upper part of formation exposed; crops out only in two small areas north of Wittens Mills)



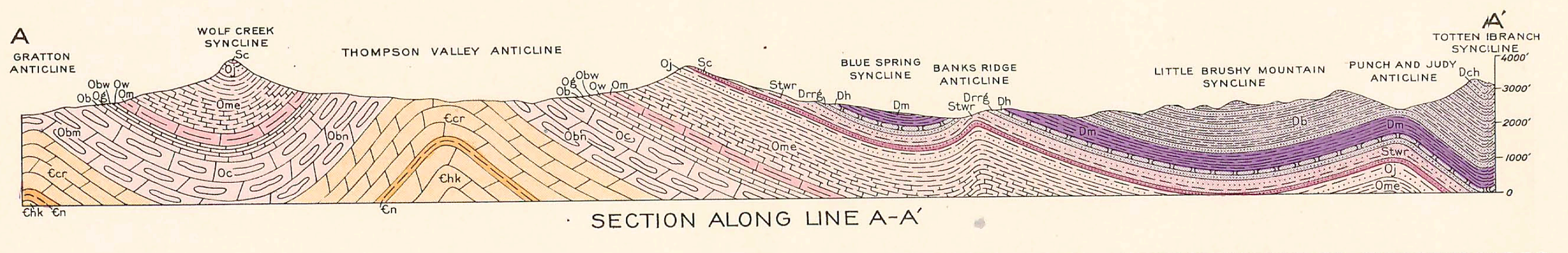
SECTION ALONG LINE D-D'



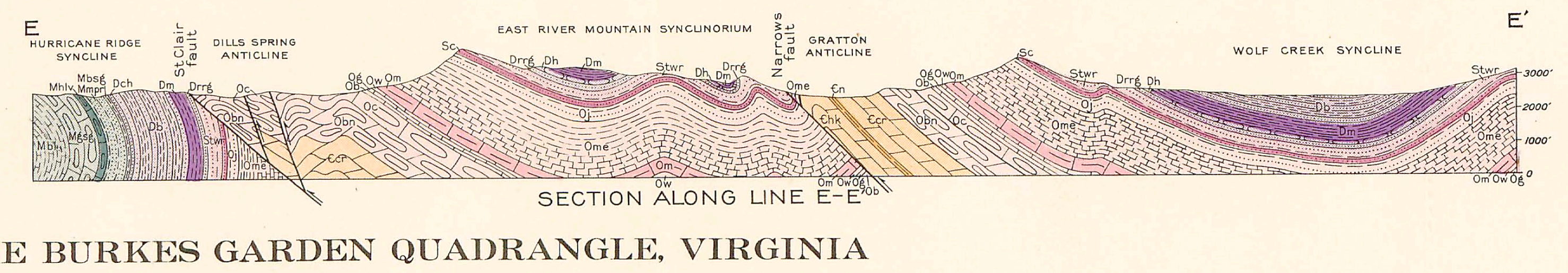
SECTION ALONG LINE C-C'



SECTION ALONG LINE B-B'



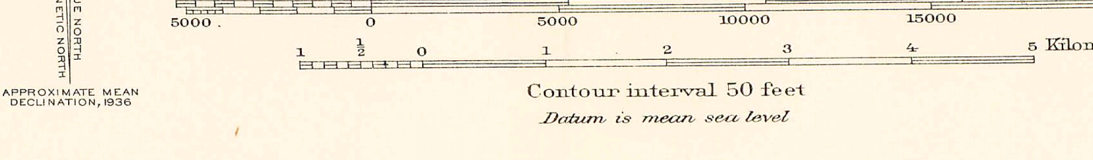
SECTION ALONG LINE A-A'



SECTION ALONG LINE E-E'

GEOLOGIC MAP AND STRUCTURE SECTIONS OF THE BURKES GARDEN QUADRANGLE, VIRGINIA

Base by U. S. Geological Survey, surveyed in cooperation with the State of Virginia. Topographic base map is available separately.



Scale $\frac{1}{62500}$

Contour interval 50 feet

Datum is mean sea level

Geology by Byron N. Cooper
1938-1940