COMMONWEALTH OF VIRGINIA

STATE COMMISSION ON CONSERVATION AND DEVELOPMENT

VIRGINIA GEOLOGICAL SURVEY

ARTHUR BEVAN, *State Geologist*

Bulletin 46

Contributions to Virginia Geology

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STATE COMMISSION ON CONSERVATION AND DEVELOPMENT

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LETTER OF TRANSMITTAL

COMMONWEALTH OF VIRGINIA

VIRGINIA GEOLOGICAL SURVEY

UNIVERSITY OF VIRGINIA

CHARLOTTESVILLE, VA., May 15, 1936.

To the State Commission on Conservation and Development:

GENTLEMEN:

I have the honor to transmit and to recommend for publication as Bulletin 46 of the Virginia Geological Survey series of reports the manuscript and illustrations of a report entitled *Contributions to Virginia Geology.*

This report contains thirteen papers by as many geologists. Most of the papers have not been published and they have been submitted to the Virginia Geological Survey for inclusion in this volume. They make important contributions to an understanding of the geology and mineral resources of certain parts of Virginia. A few other papers have been reprinted with permission of the authors, because they treat of natural features about which the Geological Survey receives numerous requests for information and they are not readily available to teachers and the general public, in the periodicals where originally published.

Respectfully submitted,

ARTHUR BEVAN,
State Geologist.

Approved for publication:
State Commission on Conservation and Development,
Richmond, Virginia, May 26, 1936.
R. A. GILLIAM, *Executive Secretary and Treasurer.*

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ORIGIN OF OUR SCENERY

BY

ARTHUR BEVAN

STATE COMMISSION ON CONSERVATION AND DEVELOPMENT
VIRGINIA GEOLOGICAL SURVEY
Bulletin 46-A
UNIVERSITY, VIRGINIA
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Origin of Our Scenery[1]

By Arthur Bevan[2]

The hills are shadows, and they flow
From form to form and nothing stands;

Well did the poet epitomize in a few apt phrases the origin of our scenery. No more truth can be added to his words, but their meaning can be interpreted in terms of modern geology and illustrated by certain landscape features of great beauty and general interest in the Hot Springs region. The lovely, almost unique, Warm Springs Valley and its oval rim of high, rather even-crested mountain ridges (Pl. 1), broken here and there by water gaps, offer a fascinating story of ancient geologic events. It is a tale of an unbroken chain of natural events through countless eons of time, estimated in units of millions of years, which have gradually given form to our present attractive landscapes.[3]

Our scenic land features have been produced by a succession of geologic processes. Each layer of rock exposed in the Valley and along the slopes and crests of the mountains is a record of contemporaneous earth history. The different kinds of sedimentary rock—sandstone, shale, and limestone—their distribution, structure or arrangement, and entombed fossil shells are mute but reliable evidences in deciphering the apparent mysteries of the remote past and reconstructing the chain of events in the geologic panorama. The landscapes themselves—the various patterns of hills and valleys and the courses of the streams—afford also excellent clues as to their origin when the mode of their interpretation is understood. Even the characteristics of the springs indicate the sources of their waters.

The first act in the geologic drama of this region was staged amid surroundings most unlike those now existing. The entire region from Piedmont Virginia westward far beyond the State boundary was covered by a shallow sea in a broad mediterranean basin or trough. Along its eastern shore there lay a large land

[1] Reprinted, with slight revisions, by permission from "The Homestead Spectator," vol. 4, no. 3, pp. 12-13, and no. 4, pp. 8-9, 23, 1933, published by the Virginia Hot Springs Co., Hot Springs, Va.

[2] State Geologist.

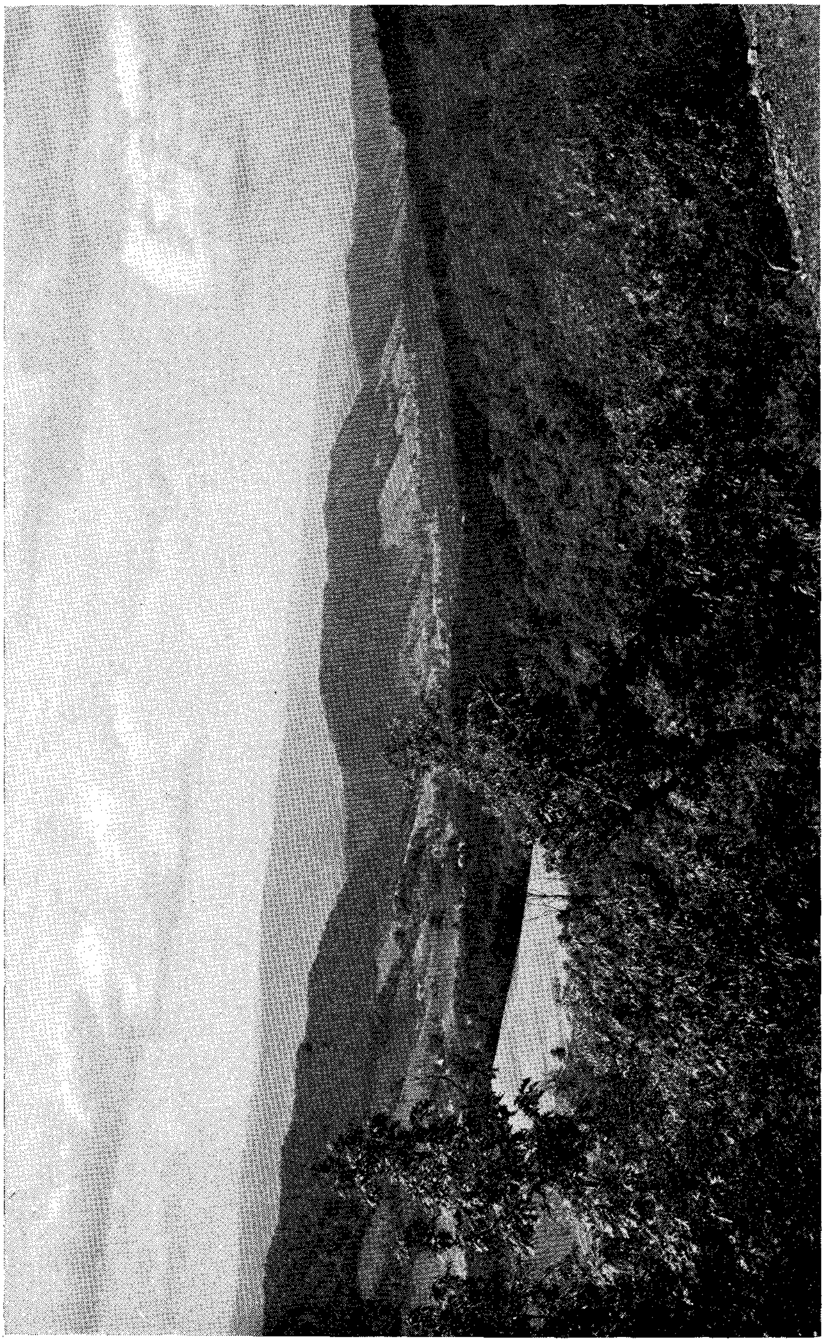
[3] The geologic story of the origin of our landscapes as recorded and interpreted in the Hot Springs area applies also with local modifications to much of the State west of the Blue Ridge.

mass, from which sediments were carried westward by streams and waves and deposited in the sea.

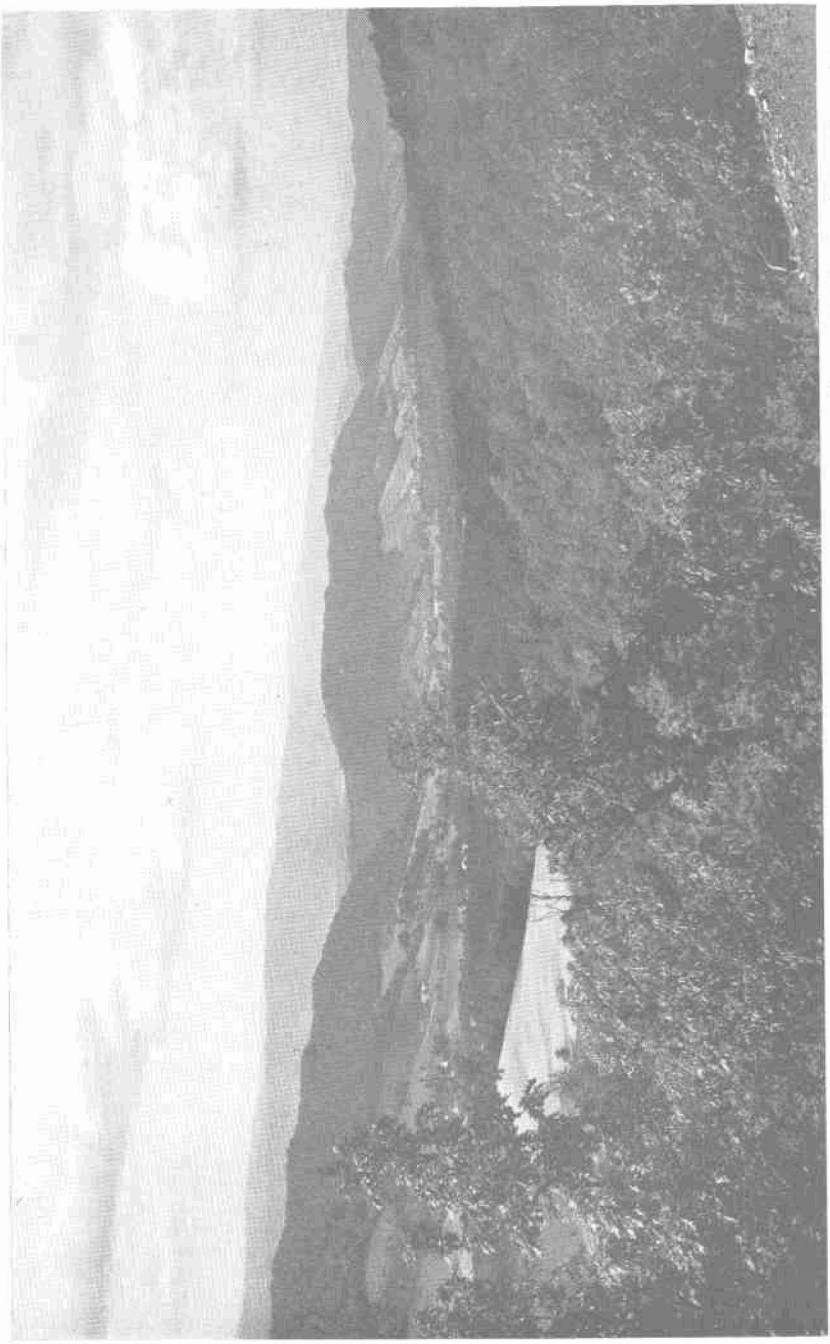
The firm sandstones along the crest of Warm Springs and other mountains were then loose sands along beaches and on the sea floor. Muds were swept out to sea to become consolidated into thin-bedded shales, such as those along the trails and roads to the crest of Warm Springs and Little mountains. With some of the muds were admixed considerable iron compounds giving rise to red shales; with others were deposited finely divided organic debris which colored them dark gray to black. Both the red and black shales are common in the Hot Springs area, and also throughout the western part of the State. Limy muds and fragments of shells which accumulated in clearer waters were later consolidated into the limestones now seen throughout the length of the Valley. Many of the beds of rock contain fossil shells of the corals, clams, snails, and crab-like animals which lived in those shallow mediterranean seas, and, in fact, unquestionably prove the former presence of the seas. These fossils are especially abundant in some layers of the shale along the middle slopes of the Valley. The sandstones and limestones in the vicinity of Fassifern Farm and along the road across Back Creek Mountain contain several kinds.

The seas invaded and withdrew from the region many times during the Paleozoic era, measured by many millions of years. During this time there accumulated in Bath County a vast pile of sediments, probably 20,000 feet or more thick. This enormous thickness of sediment accumulated in shallow waters as the sea floor or bottom of the great trough gradually sank. At no time was the sea extraordinarily deep; the kinds of sediment, the shoal-water ripple marks on sandstones and sandy shales, as near Falling Springs Gap and along the road north of Flag Rock, and the fossil shells prove that interpretation.

Toward the close of the Paleozoic era (the era of ancient life), the scene slowly changed. The sea gradually withdrew and the land began to rise imperceptibly in great billows due to the urge of accumulated forces in the interior of the earth's crust. The many beds of sediment in the very thick pile that had accumulated in the great trough were irresistibly folded like sheets of cardboard into a series of large arches, called anticlines, and adjacent troughs, called synclines. Near the Blue Ridge the lateral pressure was so intense as to cause some of the anticlines to break, and as the pressure continued unabated the upper masses of rock were shoved gradually northwestward for several miles over the underlying rocks. The overthrust masses were in the form of huge elongate blocks or thick slices of the earth's crust.



Warm Springs Valley, Bath County, Virginia. The valley has been eroded on an anticline with Silurian (Clinch) sandstone in the flanking ridges and Lower Ordovician limestones on the Valley floor. Looking northwest from Warm Springs *Mountain.* Photograph by H. A. Strohmeyer, Jr. (Courtesy of Virginia Department of Agriculture and Immigration.)



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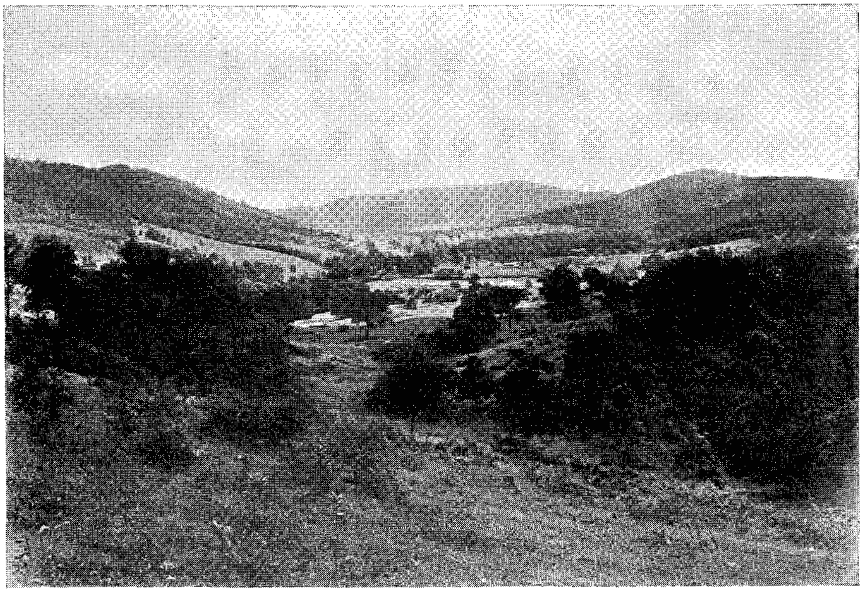
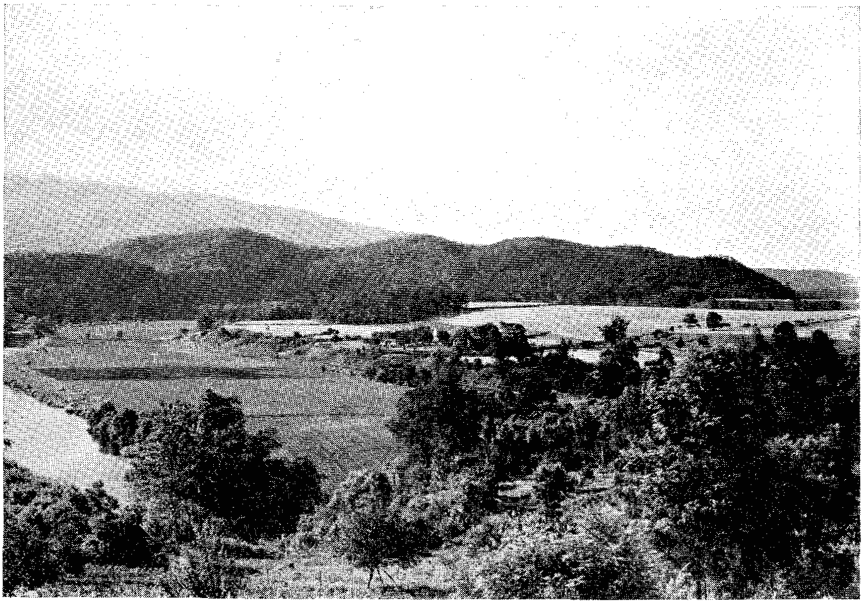


A. Northeast end of Warm Springs Valley. The Warm Springs anticline has been eroded so that the Clinch sandstone forms an encircling rim. Older shales and limestones are exposed on the slopes of the mountains and on the valley floor.



B. Terraces along Jackson River 3 miles north of Covington. Hills of Devonian shale in the immediate background. Photographs by Frank J. Wright. (From Geological Survey Bull. 11.)

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B. Terraces along Jackson River 3 miles north of Covington. Hills of Devonian shale in the immediate background. Photographs by Frank J. Wright. (From Geological Survey Bull. 11.)

Bath County was west of the zone of strongest pressure and thrust faulting; hence the rocks here are only sharply folded, but the folds are generally overturned toward the northwest sides. The Warm Springs anticline is a fine example of such a fold. We can see at many points along the Flag Rock trail that the sandstone dips steeply southeast. The trails along the west slope of the Valley show that the rocks dip steeply to the northwest. Similar dips occur at many places along the Valley highway and in the water gaps to the west. Nowhere do the rocks retain their original horizontal position.

When one stands along the road about a mile south of Warm Springs, or along some of the trails, and looks northward toward the head of the Valley, he can readily see that the rim of the Valley consists of very resistant rock. (See Pl. 2, A.) It is a hard white sandstone. He can visualize also the sandstone dipping outward from the Valley rim, or the crests of Warm Springs and Little mountains. At other points in the Valley and on the mountains a similar view can be had of the southwest end of the Valley. It is thus seen that Warm Springs Valley is an elongate narrow canoe-shaped depression encircled by outward-dipping rocks.

The large-scale wrinkling and corrugation of the outer part of the earth, with its many huge folds and fractures, gave rise to the ancestral Appalachian Mountains. They probably stood much higher than the present mountains and were more rugged, but we cannot determine their exact characteristics. The range no doubt had considerable grandeur. It was not clothed with vegetation like that on the present mountains. One can restore roughly the height of single folds by extending the inclined beds of sandstone in Warm Springs and Little mountains upward across the crest of the arch and then adding to the top some thousands of feet of beds which have been eroded away. Although great mountains were formed, their upheaval was probably so slow as not to have been perceptible if man had lived among them at that time. Earthquakes would have been the only tangible evidence of mountain growth. But the time long antedated the creation of man.

As the land slowly rose above the sea and as the mountains were gradually unwarped, weather and streams attacked the slopes, just as they do today. The rocks disintegrated and were eroded and the high places were reduced toward a common level. After very long periods of crustal quiet and stream planation the region was worn down to a vast gently rolling plain, called a peneplain.

The time involved was so long—some scores of millions of years—that both hard and soft rocks were worn to this common level. Thus the old mountains disappeared.[4]

Accumulated forces in the earth's crust came into action again, but this time they acted vertically. The plain was slowly uplifted and the rejuvenated streams dissected the slowly rising plain into a pattern of parallel ridges and valleys. The valleys were excavated on the softer rocks (Pl. 2, B), whereas the harder rocks remained as ridges. (See Pl. 1.) Remnants of the old peneplain are clearly visible on the flat crests of many of the mountain ridges, as on Warm Springs Mountain at the airport. The views eastward from the airport and Flag Rock show a remarkable series of flat-topped ridges, each carved from a former extensive plain.

The primary setting of the geologic stage for the evolution of our scenery occurred many hundreds of millions of years ago. During the subsequent long geologic periods of time, feature after feature of the present diversified landscapes has been slowly developed.

The first important event in the actual sculpturing of the rocks into existing land forms was the slow but inevitable erosion of the old mountains to the vast lowland peneplain, not far above sea level. Mountains were removed piecemeal as particles of gravel, sand and mud were carried to distant basins. The great folds were ultimately planed across by the incessant lateral cutting of streams much as the grain of a tree is cut across by a saw. The planation was so complete that hard and soft rocks, ridges and valleys, were alike reduced to a common level. Only their truncated roots remain to attest to the former existence and magnitude of the old ancestral mountains.

The flattish region was then underlain by parallel belts of resistant sandstone and weaker shale and limestone whose upturned edges were close to the surface. Irresistible forces in the interior of the earth caused the uplift of the peneplain until it stood at least 3,000 feet above the sea.

This slow vertical uplift of the land was the second great event in the origin of our scenery. As the surface rose higher and higher, the velocity of the streams was increased and hence with renewed erosive powers they began to sculpture the plain into a new pattern of land forms.[5]

Warm Springs Valley has been excavated on thick shales and limestones to a depth of about 1,000 feet below the level of the old

[4] See Wright, F. J., The Physiography of the Upper James River Basin in Virginia: Virginia Geol. Survey Bull. 11, 1925.

[5] Wright, F. J., The newer Appalachians of the South: Part 1, Between the Potomac and the New rivers: Denison Univ. Bull., Sci. Lab. Jour., vol. 29, pp. 1-105, 1934.

peneplain. (See Pl. 1.) Warm Springs and Little mountains are remnant ridges buttressed by the hard sandstones on both flanks of the Warm Springs anticline.

Meager remnants of the old peneplain are preserved as the scattered flats at an altitude of 3,000 feet or more along the summit of Warm Springs Mountain. One of the most interesting, and useful, is at the airport. Here the underlying sandstone is flexed into a shallow syncline on which enough of the old surface has remained to make a mountain-top landing field. Its altitude of 3,760 feet is about 1,500 feet higher than the Homestead Hotel. No airport could have been established on the crest of a high mountain ridge if a broad remnant of the old peneplain had not been preserved.

Numerous closely spaced shallow valleys have been eroded in the valley slope of Little Mountain. As the late afternoon shadows deepen, the grassy spur ridges and wooded valleys have the appearance of greenish billows molded in stone. At the same time the serrate profile of the ridge crest is accentuated. The surface of the mountain differs in detail from that of Warm Springs Mountain because the supporting sandstones are steeper and have been eroded more. Thus many small valleys are developing in the underlying shale.

One of the most peculiar and striking features of Warm Springs Valley is the series of water gaps through Little Mountain. (See Pl. 1.) All of the drainage is to the west, to Jackson River. The origin of the gaps and the lack of a major stream in the Valley itself are involved in the complex drainage history of the whole region.

In brief, the rivers were flowing sluggishly in meandering courses upon the old lowland plain. They crossed it irrespective of the belts of folded hard and soft rocks because these had been planed to a common level and covered with a mantle of soil and other loose rock. As the peneplain was slowly uplifted the streams were forced in turn to cut downward in the channels which they then occupied. Their courses soon became definitely established across the different belts of rock. They could cut narrow gorges only in the sandstones, while broad valleys were eroded on the shales and limestones.

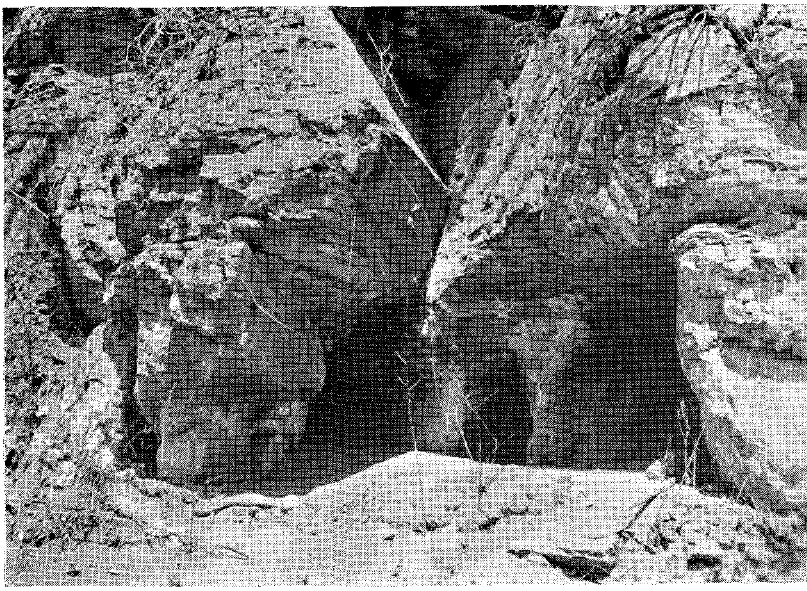
Jackson River and Back Creek are most interesting examples of streams which have inherited their courses from a previous erosion cycle. Broad open stretches of valley are found upon the relatively soft shale, as below Fassifern Farm, and at several places toward Covington. Some of the valley floors show benches or terraces which mark former levels of the river channel on earlier valley bottoms. (See Pl. 2, B.) The broad valleys are suddenly interrupted in places by abrupt changes in the course of the river into deep gorges, such as Richardson Gorge and "The Gorge," athwart the mountain ridges. The picturesque gorge of Back Creek just above its mouth is 1,000 feet deep. It is readily accessible in part along the grade of the abandoned timber railroad.

The undulatory floor of Warm Springs Valley is due in part to the erosive action of underground water. The Valley is underlain by tilted beds of more or less soluble limestone which contain numerous cracks and fissures. Rain and snow have seeped into them and gradually have dissolved the more soluble portions, thus producing underground drainage channels and caves. (See Pl. 3, A.) In several places in the region, surface streams can be seen disappearing into a gaping cavern in a limestone cliff. Continual drainage along the same fissures, abetted locally perhaps by the collapse of cave roofs, has produced numerous sink holes in the limestone belts. In Warm Springs Valley much of the precipitation flows away underground. The streams are fed mainly by springs.

Although they play only a minor role in the origin of our scenic landscapes, these springs are one of the most interesting features. They are the outlets of rain which had fallen long ago on distant slopes and traveled slowly underground through porous beds of rock. Recalling that the rocks of the region are folded into a series of anticlines and synclines, one can visualize the slow but steady movement of ground water from higher to lower levels. Some springs are warm apparently because the water has migrated to great depths where it has been heated by contact with warmer rocks. Earth temperatures increase about one degree for each 75 feet of depth. The heated waters, being under pressure, rise to the surface at places below the intake points on distant mountain slopes.

Some of the largest, as well as some of the hottest, springs in Virginia, are found in Warm Springs Valley. Falling Spring, toward the southwest end of the valley, flows about 7,000 gallons a minute. The plunge of this water into the ravine just west of the road to Covington makes one of the most beautiful waterfalls in Virginia. (See Pl. 3, B.) The cliff over which the water falls is composed of travertine (calcium carbonate). It is limestone dissolved by ground water and then precipitated at the surface under new conditions.[6] This travertine contains some well-pre-

[6] See Steidtmann, Edward, Travertine-depositing waters near Lexington, Virginia: Jour. Geology, vol. 44, no. 2, pp. 193-200, 1936.



A. Blowing Cave, Bath County, Virginia. A cavern in Helderberg limestone along State Highway 501. (From Geological Survey Bull. 36.)

B. Falling Springs Creek waterfall along U. S. Highway 220, about 8 miles northeast of Covington, Alleghany County, Virginia. The cliff is composed of travertine deposited from the creek waters. (From Geological Survey Bull. 36.)

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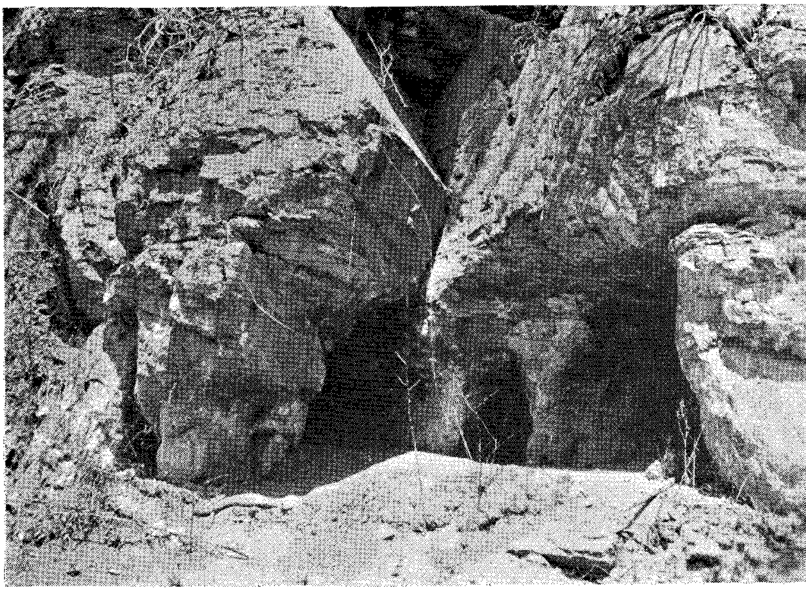

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served leaves and twigs—the first stages in the possible making of future fossil plants. Some of it is quarried for the manufacture of agricultural lime.

The temperatures of the springs range in summer from 68° to 105°. They are only slightly cooler in winter. The warmest springs are Boiler and Spout springs at the Homestead Hotel. Boiler Spring flows about 168 gallons a minute at a constant temperature of 104° to 105°. Spout Spring has a smaller flow at a temperature slightly more than 105°.[7]

No small part of the restful beauty of the Valley is produced by the vegetation. Its origin is another interesting story.[8]. Suffice it to say here that the conifers are of very ancient lineage, whereas the abundant hardwood trees and flowering plants came into existence and have evolved chiefly since the regional peneplain was uplifted. The uplift and dissection of the old peneplain which truncated the closely folded marine sedimentary rocks had far-reaching consequences in the creation of the lovely scenery and in the control of many of our modern activities.[9]

Truly we can realize with the poet that—

They melt like mists the solid lands;
Like clouds they shape themselves and go.

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[7] A discussion of these and other springs is given by Reeves, Frank, Thermal springs of Virginia: Virginia Geol. Survey Bull. 36, 1932.

[8] Interesting accounts of the ancestry of many of the trees are given by Berry, E. W., Tree Ancestors, Williams and Wilkins, Baltimore, 1923.

[9] The new detailed topographic maps of the Falling Spring, Healing Springs, Mountain Grove and Warm Springs Run quadrangles, on a scale of half a mile to an inch, show all the surface features of the Hot Springs region. They can be obtained from the Virginia Geological Survey, University, Va., at ten cents a copy.

PROSPECTING FOR NATURAL GAS AND PETROLEUM IN VIRGINIA

BY

WILLIAM M. MCGILL

STATE COMMISSION ON CONSERVATION AND DEVELOPMENT
VIRGINIA GEOLOGICAL SURVEY
Bulletin 46-B
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Prospecting for Natural Gas and Petroleum in Virginia[1]

By William M. McGill[2]

INTRODUCTION

The first important commercial oil well in North America was drilled at Titusville (Oil Creek), Pennsylvania, by Colonel E. L. Drake, in 1859. This discovery well was in the Appalachian field, as now named, and yielded only a few barrels of oil a day. Since then the search for natural gas and petroleum has been carried on diligently in all parts of the world and many rich fields have been discovered. Further scientific explorations will most probably result in the discovery of other large producing areas. Use of the principles of geology by trained geologists has played a very important part in the discovery of natural gas and petroleum-bearing areas and particularly in their successful development. Geophysical methods have also been very useful in some regions and probably will be more widely used in future explorations.

It is the ambition of most producers or drillers to "bring in" new fields, and so the search for more oil and gas continues. Explorations in unproved territory are termed "wildcat drilling." Through the intiative and exploration of "wildcatters," new areas are frequently discovered and developed.

GEOLOGICAL CONDITIONS FOR ACCUMULATION

A systematic study of proved areas has shown that, despite popular opinion to the contrary, certain geologic conditions influence the occurrence of commercial quantities of petroleum and natural gas. It is now generally believed that natural gas and petroleum have been formed principally by the decomposition of organic material in sediments of marine origin. Hence, in the search for new producing fields, areas underlain by marine sediments—fossiliferous sandstones and limestones and carbonaceous shales—such as are known to be petroliferous in proved fields, attract attention. It is thought also that carbonaceous shales, derived from shallow-water deposits of mud and clay and contain-

[1] Revision in part of an article entitled "Explorations for Oil and Gas in Southwestern Virginia," *in* the Mountain Empire, vol. 1, no. 3, pp. 10-11, 16, 1932, published at Wytheville, Va., by Southwestern Virginia, Inc.

[2] Assistant State Geologist.

ing remains of marine life, are probably the most important source beds of most of the petroleum and natural gas.

Because petroleum and gas migrate, there must be favorable beds above or near the source beds, in which the petroleum and gas may accumulate in sufficient quantity for commercial production. The most important reservoir beds are thick, porous sandstones, fractured or cavernous limestones and dolomites, and fissured shales. It is also necessary that some impervious cap rock, as shale, lie above the reservoir beds, to prevent the upward escape of the petroleum and gas. There must be also a favorable structure, such as an anticline, to trap the moving petroleum and gas. Ideal conditions under which natural gas and petroleum accumulate are shown in Figure 1.

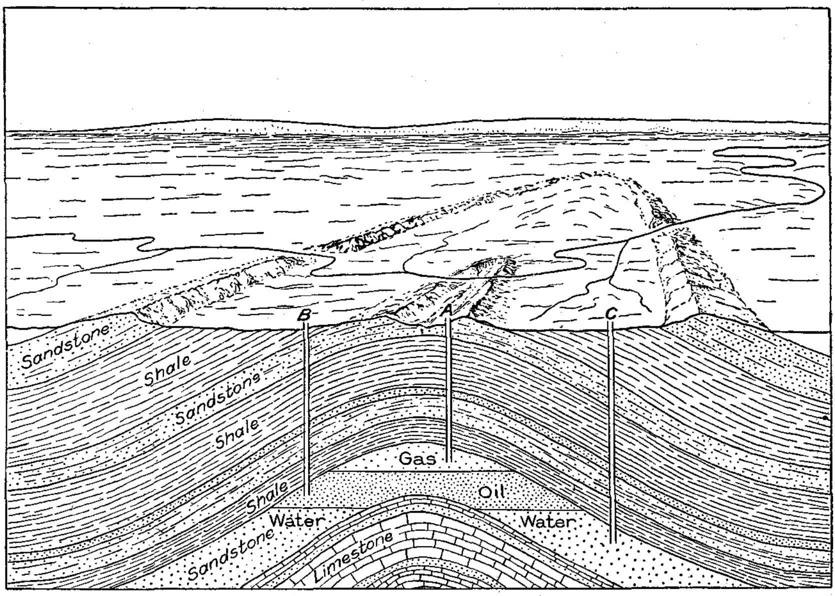

FIGURE 1.—Diagram showing geologic conditions for accumulation of natural gas and petroleum in an anticline.

In proof of these hypotheses governing the accumulation of commercial quantities of petroleum and gas it should be noted that (1) no commercial occurrence has been found in crystalline rocks, (2) the majority of the proved fields occur in areas underlain by marine sedimentary rocks, and (3) the proved fields are in warped or folded rocks. Further, most of the known producing fields occur in gently folded areas along the flanks of, or near, great mountain areas that were once beneath the sea.

Deposits of sand, mud and limy muds were laid down many hundreds of thousands of years ago by seas and rivers on old sea floors and in inland basins and lakes. These deposits became consolidated into beds of sandstone, shale, and limestone, in places of considerable thickness. Later, large areas underlain by these sedimentary rocks were uplifted and folded into belts of great mountains. Zones of folded or warped rocks were thus produced. Many beds of limestone and sandstone now exposed on the slopes and tops of high mountains contain fossil shells of the marine life that lived in the waters when the sediments were deposited.

There are many areas underlain by marine sedimentary rocks, known to be petroliferous in other places, in which no petroleum or gas has been found. Apparently favorable structures for the accumulation of petroleum and gas occur also in these unproductive areas. They are chiefly areas in which the rocks have undergone extreme deformation and alteration, usually through mountain-making movements. Some are broken by great faults along which any petroleum and gas may have escaped. Erosion has cut deeply into many of the folds, through the cap rocks and into the reservoir beds.

Many of these unproductive areas contain beds of coal. The coal was formed from plant remains in the rocks and has been carbonized in part by the heat and pressure generated by the disturbances, that is by the folding and faulting. It is thought that the heat and pressure resulting from the folding of the rocks in the intense mountain-making movements, and which aided in the expulsion of much of the volatile matter from coals of high carbon content, have been responsible for the distillation of any petroleum that may have accumulated in the sedimentary rocks. The late Dr. David White, of the U. S. Geological Survey, studied the relationship of the producing petroleum pools in the Appalachian field to the carbon content of the coals in near-by areas. He concluded that commercial quantities of petroleum would not be found where the coal contained 65 per cent or more of fixed carbon. Similar studies elsewhere have tended to justify White's law. It is possible that commercial quantities of gas may occur in portions of such areas. However, drilling would be necessary to determine its occurrences.

Plate 4, prepared by J. B. Eby for his discussion of "Oil and gas possibilities in Wise County" [Virginia],[3] shows the known occurrences of natural gas and petroleum in 1923 in adjacent parts

[3] Eby J. B., The geology and mineral resources of Wise County and the coal-bearing portion of Scott County, Virginia: Virginia Geol. Survey Bull. 24, pp. 578-583, Pl. 37, 1923.

of Kentucky and West Virginia. This plate also shows by means of isocarbs—lines connecting points where the coal has the same carbon content—the approximate carbon content of coals in southwestern Virginia. The main folds and faults of this region are also indicated on this map.

EXPLORATIONS IN VIRGINIA

Within the past 25 years there have been perhaps 25 wells drilled for petroleum or natural gas in various parts of Virginia, but no commercial production of petroleum has been obtained. Due to the fact that most of the tests were "wildcat" operations and no accurate record or log was kept by the drillers, there is little helpful information now available on these earlier tests. No detailed investigation has been made by the Virginia Geological Survey of natural gas or petroleum possibilities in Virginia; however, information on the geology and structural conditions in certain areas, which should be helpful in further study or consideration of those areas, is given in publications of the Geological Survey.[4]

Early explorations.—One of the earliest known test holes for petroleum and natural gas in Virginia was drilled on the Nettle Patch farm of G. W. Gish, about 2 miles south of Ramsey in Wise County in the late nineties.[5] A slight flow of gas was found at a reported depth of 628 feet, but no indications of petroleum were obtained. A small quantity of oil was discovered in a well drilled near Rose Hill in Lee County in 1923. The oil was encountered at a depth of about 303 feet, in the Clinton formation of Silurian age.[6] Although both of these showings aroused considerable interest locally, no further drilling was done in either vicinity, the opinion prevailing, until recent years, that commercial quantities of neither petroleum nor natural gas would be found in those areas.

Showings of natural gas have been reported from various test holes drilled during explorations for coal seams locally in the coal-bearing region of southwestern Virginia and seepages of both natural gas and petroleum have been reported locally from springs, water wells, and other localities throughout the Appalachian Val-

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[4] Eby, J. B., The geology and mineral resources of Wise County and the coal-bearing portion of Scott County, Virginia: Virginia Geol. Survey Bull. 24, pp. 578-583, Pl. 37, 1923.

Butts, Charles, Oil and gas possibilities at Early Grove, Scott County, Virginia: Virginia Geol. Survey Bull. 27, 18 pp., 1927.

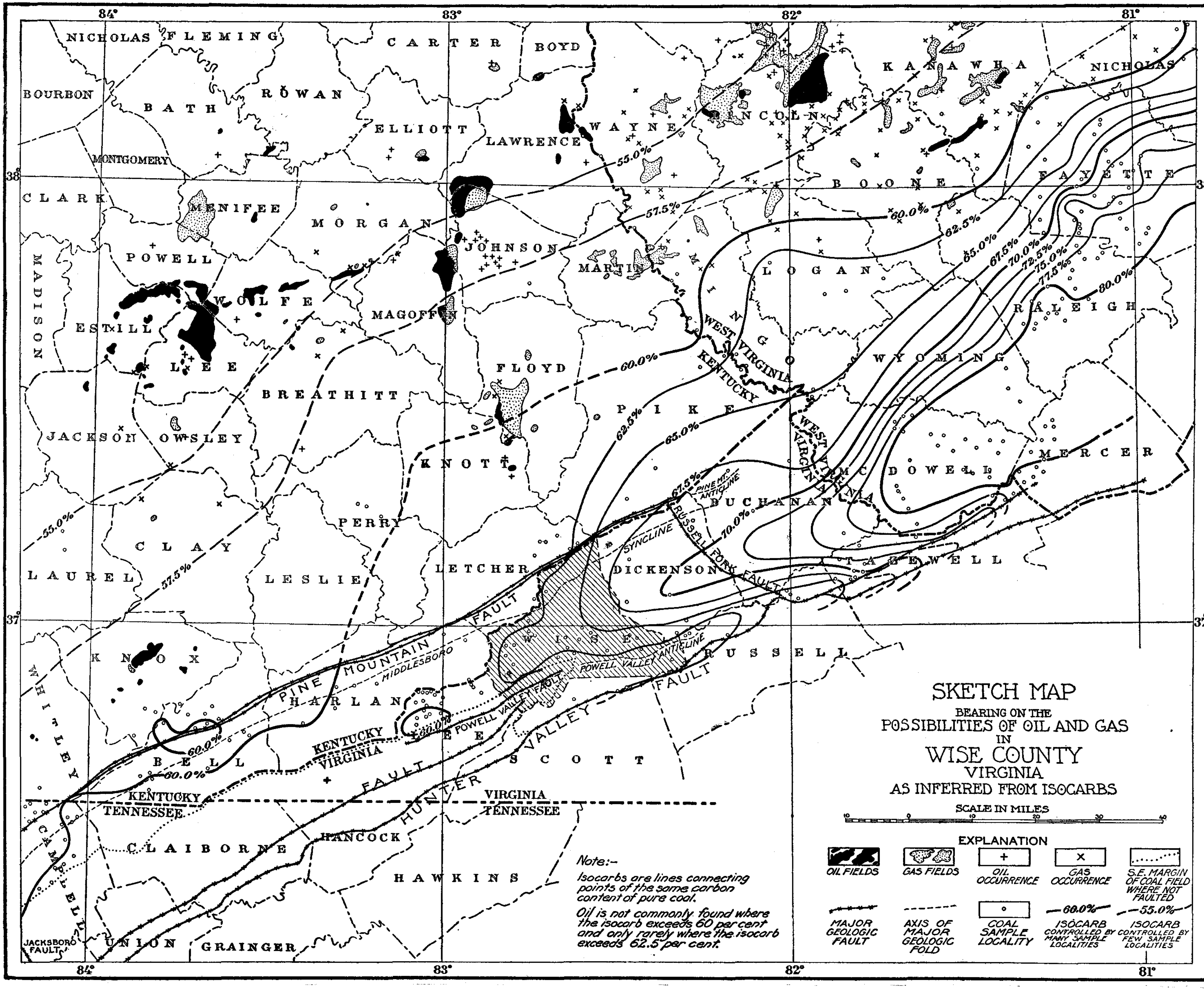
...................., Oil, *in* Fensters in the Cumberland overthrust block in southwestern Virginia: Virginia Geol. Survey Bull. 28, pp. 10, 12, 1927.

U. S. Geological Survey, Oil in Lee County, Virginia: Press Notice no. 15555, 4 pp., map, July 3, 1923.

[5] Eby, J. B. op. cit., pp. 581-582.

[6] Butts, Charles, Fensters in the Cumberland overthrust block in southwestern Virginia: Virginia Geol. Survey Bull. 28, p. 10, 1927.

U. S. Geological Survey, idem.


SKETCH MAP
BEARING ON THE
POSSIBILITIES OF OIL AND GAS
IN
WISE COUNTY
VIRGINIA
AS INFERRED FROM ISOCARBS
SCALE IN MILES
EXPLANATION
OIL FIELDS
GAS FIELDS
OIL OCCURRENCE
GAS OCCURRENCE
S.E. MARGIN OF COAL FIELD WHERE NOT FAULTED
MAJOR GEOLOGIC FAULT
AXIS OF MAJOR GEOLOGIC FOLD
COAL SAMPLE LOCALITY
60.0%
ISOCARB CONTROLLED BY MANY SAMPLE LOCALITIES
55.0%
ISOCARB CONTROLLED BY FEW SAMPLE LOCALITIES
Note:-
Isocarbs are lines connecting points of the same carbon content of pure coal.
Oil is not commonly found where the isocarb exceeds 60 per cent and only rarely where the isocarb exceeds 62.5 per cent.
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81°
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BOURBON
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MERCER
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TAZEWELL
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LETCHER
DICKENSON
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KNOX
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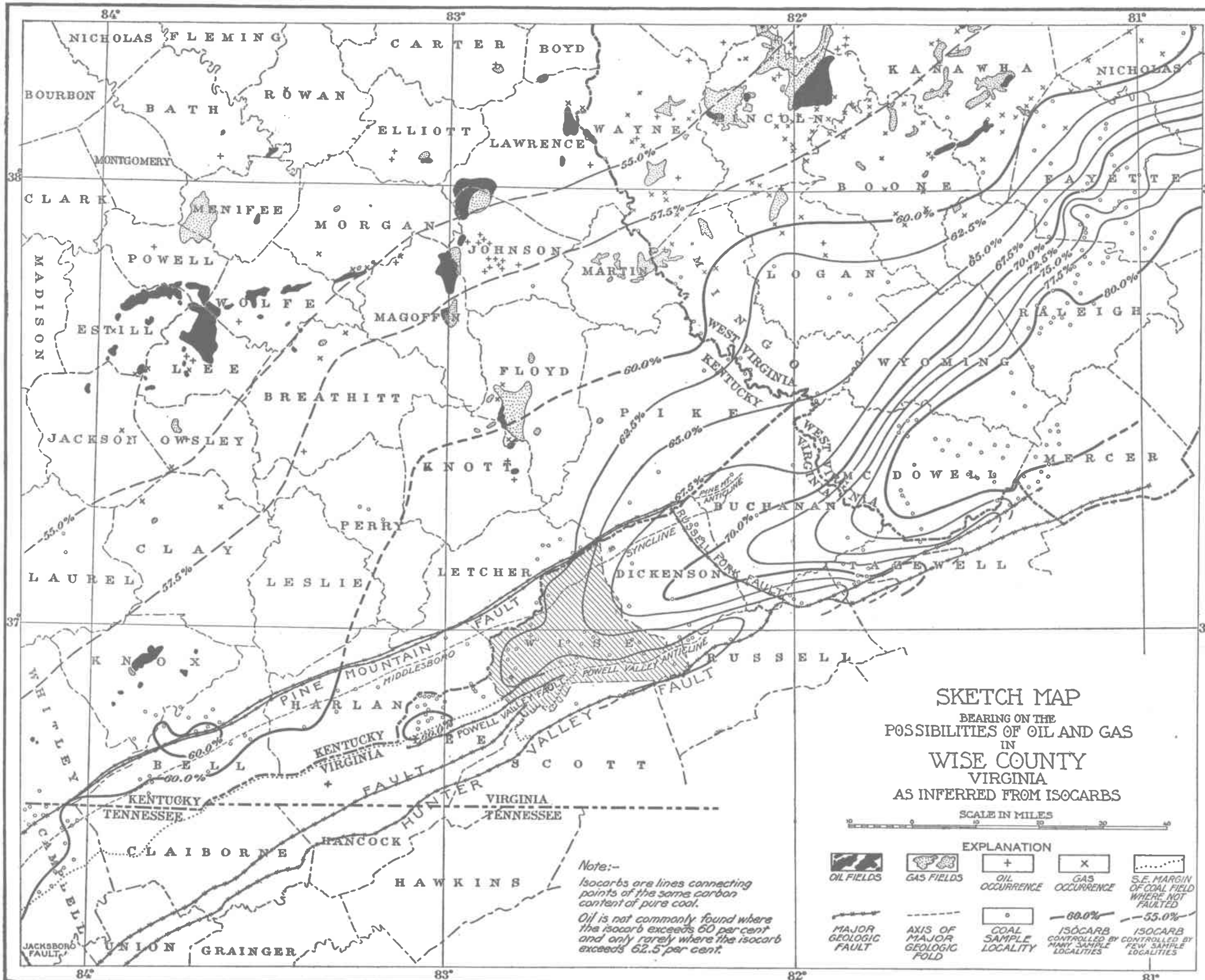
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ley region from Frederick County southwestward to Washington and Lee counties. Other more recently reported test holes for petroleum have been drilled near Ironto in Montgomery County, near Seven Mile Ford in Smyth County, near Abingdon in Washington County, near Pulaski in Pulaski County, and in Bland County.

Recent explorations.—In 1929, Davis Elkins and associates of West Virginia became interested in the reported occurrence of showings of gas in Mathews County in the Coastal Plain region of Virginia. After investigating the area and securing leases, they drilled a test hole about half a mile south of the town of Mathews. The well was abandoned in July, 1929, at a depth of 2,325 feet as a dry hole, without having encountered any trace of petroleum or natural gas. It penetrated the underlying Tertiary and Cretaceous formations and went 7 feet into the basement granite underlying the Coastal Plain region.

Undaunted by this failure to find petroleum or natural gas in the Coastal Plain region, representatives of the Elkins interests began a study of other parts of Virginia in the hope of finding more favorable territory for further explorations. They decided to drill a test on the Early Grove anticline in Scott County, where Charles Butts,[7] of the U. S. Geological Survey, in cooperative work with the Virginia Geological Survey, had called attention to the fact that "the chance is better here than anywhere else in southwest Virginia, and that if anyone is determined to drill in that region, as some are, this location is suggested as the most promising."

On June 4, 1930, the Elkins interests "brought in" on a location on the Early Grove anticline, the first natural gas well of probable commercial importance in Virginia. The well "came in" with a reported volume of about 1,000,000 cu. ft. of gas per day. The gas was encountered at a depth of 3,272 feet, presumably in the lower part of the Mississippian rocks, probably the Maccrady formation.

Greatly encouraged by the results of this test, Davis Elkins and associates soon commenced a second hole within half a mile of the "gasser." This was abandoned in 1930 as a dry hole at a depth of approximately 2,900 feet, with no indications of either natural gas or petroleum having been found. A third hole, commenced during the summer of 1935, near the first well, has recently been reported to have also "come in" as a gas well.

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[7] Butts, Charles, Oil and gas possibilities at Early Grove, Scott County, Virginia: Virginia Geol. Survey Bull. 27, p. 18, 1927.

Soon after the Elkins interests began the first Early Grove well, acreage was obtained by other parties in several localities in southwestern Virginia and other test wells were planned. The Penn-Ohio Gas Company of Pittsburgh, Pa., drilled two holes in 1932-1933; one on property of the Clinchfield Coal Co., on the flank of Sourwood Mountain in Russell County, several miles north of Cleveland, and the other on the Buck Knob anticline, along Guest River north of Norton in Wise County. Although slight showings of gas were reported in both holes, they were abandoned as "dry holes," at reported depths of 6,000 and 3,650 feet, respectively. The Russell County test is the deepest hole yet drlled in Virginia.

Within the past two years two reported "tests for petroleum" have been in progress in northwestern Rockingham County, several miles distant from Harrisonburg and west of Broadway. From what is known of the geology of the region, it is not considered a favorable location for finding petroleum in commercial quantities.

OUTLINE OF GEOLOGICAL CONDITIONS IN VIRGINIA

The State of Virginia is divided into five physiographic and geologic provinces, or regions, which are from east to west: The Coastal Plain, the Piedmont, the Blue Ridge, the Appalachian Valley, or the Valley and Ridge, and the Appalachian Plateau. But a small part of the State, the coal-bearing plateau region of southwestern Virginia, lies within the Appalachian Plateau province. (See Figure 2.) These physiographic provinces are closely related to the kinds and structure of the underlying rocks and therefore the mineral or petroleum and natural gas possibilities of these different provinces are likewise dependent upon the kind and structure of the rocks forming them.

The Coastal Plain region is underlain chiefly by loosely consolidated, nearly horizontal, beds of clay, marl, sand, and gravel of Cretaceous, Tertiary and Quaternary age. The Piedmont and Blue Ridge regions are underlain mainly by very old crystalline rocks, such as granite, gneiss and schist of Cambrian and pre-Cambrian age. The Appalachian Valley region is underlain principally by belts of limestone, sandstone, and shale of Cambrian to Mississippian age. The southwestern plateau, or Appalachian Plateau region, is composed principally of coal-bearing sandstone, limestone and shale formations of Pennsylvanian age.

The Coastal Plain region contains marine beds that may have been satisfactory source beds for natural gas or petroleum and also

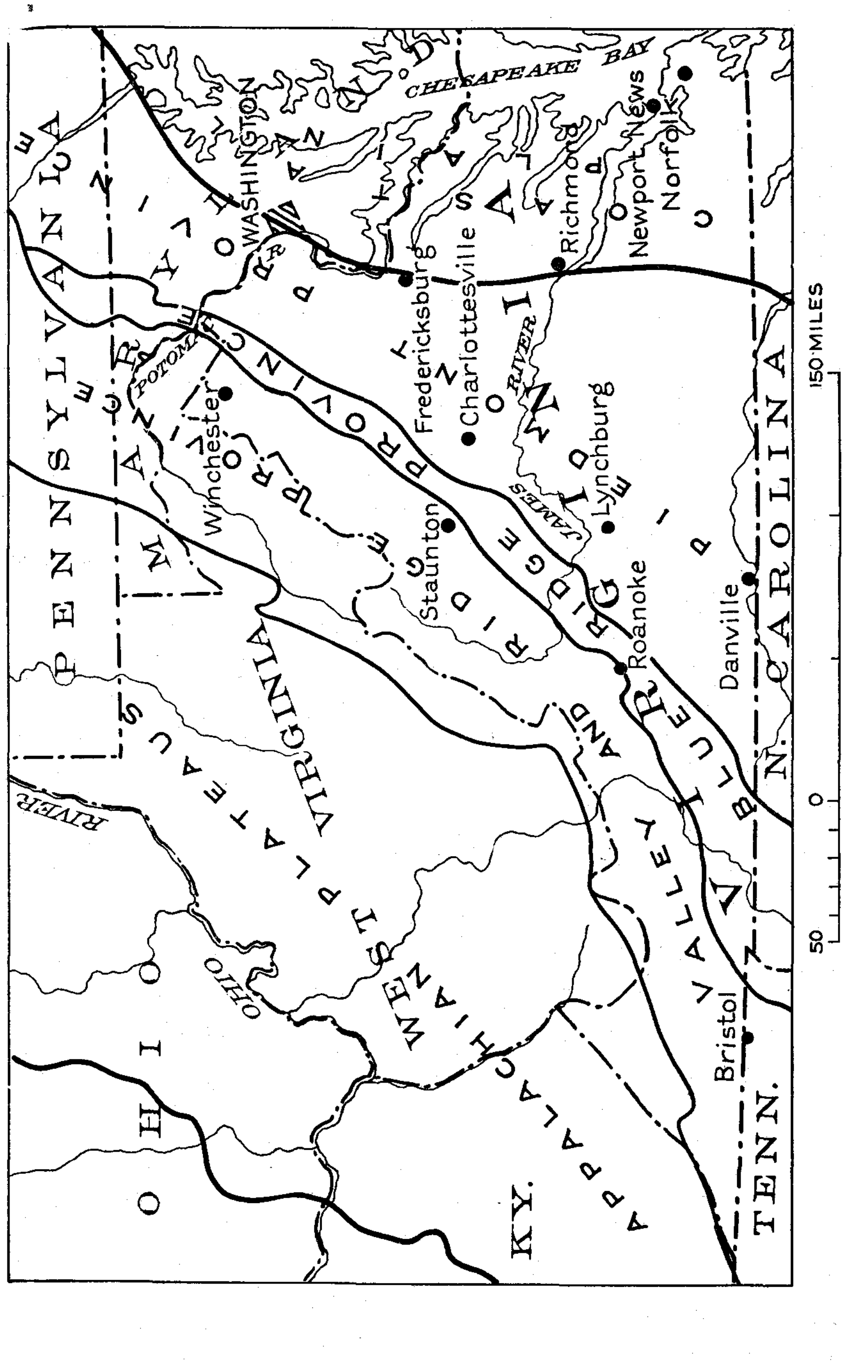


FIGURE 2.—Physiographic divisions of Virginia.

has favorable reservoir beds, but favorable structures or structural conditions necessary to trap or hold petroleum or natural gas are lacking. Even though petroleum or natural gas may have been formed in that region, it is most probable that neither is present at this time. This is pretty well borne out by the fact that, in the deep test drilled at Mathews Court House in Mathews County, no indications of either petroleum or natural gas were encountered.

With the exception of the areas underlain by Triassic sedimentary rocks, and a few small scattered areas of limestone, most of which is metamorphosed, the Piedmont region is an area of crystalline rocks, and does not contain either source beds or reservoir beds. No commercial quantity of petroleum or natural gas has been found in areas of crystalline rocks.

Like the Piedmont province, the Blue Ridge is mainly an area of crystalline rocks and does not have the three favorable geologic factors—source beds, reservoir beds and favorable structural conditions—considered essential to the accumulation of commercial petroleum and natural gas reserves.

There are in the Appalachian Valley region extensive beds of marine origin that may have been satisfactory source beds for both petroleum and natural gas. Good reservoir beds also occur. Throughout the Appalachian Valley the rocks have been greatly folded and in places broken by great faults. Exposures of deep-lying older rocks, some of which may have been petroliferous, have been caused by faulting and the faulting has opened avenues of escape for possibly former accumulations of petroleum. Also, erosion following the folding and faulting has deeply eroded these areas, particularly where favorable structural conditions may have existed, and laid bare underlying formations as old as Cambrian, so that any quantities of petroleum that may have occurred have had ample opportunity to escape.

A large syncline along the southeast flank of Clinch Mountain is underlain by a considerable thickness of Missisippian and Devonian rocks. This synclinal area is abruptly terminated on the southeast by a huge overthrust fault. Along this fault, older formations, ranging from Cambrian to Devonian, are thrust over the Mississippian formation. The Early Grove anticline is along the eastern border of this synclinal area, near the overthrust fault. Several black shales, particularly the thick carbonaceous Devonian shale, and several fossiliferous limestones and sandstones of Mississippian age, underlying this general area may have been petroliferous.

The southwestern plateau region is underlain by a great thickness of sedimentary rocks, ranging in age probably from Cambrian through Pottsville (Pennsylvanian). Formations of Devonian and Mississippian age are exposed along the southeast boundary. Still older rocks are exposed in the Powell Valley anticline, which pitches northeastward, in southern Wise County. This area, however, is not strictly speaking a part of the southwestern plateau region but is a reentrant or embayment of Valley formations and structure. Throughout the southwestern plateau region the rocks are gently warped and folded. Folding and faulting are pronounced along the southeastern margin.

Source beds and reservoir beds occur in the plateau region. It is possible that structural conditions favorable for the accumulation of petroleum and natural gas, particularly the latter, occur locally; however, deep drilling would be necessary to determine this, because the formations which would be considered as most favorable source and reservoir beds (Devonian and Mississippian) are deeply buried. It should be noted here that the maximum thickness of the overlying Pottsville beds in this region is about 5,800 feet. This is the main coal-bearing region of Virginia. The carbon content of the coals averages around 65 per cent or higher. This condition, according to White's law discussed above, would tend to leave the southwestern plateau region open to question as to the possibility of the occurrence of commercial quantities of petroleum here. There is, however, greater possibility of finding natural gas in this region.

CONCLUSIONS

In general it is thought that the folding of the rocks of the Appalachian Valley and southwestern plateau regions developed sufficient pressure to have dissipated any petroleum that might have been present in the sedimentary rocks involved in the folding. It appears probable that natural gas could have been trapped in other small structures like the Early Grove anticline. Natural gas may be found locally in areas which have not been too extensively or too intensively deformed or where local favorable structural conditions prevail. It is also possible that minor showings of oil, not of commercial importance, may likewise be found in such areas. Further drilling will be necessary to determine this.

It is very probable that the success of the two wells on the Early Grove anticline will lead to additional drilling in this and other areas in southwestern Virginia. It is expected that the results of further drilling will yield more helpful information on the possible occurrence of natural gas in commercial quantities in Virginia.

RECENT TEST

Several "showings" of gas have been reported, during the past several years, from explorations and test holes for coal in Buchanan County. As a result of an interesting "showing" reported a few years ago, a test for oil and gas was "spudded in" about September 6, 1935, by Thomas D. Cabot, Inc., of Charleston, W. Va., on a tract of land on Guess Fork, a short distance from the mouth of Left Fork, owned by the National Shawmut Bank of Boston, Mass. It is reported that the well was abandoned at a depth of 4,998 feet, and that shows of gas were encountered at depths of 1,871 and 3,825 feet. The first gas was in a sandstone about 165 feet thick, reported to be about 530 feet above the Big Lime (Mississippian) of adjacent McDowell County and adjoining counties in the southeastern part of West Virginia where oil and gas tests have been made. The lower gas was found in a sandstone 25 feet thick, about 225 feet below the Pocono sandstone (basal Mississippian).

WILLIAM BARTON ROGERS AND HIS CONTRIBUTION TO THE GEOLOGY OF VIRGINIA

BY

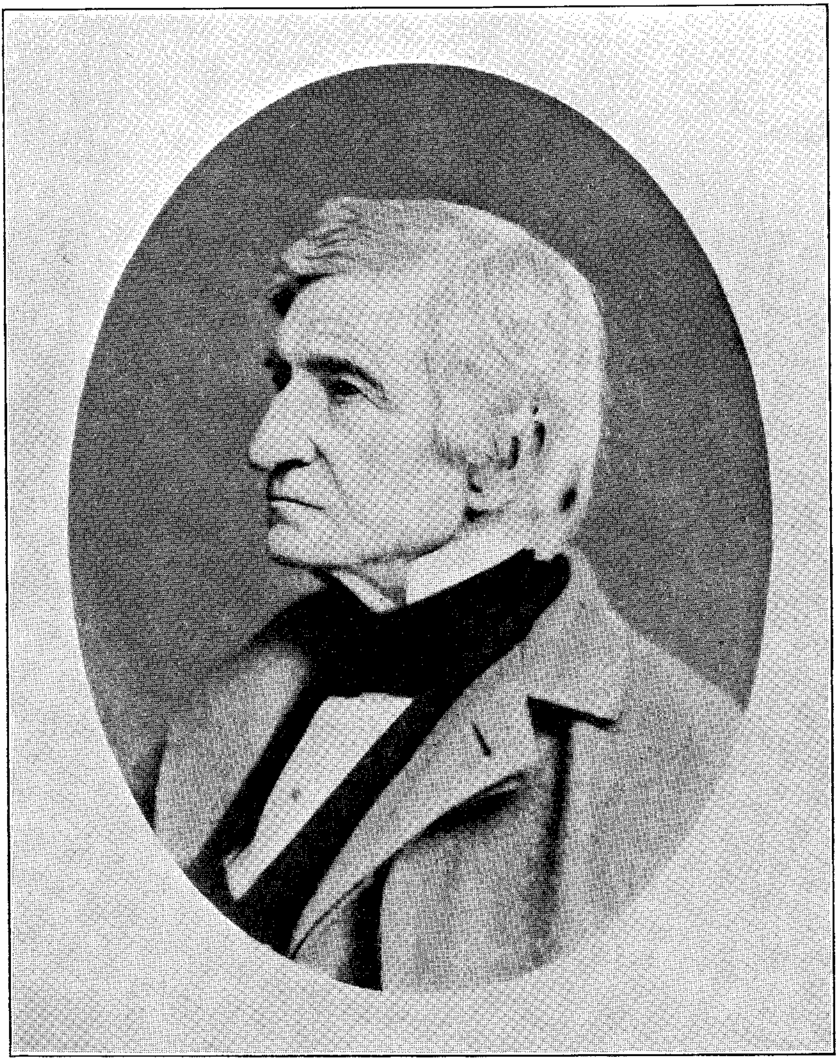
JOSEPH K. ROBERTS

STATE COMMISSION ON CONSERVATION AND DEVELOPMENT
VIRGINIA GEOLOGICAL SURVEY
Bulletin 46-C
UNIVERSITY, VIRGINIA
1936

ILLUSTRATION

PLATE PAGE

5. Portrait of William Barton Rogers ---------------------------------- 24



Portrait of William Barton Rogers, first State Geologist of Virginia. From Account of the Memorial Meeting Held October 12, 1882, by the Society of Arts of the Massachusetts Institute of Technology.

William Barton Rogers and His Contribution to the Geology of Virginia[1]

By Joseph K. Roberts[2]

The year 1935 marks the hundredth anniversary of William Barton Rogers's arrival at the University of Virginia to enter upon his duties as Professor of Natural Philosophy, and State Geologist. This is an opportune occasion to pay homage once more to a great investigator, teacher and citizen, especially since he served as third president of the National Academy of Sciences, succeeding Joseph Henry upon the latter's death in the year 1879. William Barton Rogers has never needed any eulogy to keep aglow his name, for his achievements have built a shaft far more imposing than mere words can express, and the rank which he attained in the development of American geology will endure as long as the science itself.

His labors in this Commonwealth form the first real and scientific approach towards field and laboratory studies of geology, which he pursued with such zeal and devotion despite the lack of encouragement and proper support from the governing body of Virginia. Truly Rogers was a naturalist: in his early years his interests were largely centered around chemistry and physics; later, however, his inclination towards the inorganic side of geology manifested itself. But throughout a busy life his versatility in the natural world was constantly illustrated in his observations of a many sided nature.

It is difficult to evaluate the work of William Barton Rogers without some consideration of his brothers James, Henry, and Robert, particularly, Henry Darwin Rogers. Their father, Patrick Kerr Rogers, was born in Ireland, and the mother, Hannah Blythe was of Scottish descent. The father followed the practice of medicine in Philadelphia and later in Baltimore, apparently without marked success, and in October, 1819 moved with his wife and four sons to Williamsburg, Virginia, where he had been appointed to the chair of chemistry and physics at William and Mary College. In this institution William was a student from 1820 to 1825. Following the death of his father in 1828, William was recalled from Baltimore where he was teaching in the Maryland Institute, and was appointed his father's successor at William and Mary.

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[1] Read before the National Academy of Sciences at the University of Virginia meeting, November 19, 1935.

[2] School of Geology, University of Virginia.

Here he remained until the summer of 1835 when appointed Professor of Natural Philosophy at the University of Virginia in August of that year, and first State Geologist as provided for by an Act of the Legislature of Virginia passed on the sixth of March, 1835.

At the University of Virginia, Professor Rogers succeeded Robert M. Patterson, the latter having followed Charles Bonnycastle, the first Professor of Natural Philosophy at the University. Here Professor Rogers continued for a period of eighteen years, resigning in 1848; but being urged to remain by his friends, his resignation did not actually take effect until the year 1853. His position as State Geologist was short lived, terminating in 1841 when the Legislature declined to appropriate necessary funds to continue the survey.

Upon leaving Virginia, Professor and Mrs. Rogers removed to Boston where his activities were continued, and his administrative talent found expression in the establishment of an institution destined to take its place with the foremost of its kind. His long cherished ambition had been to establish a school for technical training, and in 1859 he gathered around him certain citizens of Boston who had become interested in such a project. In 1862 the Legislature of Massachusetts chartered the Massachusetts School of Technology, and Professor Rogers became its first president. In this capacity he served for two brief periods.

His last visit to Virginia was in April, 1882, following his attendance upon the meetings of the National Academy in Washington. He returned to Boston and while delivering the commencement address at the school he had shaped and watched well on its way to successful operation, he collapsed from a heart attack on May 30, 1882 in his 78th year.

Professor Rogers began as an investigator in 1828, and his activities extended over a period of more than half a century. From 1833 until the time of his departure from Virginia he made observations, which formed the basis for his many reports and discussions during this interval and in later years. Many of the discourses were collaborations with his brother, Henry Darwin Rogers of Pennsylvania. His outstanding contributions were in the earth sciences, yet he made noteworthy investigations in chemistry and physics. In 1834 he made his first contribution on the greensand and marl deposits of eastern Virginia. From 1836 to 1842 seven annual reports were made to the legislature on the progress of the survey; these reports are among the masterpieces of their time as regards form of expression and comprehensiveness of knowledge. His studies led him into the fields of physiography, mineralogy, petrology, economic geology, paleontology, and stratigraphy.

Following the paper on greensand and marl in 1834 his more noteworthy contributions in geology were upon the Tertiary Formation of Virginia, the Physical Structure of the Appalachian Chain, the Coals and Associated Strata of Eastern Virginia, Thermal Springs and Their Relation with Anticlinal Axes and Faults, Infusorial Earth in the Vicinity of Richmond and Petersburg, Classification of the Paleozoic and Later Formations of the United States, and the Geological Map of the Virginias.

In all probability Professor Rogers regarded the work on the Appalachian Mountains with his brother, Henry, the most significant; certainly the field observations for this paper embraced a larger territory than any other, and the article received more comment in Europe and America. The Appalachian chain was studied in Virginia and southward by William, and in Pennsylvania and northward by Henry. They discovered that the rocks of this great chain comprised strata ranging in age from the Potsdam into the Coal Measures. This chain comprises five straight, and four curved belts, which alternate and vary from 100 to 150 miles in length. The persistence of the Appalachians in extent, their marked narrowness, steepness, evenness of crests, and uniform degree of parallelism—all these are facts noted by the two Rogers. They also observed the predominance of southeastern dips, the normal inverted and broken flexures, and the passing of the latter into faults. Time and again their findings have been checked, and have survived the test of almost a century. The only major structural feature not mentioned is the overthrust faulting of the southwestern Appalachians; however, they do mention the great reverse faults of southwestern Virginia where rocks of Cambrian age have been brought into juxtaposition with those of the Lower Carboniferous.

Their interpretation of the mountain-forming processes has not endured in its entirety. While this explanation was in considerable advance of its day, yet it shows certain Wernerian influences though not to the extent as indulged in by William Maclure, an earlier student in Appalachian geology. The Rogers brothers accepted neither tangential nor vertical forces in mountain-building in the present day sense. They attributed the formation of the Appalachian flexures to tangential and earthquake-like undulations arising in the subcrustal viscous or lava-like material. Such parallel waves gave rise to folds in the overlying crust or marine strata, and when this crust was once folded, it remained so because of its rigidity; and congealed portions of the viscous material filled any fissures formed during the disturbance, which along the border of the Blue Ridge has made appearance as dikes in the most highly disturbed zone. Faulting, in their opinion, was attributable to rifts in the overlying Paleozoic strata caused by the escape of the more volatile portions of the igneous materials. Structural sections in the Appalachians from the southeast towards the northwest were shown as follows: (1) Inverted flexures in the Blue Ridge section where the folds are closed and often faulted, (2) to the northwest, normal or open folds of the Allegheny Mountains, and (3) west of the Alleghenies, the gentle folds and domes of the coal-bearing regions.

When the conditions under which Professor Rogers traveled and studied in the Virginias are considered, his accomplishments assume more than usual significance. Roads were few and all unimproved, fresh exposures along roads and railroads were so limited as to be negligible, maps most generalized and scarce, and insufficient means were available to carry on proper field and laboratory studies. Many other obstacles over which he had no control added to his difficulties. Yet in the face of all these discouragements, he was painstaking and patient, industrious and capable, philosophical in spirit and intellectually honest. He carried these characteristics into the class room, and into every other phase of life. That he was brilliant and inspiring as a lecturer is borne out by his students. From experience of his early teaching he long planned to introduce experiments and have them conducted in a laboratory by students instead of performing them on the lecture desk in a limited manner. Such a desire was realized in the technical school established in Boston, and William Barton Rogers may, therefore, be looked upon as the father of our modern laboratory practice.

On leaving Virginia Professor Rogers carried with him the kindest of memories of many of his colleagues and students. Had he not entertained a tender regard for the place where he had spent eighteen of the best years of his life, even these years were crowded with many inconveniences, it is hardly possible that he would have returned for the semi-centennial celebration of 1875 to make one of the principal addresses and to contribute from his own resources a thousand dollars towards the establishment of a museum.

Those who are familiar with his contributions and with the progress of geology in the State of Virginia for the past century, know well that the foundations were laid by him from 1835 to 1853. His name is indelibly written in the annals of American geology, and he is justly acclaimed a distinguished citizen, gentleman, and scholar of the highest rank and achievement.

ORIGIN OF THE ORISKANY IRON AND MANGANESE ORES

BY

R. J. Holden

State Commission on Conservation and Development
VIRGINIA GEOLOGICAL SURVEY
Bulletin 46-D
UNIVERSITY, VIRGINIA
1936

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Origin of the Oriskany Iron and Manganese Ores

By R. J. Holden[1]

INTRODUCTION

Oriskany iron ore has been extensively mined along the southeastern side of Alleghany County and the adjacent portions of Botetourt and Craig counties. To a less extent it has been mined in various other places throughout the western portion of the State.

These ores were first mined for charcoal furnaces more than a century ago. About 1870 they began to be smelted in coke furnaces in the Clifton Forge region. Altogether about 7 coke furnaces were built in that region for the use of these ores and were operated continuously for about 40 years. The Longdale, Low Moor, Rich Patch, Iron Mountain, Dolly Ann, Stack, Oriskany, Wilton and Fenwick mines were leading producers. Several of these produced one to two million tons of ore each.

ORE BODIES

The ore bodies, which were bedlike in shape, had thicknesses up to 30 feet or more. They generally cropped out and were usually mined several hundred feet down the dip. The Longdale and Oriskany mines were exceptional in their dip distances, being down 700 and 1,400 feet respectively. Some of the ore bodies extended for half a mile or more on the strike. The formations associated with the iron ore are the Romney, Oriskany, and the Helderberg, all of Devonian age. The Romney is a black shale which has thicknesses of several to many hundred feet. The Oriskany is a sandstone or limestone-sandstone with thicknesses in the vicinity of producing mines which commonly did not exceed 20 feet. The thickness locally was much less. In later formation terminology the limestone associated with the iron ore is the Becraft. Underlying this and below the iron-ore horizon is the New Scotland limestone. The Becraft consists of fairly pure limestone with thicknesses up to 30, or possibly 40 feet, and an underlying flinty limestone in which locally the flint layers are closely spaced.

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The iron ore occurs chiefly in the upper member of the Becraft, with Oriskany sandstone forming the hanging wall and the flint forming the footwall. In places the sandstone was sufficiently rich in iron to be mined as an ore and in some places there was minable ore in the base of the Romney. In one place there was minable ore below the highest of the flint beds. The Oriskany sandstone generally cropped out on the lower third of the mountain slope. It is sufficiently resistant to weathering to form commonly a small bench on the slope.

STRUCTURE

The region has been considerably folded with faulting, the typical structure being an asymmetric fold somewhat steeper on the northwestern limb. The Silurian sandstones with a thickness of several hundred feet formed the neutral axis of folding and constitute the major structure. Since erosion has generally removed the Romney, Oriskany, and Helderberg from the upper slopes, and this means the crest and limbs of the larger anticlines, these formations are found only in the troughs of the synclines. Since the Silurian sandstones were the neutral axis of folding, the overlying Helderberg, Oriskany, and Romney were compressed in the synclines. As a result of this compression the Helderberg and Oriskany developed a number of minor folds and some faults which are not in accordance with the main synclinal structure. These minor folds and faults have been factors of fundamental importance in the formation of the iron ore.

ORIGIN OF IRON ORE

The unweathered Romney shale carries considerable pyrite. The iron ore is chiefly a porous limonite. At depth in two places there has been found an iron carbonate which carries the textures of the limestone, including fossils. Around some of the fossils and in some other places there are small sheet-like openings. Barite is found in occasional particles in the limonite and at some places is abundant in the hanging-wall sandstone. In one place barite occupies all the space that as a rule is occupied by limonite.

The iron ore of the limestone horizon is believed to have originated as follows. The pyrite in the Romney shale was oxidized to ferrous sulphate, taken into solution, carried downward through the Oriskany sandstone and deposited in replacement of the limestone as iron carbonate. The iron carbonate was later oxidized to limonite. The iron ore which occurs in the base of the Romney shale and in the Oriskany sandstone was derived from the same sources as the limestone ore and was deposited in replacement or partial replacement of those formations. To some small extent some of the limestone ore has been deposited directly in cavities by oxidation of the ferrous solution to limonite.

Here is an example of metamorphism which has taken place on a large scale. Beds which were once limestone with a thickness of 30 feet or more are now limonite for distances of as much as half a mile on the strike and 500 feet or more on the dip, with a million or more tons in a single deposit.

LOCALIZATION OF ORE

Since the formations associated with the iron ore crop out through hundreds of miles entirely across the western portion of the State, the question at once arises as to why the strong development of iron ore is limited to the vicinity of Clifton Forge. The Oriskany outcrops throughout these hundreds of miles are commonly iron stained or manganese stained and in many localities there are small bodies of iron ore at various places along such outcrops. It is evident that the processes which produced the ore bodies in the Clifton Forge area were active throughout the western part of the State but that certain favorable conditions existed in that area which did not prevail elsewhere.

There are four conditions which are believed to be essential for the formation of a large ore body: An adequate supply of pyrite in the Romney shale, a thin or permeable sandstone, a replaceable limestone of suitable dimensions, and a strike drainage in the limestone. It is believed that all of these four conditions are essential to the formation of a large body of ore and that the failure of any one of them was sufficient to prevent the formation of ore in quantity.

It is impossible to state which of these conditions are wanting in all cases. Presumably, in many places there is not an adequate supply of pyrite in the Romney shale. In others, the sandstone has clearly been impermeable. Twenty feet of unbroken sandstone is generally an effective bar to the passage of iron solutions. On the crests of the minor anticlines a 20-foot thickness of the Oriskany may be so shattered as to be readily permeable. The absence of such broken anticlines or of equally effective faults is a bar to ore formation when all other conditions are favorable. Throughout much of the State there is insufficient replaceable limestone. It seems probable that only in exceptional places was there suitable strike drainage. For everyone of the larger ore bodies conditions existed which are favorable to strike drainage. In some areas the direction and distance of these drainages are pretty well known. In some of the best known cases the distance from the ore body to the surface stream receiving the drainage or to the spring in which there is an outflow on the surface is several miles.

MANGANESE DEPOSITS

Oriskany manganese has been mined commercially but much less extensively than Oriskany iron ore. The manganese ore bodies occupy a much less definite stratigraphic position than do the bodies of iron ore. They may occur on top of the Oriskany sandstone, in it, or under it. The conditions necessary for the formation of the manganese ore body are approximately the same as those needed in the formation of an iron ore body, but with important modifications. Manganese is much less abundant in nature than iron. Also, being more valuable than iron it can be mined in smaller deposits. Consequently, a smaller percentage of manganese in the Romney shale would be adequate for the formation of a workable manganese deposit than would be required of iron for formation of an iron ore body. Manganese has a greater capacity than iron for penetrating into small openings and consequently will penetrate farther into the sandstone or more readily pass through it than iron solutions will. In consequence, in some deposits iron ore is found on the upper side of the sandstone and manganese ore below it. Deposits of manganese can be smaller than those of iron, because not as much replaceable limestone is required for manganese as for iron. Since manganese can be mined in smaller ore bodies than iron, minable deposits of manganese may occur where strike drainage is absent or limited. However, in the only manganese ore body which is known to extend to any considerable depth there was an excellent opportunity for strike drainage. Inasmuch as manganese concentration is less dependent on the fortunate coincidence of the four geological conditions specified above than is that of Oriskany iron ore, the Oriskany manganese deposits are much more widely distributed than the Oriskany iron ore.

HUMIDITY AND WATERS OF A LIMESTONE CAVERN NEAR LEXINGTON, VIRGINIA

BY

EDWARD STEIDTMANN

STATE COMMISSION ON CONSERVATION AND DEVELOPMENT
VIRGINIA GEOLOGICAL SURVEY
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Humidity and Waters of a Limestone Cavern Near Lexington, Virginia[1]

By Edward Steidtmann[2]

INTRODUCTION

During the last three years, the geology department of the Virginia Military Institute has been engaged in the study of travertine and travertine-depositing waters. The cavern studies outlined in this paper have evolved from the earlier work on travertine. Because of the inherent relation between the two subjects, a summary is given of the earlier studies on travertine-depositing waters.

TRAVERTINE-DEPOSITING WATERS

The feeder springs of the travertine-depositing creeks are highly supersaturated with $CaCO_3$. They contain more of this compound than they can retain permanently in the presence of the relatively low CO_2 pressure of the atmosphere, which is only about .0003 of the total atmospheric pressure. Published analyses of soil gases indicate that their CO_2 content may be as high as 8 per cent by volume. Since CO_2 tension is one of the most important factors in the solution of $CaCO_3$, it is evident that the supersaturation of limestone spring waters is largely if not wholly due to the high CO_2 content of subsurface gases. This subsurface CO_2 is derived mainly from decaying vegetation.

Feeder spring waters commonly lose from 100 to 130 parts per million of calcium carbonate when aerated in the presence of powdered calcite at temperatures of 21°-22° C. until the composition of the water is constant. The creek waters fed by these springs are likewise supersaturated with $CaCO_3$. Successive stations along the creek record a progressive loss of this constituent except in cold weather when the temperature of the water is 8° C. or less. The loss is most marked on cascades, where aeration is vigorous. The maximum loss of calcium carbonate of the creek waters when aerated in the presence of calcite is about 70 parts per million at a temperature of 22° C.

[1] Read before the Virginia Academy of Science, Section of Geology, Lexington meeting, May 1, 1936.
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The adjustment of supersaturated $CaCO_3$ solutions is very slow. A solution with 200 parts of $CaCO_3$ per million and 1 part of free CO_2 was reduced in 28 hours to saturation by vigorous aeration with a laboratory suction pump, when calcite was suspended in the solution. The temperature was 22° C. When the solution was freed from calcite by repeated filtration, adjustment had not been completed after 19 days of vigorous aeration.

Calcite accelerates the rate of adjustment of supersaturated $CaCO_3$ solutions. A solution with 330 parts per million of calcium carbonate was almost adjusted when it had stood quietly for 10 days in contact with powdered calcite. The same solution kept free from calcite had not been reduced to saturation after 21 days. The excess amounted to 6 parts per million. The frequency of filtration would most probably affect the result. In each experiment, the depth of the solution was 3 inches. The results of the studies of travertine outlined above have a bearing on the studies of caverns in view of certain obvious similarities and dissimilarities between limestone caverns and travertine-depositing creeks. Both caverns and creeks give evidence of an initial excavational stage. This was followed by a depositional phase which gave rise to the travertine of both creeks and caves.

Creek travertines as shown by the entombed remains of living plant and animal species are of recent age; certainly not older than late Pleistocene. As yet the cave deposits of Virginia have given no indication of greater antiquity.

At present, both caves and travertine-depositing creeks are the loci of depositional as well as excavational processes. The increased height and frequency of floods initiated by cultivation of the land has placed the excavational processes foremost in the creeks. Most travertine along the creeks is being rapidly destroyed. It is not evident that cultivation has inaugurated a similar destructive episode in cave deposits.

Creek travertine was deposited upon plants. Algae and mosses form a framework upon which these calcitic deposits were placed. Deposition takes place mainly upon the dead tissues. Cave deposits give no indication of a structural or genetic relation to plants. The lack of such a relationship in caves supports the argument that purely physico-chemical rather than biological processes also cause the deposition of these calcitic masses in creeks.

Creek travertines are characteristically cellular and porous. This is a consequence of their accretion around plants. Cave travertine having no organic skeleton is much more compact. Stratification is a characteristic feature of the creek deposits. The cascade strata, standing at a vertical or very steep angle, are most common. They reflect seasonal deposition. Summer is the time of most rapid accumulation. Strata which formed on mosses are commonly 1 to 2 inches thick. Their calcite is granular and mossy in structure. The algal strata have a fibrous structure. The fibers are normal to the layers and rarely exceed one-eighth of an inch in length. Certain strata of the algal type consist of divergent calcite fibers interspersed with similarly diverging algal fibers. Other strata of the same type of accretion consist of compact parallel needles of calcite. These layers show no organic residues and they are lighter in color than those which have them. An alternation of the two types of strata is characteristic of the algal type of deposit.

Cave travertines are also stratified as a rule. Like the algal strata, they are composed of calcite needles arranged at right angles to the stratification surfaces. These strata likewise reflect variations in the rate of deposition. Rhythm in cavern deposits is probably due to variations in water supply rather than to changes in temperature conditions.

CAVERN STUDIES

General statement.—Caverns have been studied mainly as products of the past. Their relation to stratigraphy and geologic structure has received considerable attention. Their history has been related to surface drainage lines, to the water table, and to the permeability of the formations in which they occur. The physiographic cycle has been invoked in recreating the story of their evolution.

Caverns can be studied as the sites of still active geologic processes. The air and waters of a cave constitute a physicochemical system. What is the nature of this system? What are its products? Pia, the Austrian geochemist, recently summarized the literature dealing with this phase of cavern study. He reports that systematic studies of the subject are lacking. Nevertheless, the humidity and the CO_2 concentration of cave air, evaporation in caves, and the CO_2 tension of cave waters, all have a part in current theories on the origin of caves and of dripstone. It is obvious that such speculations deduce the physics and chemistry of caves from the results of cavern processes, and not from direct observation.

Purpose.—The aim of the present studies is to obtain data on the humidity and CO_2 content of cave air and its circulation; on the CO_2 and $CaCO_3$ concentration of drips and drip pools, in contrast to the concentration of these substances in the permanent streams of the cave; and to observe if possible, the contemporary processes of solution and deposition. This paper is a preliminary report of progress.

Location.—The cave system under observation is located about 1.2 miles west of Lexington, in a bluff south of North River. The portal of the cave is 166 feet above the mouth of Cave Spring, a large tubular spring, issuing from the base of a cliff on the south side of the river. Cave Spring drains the cave system under consideration. The distance from the portal of the cave to Cave Spring is about 750 feet in a N. 45° W. direction.

Characteristics of the cave.—A plan view of a part of the cave system has been prepared by Cadet D. O. Duncan on a scale of 5 feet to 1 inch. The map shows also elevations of numerous subsurface stations with respect to the portal of the cave. It shows that the cave system follows joints striking N. 50°-70° E. and N. 5°-20° W. These joint systems are plainly exposed south of the portal, where the surface shows more or less rectangular rock outcrops bordered by narrow strips of sod. The sod strips have the same general trend as the chambers of the cavern system.

The strata in which the caverns are cut include the basal beds of the Whitesburg formation and a part of the underlying Holston limestone. They strike N. 50° E. and dip about 10° SE. Local dislocations due to subsidence are common.

As the parts of the cave studied are about 100 feet above North River they have no appreciable flow of water except in times of heavy rainfall. Such times leave their record of torrential flow. At ordinary times, they show only drips, films and small pools. The only waters from the saturated zone of the cave system, that are readily available, are those of Cave Spring. Waters from two sources have been analyzed systematically since October 13, 1935. One is a drip pool of nearly constant volume and concentration located 40 feet below the portal. The other source is Cave Spring. The spring fluctuates greatly with rainfall. It is very turbid during heavy rains and for some time thereafter. Its concentration varies in some inverse ratio to the discharge.

Characteristics of the waters.—The water in the drip pool has traveled about 40 feet vertically. It may have come from a sink a short distance to the north, in which case its vertical descent is less than 40 feet. Although the water has migrated only a short distance vertically, it is highly supersaturated with $CaCO_3$. The total calcium content of the water, calculated as $CaCO_3$, is about

250 parts per million. It has only about 1 part per million of free CO_2. When aerated in the presence of suspended calcite, it loses about 170 parts per million of $CaCO_3$ at a temperature of 23° C. In this connection, it is interesting to find that, in the Lexington area, the shallowest seeps on limestone directly below the residual mantle have shown the highest concentration of $CaCO_3$. The drip pool studied is of this type. A similar seep on top of bedrock and directly below the mantle has a concentration of 440 parts per million of $CaCO_3$. It is located on a wooded slope of Institute Hill at Lexington. More data are being collected to determine the relation between $CaCO_3$ concentration and the depth of the water in the vadose zone.

The waters of Cave Spring are similar to those of some of the travertine-depositing creeks. Its $CaCO_3$ concentration is lower than that of the drip pool. The highest concentration of calcium calculated as $CaCO_3$, 138 parts per million, was reported on October 13 after about a month of drought. The free CO_2 content has varied from 4 to 9 parts. The loss of $CaCO_3$ resulting from aerating the waters in the presence of suspended calcite is high. The highest amount noted so far is 71 parts per million. The temperature of aeration was 23° C. The low concentration of Cave Spring compared with more surficial waters is due to the loss of $CaCO_3$ in the aerated passages of the cave system. During rains, the direct inflow of rain water also contributes to their low $CaCO_3$ content.

The analytical data obtained so far point to the shallow parts of the vadose zone as the region of maximum solution of limestone. Here the limestone waters have the highest concentration of $CaCO_3$. The waters in open caves of the zone of the water table have a lower concentration than those directly below the bedrock surface. In air, they are supersaturated and can not dissolve limestone. Compared with the shallower waters, they give indications of a loss of $CaCO_3$ in the transit from the surface to deeper levels. For times of prolonged drought, there is no escape from this conclusion.

Characteristics of the cave air.—The humidity, temperature, and circulation of the cave air have been studied at three stations, located at depths of 40, 50, and 65 feet below the portal of the cave. The humidity of the lower levels has varied from 95 to 100 per cent. In late April, the humidity at the higher level decreased to 90 per cent. The temperature of the lowest levels has been 54° F. According to Col. Francis Mallory, the official weather observer at Lexington, this temperature is also the average temperature of

Lexington for the 53 years preceding 1930. The temperature of the 40-foot level of the cave has varied from 51° to 53.5° F. during the period of observation.

The main passages of the cave have a marked down draft. The tubular opening at Cave Spring has an outdraft. However the outdraft at the spring is not equal to the air flow within the cave. At times the tube at the spring is filled with water, yet the draft within the cave continues. No relation between the draft and the barometric pressure has been observed. The humidity and temperature of the deeper levels of the cave have been independent of the outside temperatures and humidities.

The high humidity of the cave indicates that evaporation can not be an important factor in causing the formation of dripstone in this cave. Experiments on evaporation within the cave should be made. Some observers claim that evaporation may take place even with a humidity of 100 per cent, provided the air circulates and the water is colder than the air. Dripstone is abundant in this cave, but the studies made thus far suggest that evaporation has played a very minor role in its deposition.

Cave problems.—Experiments which would disclose the rate of adjustment of the supersaturated waters in the drip pool should be made also within the cave. Data on the CO_2 concentration of cave air are still lacking. The growth of stalactites is still an unexplored field. Until the total CO_2 content of the cave waters is known, it is impossible to know the exact status of the carbonates which it holds, whether they are all in true solution as bicarbonates or in part crystalline particles in a minute state of division.

On a priori grounds, caves can be placed into two categories—those with an effective air circulation and those which lack such a circulation. In caves lacking an effective air circulation, the deposition of dripstone should be at a minimum. Here supercharged CO_2—$CaCO_3$ solutions are not in contact with the low CO_2 pressure of the atmosphere. In such caves solution and mechanical erosion should be dominant processes. In caves with an effective air circulation, the deposition of dripstone should take place wherever thin films of water, drips, and shallow pools of water from the overlying humic zone come in contact with solid calcite and normal air. The catalytic effect of calcite in hastening deposition as shown by experiment should be an important factor.

Solution.—Analyses of vadose waters indicate that solution is most vigorous in the upper parts of the limestone, directly below the mantle rock, where humic waters first reach the bedrock. Such waters are soon saturated with respect to the solid and gaseous phases which they encounter. Not only do the analyses show that the surface of the bedrock is the zone of maximum solution, but the very fact that this is the zone where nearly all the residual material accumulates, proves this beyond argument. Cross sections of the residual mantle also show that solution is most active along joints or other supercapillary openings of the bedrock surface. The residual mantle descends along joints.

Analyses show that the deeper levels of the vadose zone commonly lose rather than take on more $CaCO_3$. The distribution of the residual soil also shows that the deeper levels of the vadose zone are not sites of intensive solution, devoid of mechanical erosion. Even in very permeable rocks, the water table is not a zone of intense solution unless it is coincident with the bedrock surface. If it were otherwise, then residual deposits would form quite commonly at the horizon of the water table.

Mechanical erosion.—Wherever solution has widened a fracture surface sufficient to permit free gravitative flow, though the opening be no more than an inch wide, mechanical erosion becomes a factor in widening such openings. Where the flow is permanent, this effect is intensified. As in surface streams, most of the mechanical work of subsurface streams is done during times of flood. Mechanical erosion should also be aided greatly by the tendency of limestones to soften when permanently wet. The softness of Bedford limestone, of Florida coquina, and of Italian travertine when quarried and their subsequent increase in coherence on drying are well known facts. The possibilities of studying such changes in the laboratory with a precision sclerometer are very inviting. The bearing of such studies on the efficiency of subsurface mechanical erosion by streams is evident.

That subsurface streams erode mechanically is an accepted fact. The relative importance of solution and corrasion by such streams has been a mooted question. The presence of transported water-worn pebbles in subsurface streams, the occurrence of pot holes, undercut cliffs, and polished walls in caverns have all been cited by various writers as evidence of corrasion rather than of corrosion. The absence of residual clays in most limestone caverns, except where the surface residual clay zone has advanced downward into the cavern zone, should also be accepted as strong evidence of mechanical erosion. Furthermore, the characteristic muddiness of waters flowing from many tubular springs during and for some time after rains supports the same conclusion. The only time in which subsurface streams are likely to corrode is when they receive large volumes of water from heavy rains by direct inflow through sinks. It is nearly impossible to think of them as corroding when they receive their supplies from seeps through the vadose zone, which is their source when there is no rainfall. The subsurface stream is essentially like a surface stream. It works with the same tools, is subject to the same laws, and achieves the same results. The enlargement of the cavern by the subsurface stream is accomplished mainly by mechanical erosion coupled with overhead and lateral gravitative stoping.

The subsurface stream in limestones appears to have had its beginnings in an intermittent seep in joints of the bedrock directly below the residual mantle. In compact limestones, the intermittent seep may become a permanent flow along joints when it is still many hundred feet above the surface of the local streams. In the early stages, the seep is in the zone of strong humic acids and high CO_2 concentration. It is an agent of solution. Mechanical erosion becomes increasingly important as the flow descends to deeper levels and is fed by waters that have already passed through the zone of maximum solution, the bedrock surface below the residual soil. When the cavern has been enlarged to the stage where it has an effective air circulation, mechanical erosion is the principal work of the subsurface stream. Then the thin sheets of water descending along the cavern walls precipitate travertine. The cavern has reached the depositional stage in its history.

Classification of cavern zones.—A tentative classification of the mature cavern-making zone of limestone is herewith offered. It divides the processes of this zone into three parts. At the bedrock, directly below the residual mantle, is the zone of most rapid solution, which attains its greatest intensity along joints. The permanent subsurface streams are the loci of mechanical erosion, whose intensity varies with the velocity, volume, and abrasive tools of each stream. Between the zone of permanent streams and that of intensive solution is the belt of dripstone deposition. Here air, calcite, and supersaturated $CaCO_3$ solutions in the form of drips and films interact to cause deposition. These zones may overlap at various times and at various places. The upper zone of intense solution is universal. The two lower zones in some localities have not yet formed; in others, they have been destroyed. All three zones are well developed in mature cave systems. In a region of downcutting streams, all three zones should be migrating downward. Where streams have reached a state of equilibrium, the zone of solution would gradually encroach upon the lower zones. Eventually the caverns and their deposits would vanish and the cavern cycle would be closed.

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AN EBB AND FLOW SPRING NEAR FAIRFIELD, VIRGINIA

BY

MARCELLUS H. STOW

STATE COMMISSION ON CONSERVATION AND DEVELOPMENT

VIRGINIA GEOLOGICAL SURVEY

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An Ebb and Flow Spring Near Fairfield, Virginia[1]

By Marcellus H. Stow[2]

Two miles southeast of Fairfield, Virginia, on the north tributary of Marlbrook Creek, half a mile northeast of its confluence with South River, a spring issues from Conococheague limestone on a hillside. Observations made in December, 1933, after a long period of dry weather showed that the flow of water from the spring fluctuated with great regularity. During a cycle of fluctuation the minimum depth of the water at the spring was 6¾ inches and the maximum 10¼ inches. The average time during which the flow was increasing was 4 minutes and 30 seconds. This increased flow was followed by a period of about 1 minute during which the spring flowed at a constant maximum. This was followed by decreasing flow during a period of 5 minutes and 50 seconds, which in turn was followed by a constant minimum flow for 2 minutes and 15 seconds.

Another examination in April, 1935, after an exceptionally wet season, showed that the spring was not intermittent but flowed with constant volume.

In the laboratory, a tube was arranged in such a manner as to empty a flask of water, by siphon action, at a faster rate than the water was entering the flask from another source. By proper arrangement of the outlet tube of the siphon and regulation of the rate of flow of the water coming into the inlet tube, the flask was alternately filled and emptied, essentially duplicating conditions as observed at the ebb and flow spring under discussion.

If certain conditions, which could exist in the limestones of this area, are assumed, the intermittent flow of the spring may be explained. It is necessary to assume the existence of either a small cave or a fissure in the limestone, into which ground water enters and from which it can flow only by siphon action through an isolated fissure to appear at the surface as the spring. If water is siphoned from this cavity at a greater rate than water enters it, the volume of flow at the spring would be greatest while the siphon is functioning. The flow would be nil when the siphon has emptied the cavity. It would remain so until the cavity is

[1] Read before the Virginia Academy of Science, Section of Geology, Richmond meeting, 1935.

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THE NATURAL BRIDGE OF VIRGINIA

(Courtesy Natural Bridge of Virginia, Inc.)

The Natural Bridge of Virginia[1]

By Frank J. Wright[2]

GENERAL STATEMENT

The Natural Bridge of Virginia, a most unique and impressive scenic feature, is located in the Valley of Virginia, 14 miles southwest of Lexington. It spans a picturesque canyon and carries U. S. Highway 11, the arterial route through the Appalachian Valley.

It is only to be expected that such an attractive object as *Natural Bridge should* find its place in the notes and journals of early travelers in this region. Its legendary renown dates back to Indian days. According to Reeds,[3] the earliest reference to the Bridge is by Burnaby, who spoke of it as "A natural arch or bridge joining two high mountains, with a considerable river underneath." A charming story from the early history of the region runs as follows:[4]

"The Monacan Indians handed down through generations the history how their tribe was wasted and decimated by long wars with the Shawnees and Powhattans. Worn by famine and despair, they were flying closely pursued through strange forests when they came upon a great chasm of incredible depth, a hundred feet from brink to brink, extending for miles to the eastward and to the westward. In the anguish of defeat, they prostrated themselves, and called upon the Great Spirit to spare his children. And when they arose and looked, behold a bridge spanned the abyss! The women and children were sent forth to try its strength. Seeing that it bore them, the prudent braves followed; and their pursuers coming up, they held the bridge as it were Thermopylae, and put many times their own number to death or flight. Therefore, the Monacans called it the Bridge of God, and worshipped it."

The visitor to the Bridge is shown the initials "G. W." which are carved on the southeast wall more than twenty feet above Cedar Creek. These are supposed to have been chiseled by George Washington himself. A few years ago some workmen, while exca-

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[1] Reprinted, with slight revisions, by permission from Denison University Bulletin. Jour. Sci. Laboratories, vol. 29, pp. 73-101, 1934. This article was originally published as part of "The Newer Appalachians of the South: Part, I, Between the Potomac and New Rivers," idem., pp. 1-105.

[2] Department of Geology, Denison University.

[3] Reeds, C. A., The Natural Bridge of Virginia and its environs: New York, Nomad Publishing Co., Inc., 62 pp., 1927.

[4] Idem.

vating along the side of the canyon below the Bridge, discovered a huge boulder which bears the marks of a surveyor. That Washington visited the Bridge is well within the bounds of possibility, although historical confirmation is lacking.

On July 5, 1774, the tract of land comprising 157 acres on which the Bridge is situated was transferred by King George III of England to Thomas Jefferson. The consideration was 20 shillings. Mr. Jefferson took great pride in this property and once referred to the Bridge as "the most sublime of Nature's work." He even made the first known map of it the year after his first inauguration as President of the United States. During the period of its ownership by Jefferson, many distinguished persons were entertained in a cabin erected by Jefferson which was presided over by Patrick Henry and his wife.

Reeds[5] refers to the prominent place given to this feature by de Chastellux in his volume entitled, "The Travels of Marquis de Chastellux in North America in 1780-82." This description was widely circulated in Europe and through it the Bridge became well known abroad.

The origin of the Bridge has received attention from Jefferson's time to the present. Five of these contributions will be noted, although there are just two published theories which deserve serious consideration.

REVIEW OF PREVIOUS WORK

Jefferson, in his "Notes on the State of Virginia," speaking of the Bridge, says, "It is on the ascent of a hill which seems to have been cloven through its length by some great convulsion." Gilmer,[6] in commenting upon this explanation, makes the following pertinent statement: "Mr. Jefferson's hypothesis rested entirely upon the supposition, that some sudden and violent convulsion of nature, tore away one part of the hill from the other and left the bridge remaining over the chasm."

Accompanied by Jefferson, Francis W. Gilmer visited Natural Bridge in 1815. In his discussion[7] of the origin of the Bridge, he opposed the cataclysmic idea which Mr. Jefferson had previously stated. The essence of Gilmer's theory is contained in the following lines: "It is probable, then, that the water of Cedar Creek originally found a subterranean passage beneath the arch of the present bridge, then only the continuation of the transverse ridge

[5] Op. cit.
[6] Gilmer, F. W., On the geological formation of the Natural Bridge of Virginia: Am. Philos. Soc. Trans. new ser., pp. 187-192, 1818.
[7] Idem.

of hills. The stream has gradually widened, and deepened this ravine to its present situation. Fragments of its sides also yielding to the expansion of heat and cold, tumbled down even above the height of the water. . . . The stone and earth composing the arch of the bridge, remained there and nowhere else; because, the hill being of rock, the depth of rock was greatest above the surface of the water where the hill was highest, and this part being very thick, and the strata horizontal, the arch was strong enough to rest on such a base." It is remarkable that at this early date Gilmer recognized the fact that the surface features of the earth are produced not by sudden cataclysms, but through the long continued operation of orderly processes. He expresses this idea in the following words: "Instead of its being the effect of a sudden convulsion, or an extraordinary deviation from the ordinary laws of nature, it will be found to have been produced by the very slow operation of causes which have always and must ever continue to act in the same manner."

Both Jefferson and Gilmer refer to the feeling of fear aroused in those who viewed the Bridge from above. One can well imagine, as he stands behind the protecting rail on Pulpit Rock and looks down into the gorge beneath him, the state of mind of those early observers. Jefferson says, "If the view from the top be painful and intolerable, that from below is delightful in an equal extreme." Gilmer[8] adds, "The curiosity of most persons, however, is overcome by fear, before they reach the margin of the precipice; they either abandon the enterprise, or timidly accomplish it by resting on a tree or rock, while they peep into the chasm which yawns beneath."

The theory presented by Walcott[9] in 1893 was the next to receive serious consideration from geologists. It was widely accepted and it appears in some textbooks. Diagrams were made to show how the water of Cedar Creek entered the bed of the stream above the present site of the Bridge and emerged at the base of a supposed fall located below the Bridge. Walcott summarized the theory as follows: "Cedar Creek was engaged for a considerable period in excavating the gorge from the James River to a point not far below the present site of the Bridge, where a fall appears to have existed, the summit of which was not far, if at all, below the present level of the top of the Bridge. About this time the water found a subterranean passage in the limestone further up the stream than the present site of the Bridge, and through

[8] Op. cit.

[9] Walcott, C. D., The Natural Bridge of Virginia: Nat. Geog. Mag., vol. 5, pp. 59-62, 1893.

this it flowed and discharged beneath the brink of the falls. The passage gradually enlarged until all the waters of the creek passed through it and the bridge began its existence. What the length of the subterranean passage was is a matter of conjecture; it may have been one hundred or several hundred feet. All of its roof has disappeared except the narrow span of the Bridge, and the abutting walls have been worn back by erosion until the gorge or canyon is much wider than at the Bridge."

Chester A. Reeds,[10] in 1927, made a study of Natural Bridge under the auspices of the Natural Bridge of Virginia, Inc., and prepared an attractively illustrated guidebook primarily for the use of tourists. It contains an elaborate description of the Bridge and many other local features of interest and beauty, such as Cascades Creek, Lost River, and Lace Falls. The author also gives a clear account of the geologic and physiographic history of the region and especially that of the Bridge itself. The local history since Indian days is carefully reviewed as is also the bibliography of Natural Bridge.

Malott and Shrock[11] examined the gorge and the topographic features of the surrounding area, and presented their results in 1930 in the American Journal of Science, under the caption, "Origin and Development of Natural Bridge, Virginia." They confirmed, and elaborated at length the Gilmer Theory. Under their treatment, the theory becomes attractive and reasonable. They believe that the Bridge and the gorge are due to a subterranean cut-off of a meander loop of Cedar Creek. Thus they say, "It appears that the waters of Cedar Creek were diverted through a subsurface passage beneath a rather open meander spur." These authors have gone exhaustively into the literature of Natural Bridge, and the reader is referred to this excellent essay for a thorough treatment of the problem of origin and for a complete list of references.

THE NATURAL BRIDGE

Natural Bridge is a natural arch or slab of limestone which spans the gorge of Cedar Creek. (See Pl. 6.) The length is approximately 90 feet, the width varies from 50 to 150 feet, and the thickness averages 50 feet. Reeds estimated the weight of the Bridge as 36,000 tons. The height of the upper surface of the Bridge above the water of Cedar Creek is given by the same author as 195.5 feet.

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[10] Op. cit.

[11] Malcott, C. A., and Shrock, R. B., Origin and development of Natural Bridge, Virginia: Am. Jour. Sci., 5th ser., vol. 19, pp. 257-273, 1930; abstract, Geol. Soc. America Bull., vol. 41, no. 1, pp. 106-107, 1930.

THE NATURAL BRIDGE REGION

Natural Bridge is located in a narrow section of the Valley of Virginia where the easternmost members of the Appalachian Ridges to the west are not more than 7 or 8 miles from the Blue Ridge. The region under consideration extends from Lexington southwestward a distance of approximately 25 miles to Buchanan. At the latter point, the Appalachian Valley is barely 2 miles wide, while at Lexington its width is about 15 miles. In the vicinity of Natural Bridge, halfway between Buchanan and Lexington, the distance is approximately 8 miles from Short Hills on the west to the Blue Ridge on the east. These two mountains form the conspicuous boundaries of the Valley in the vicinity of Natural Bridge. James River, the master stream, flows from Buchanan northeastward by Natural Bridge Station to Glasgow, where it breaks through the Blue Ridge. North River, rising in the mountains to the west, flows eastward by Lexington and is joined by South River near the base of the Blue Ridge, before continuing southwestward to unite with the James east of Glasgow. Buffalo Creek, another important tributary from the west, crosses the Valley between Lexington and Natural Bridge and enters North River.

Cedar Creek, the stream which flows under Natural Bridge, has its source near the southern end of the synclinal Short Hills mountain, and flows northeastward along the axis of this fold until it discharges down its northeastern end. Once off the mountain, it turns southwestward, then southeastward across the rock structure, and passes on through its gorge under the Bridge until it finally empties into James River at Gilmore Mills.

Just west of Glasgow and Balcony Falls, stands Sallings Mountain. It is composed of Cambrian quartzite, and it is almost cut into two parts by a deep wind gap, the floor of which has approximately the same elevation as the Harrisburg surface to the west.

The features of the region between Lexington and Buchanan are shown on the Buena Vista (Lexington) and Rockbridge quadrangles of the United States Geological Survey. For the local area of the Bridge, the reader is referred to the Natural Bridge Special topographic map. The entire course of Cedar Creek and most of the critical points in the topography of the region are portrayed on this map. Sallings Mountain, however, appears near the western margin of the Buena Vista (Lexington) quadrangle. The drainage lines are shown in Figure 3.

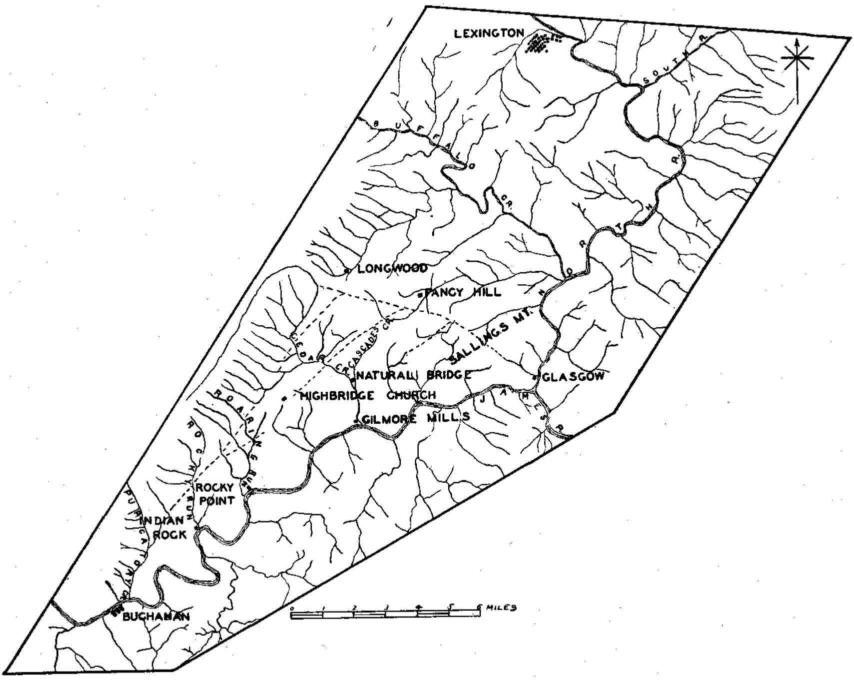


FIGURE 3.—Drainage map of the Natural Bridge region, Virginia. Broken lines indicate the position of streams in the Harrisburg cycle. Data from the United States Geological Survey topographic maps. (Reprinted by permission from Denison University Bulletin, Journal of the Scientific Laboratories.)

PROBLEM OF TWO HARRISBURG SURFACES

The origin of Natural Bridge and the gorge of Cedar Creek should be sought in the drainage history of the region. For this purpose an area extending from Lexington to Buchanan and involving a number of streams has been studied in the field and laboratory. Any explanation that is proposed for the local features in the vicinity of Natural Bridge must fit into the history of this larger area.

In order to understand the present features of the region, it is necessary to go back as far as the Harrisburg cycle. It is obvious that we must investigate the positions of streams of that time in order to determine what modifications, if any, have resulted in the present system.

After a careful study of the field and map evidence, it appears that we are dealing here with two Harrisburg surfaces which are separated by an escarpment of approximately 250 feet in the vicinity of Natural Bridge. First, there is the erosion surface of James River which at Buchanan has an altitude of about 1,050 feet. It descends gradually downstream to an elevation of 1,000 feet at Natural Bridge Station and Glasgow. The other Harrisburg surface was developed by subsequent tributary streams which occupied positions northwest of the present Natural Bridge. One of these had its source near Highbridge Church and flowed southwestward in the general direction of the Plank Road. Another stream carried the drainage from Highbridge Church northeastward and eastward through Sallings Mountain to North River. This was a part of the ancestral Cedar Creek drainage system. The Harrisburg surface of each of these tributary streams rises upstream to a maximum elevation of approximately 1,400 feet on the divide between them. From this point there is a definite downstream slope to the Harrisburg surface of the James River at Buchanan and a corresponding slope toward the wind gap in Sallings Mountain. The escarpment between the two surfaces is traced on the map and in the field from a point just north of Buchanan to Sallings Mountain. It is highest near Natural Bridge, and Cedar Creek discharges across it near the point of its maximum elevation.

EVIDENCE IN SUPPORT OF TWO HARRISBURG SURFACES

In another section of this paper it has been shown that Harrisburg surfaces rise upstream along the master stream as well as along its tributaries. So far as the writer is aware, this is almost universally true in the Southern Appalachians except where piracy has occurred. Since James River flows northeastward from Buchanan to Natural Bridge Station the Harrisburg surface of this stream should slope down in that direction. It should be remembered also that in this part of its course the James is a subsequent stream, while just below this stretch it is cutting on the resistant rocks of the Blue Ridge. Its subsequent character combined with a downstream barrier would normally result in a relatively slight upstream rise of the Harrisburg surface in this part of its course.

Turning to the field evidence, we find the Harrisburg surface in the Buchanan area at the present time approximately 1,050 feet above tide. As in other areas, the accurate determination of the present altitude of the Harrisburg is extremely difficult. It is particularly difficult in the area between Buchanan and Natural Bridge Station because of the extreme narrowness of the valley of James River in the Harrisburg cycle. As will be shown later, the tributaries of the James from the west were extremely short and arose against the escarpment separating the lower James River basin from the higher basin of the tributary whose course followed the present Plank Road. The present meander belt between Buchanan and Rockypoint represents the approximate width of the valley of the James during the Harrisburg cycle. This, of course, does not take into account the basins of tributaries which come from the Blue Ridge to the east. The elevations of the intermeander spurs between Buchanan and Rockypoint are between 1,000 and 1,050 feet. If these spurs preserve approximately the flood plain level of Harrisburg time, it is to be expected that the valley walls would rise at least 25 to 50 feet higher. The point of striking interest here, however, is the fact that this intermeander level so splendidly preserved on the flat spurs northeast of Buchanan is so nearly the elevation of the Harrisburg peneplane southwest of Buchanan some distance away from the stream; also, the further fact that this same surface can be traced without interruption downstream to and beyond Natural Bridge Station. It is slightly higher back from the stream than it is on the valley walls but its apparent continuity is noteworthy. As nearly as the writer can estimate, the elevation of this surface is approximately 1,050 feet at Buchanan and 1,000 feet at Natural Bridge Station. There is not sufficient field evidence on which to base an estimate of its elevation near Glasgow, and hence we shall use the figure of 1,000 feet for the general region of Natural Bridge Station and Glasgow. In view of its continuity and its slight downstream slope from Buchanan to Natural Bridge, it seems to the writer that its restoration in this area is a matter of reasonable certainty. Furthermore, the broad, intrenched meanders are quite similar to features in numerous other Harrisburg lowlands in the southern Appalachian region.

An alternative to the above interpretation is the possibility of the surface along James River being the remnant of a lower and younger peneplane, which was not developed in the upland back from the stream. The writer has considered this idea but is not inclined to it. Among the arguments against its acceptance, one could mention the fact that the Harrisburg surfaces in the tributary valleys seem to slope down to and merge with the Harrisburg surface of the James River valley where the streams empty into the James.

A second line of evidence in support of the idea of two Harrisburg erosion surfaces consists in the normal upstream rise of the Harrisburg surface along the tributary valleys west of Natural Bridge. From a point about one mile north of Buchanan, one can look to the north and see the upstream rise of the basin along the Plank Road. The ascent in this basin is much steeper than along the James. This is normal for tributary streams. Turning in the other direction, one looks to the south to see the lower James River surface.

According to the present interpretation, Rocky Run and Roaring Run, with their tributaries, occupy territory which drained formerly toward the southwest through a stream which had approximately the present position of the Plank Road. The Harrisburg surface rises along this basin to a point a short distance beyond the Rockbridge-Botetourt county line. At Rockypoint and Indianrock the westward swinging meanders of James River are cutting into the eastern slope of the escarpment separating the upper and lower Harrisburg surfaces.

From the Harrisburg divide, a short distance north of the county line, the drainage flowed northeastward to join Cedar Creek, which formerly passed from the Short Hills across the low col just east of the Plank Road. By some route, unknown at present, this stream flowed eastward across the Valley and through a gap in Sallings Mountain. The Harrisburg surface, with an elevation of approximately 1,400 feet at the divide, slopes southwestward to 1,050 feet at Buchanan. In the opposite direction, that is, toward the northeast and east, it descends along the former course of Cedar Creek across Sallings Mountain to merge with the South River surface at an elevation of approximately 1,000 feet.

The above features of Harrisburg erosion are entirely in accordance with stream directions as just stated, but not with the present direction of flow and position of Cedar Creek.

A third feature in support of the theory of two Harrisburg erosion surfaces is the escarpment which borders James River on the west. At Buchanan the Harrisburg basin of the subsequent tributary fused with the Harrisburg basin of the James River. About a mile north of the town the erosion surface of the tributary stream is rising to the north while the level of the James is declining toward the northeast. Consequently there is an escarpment between them. The farther from Buchanan, the greater the disparity between the two basins becomes, until the former transverse divide near Highbridge Church is reached. At this point the contrast in elevation is greatest, the higher basin being more than 1,300 feet above the sea, and the lower slightly more than 1,000 feet. From this point toward the northeast the escarpment gradually becomes lower until it intersects the western slope of Sallings Mountain. It is seen at a number of points between Buchanan and Natural Bridge Station, as shown in Plate 7. The highway leading from Natural Bridge toward Lynchburg crosses it a short distance east of Natural Bridge, the descent being approximately 250 feet. It will be noted that Cedar Creek flows across this escarpment just south of Natural Bridge.

The preceding three lines of evidence in support of two contrasted Harrisburg surfaces, the one developed by the master stream, the other formed by tributary streams, are supported not only by field studies but equally well by two series of profiles, the one from northeast to southwest, the other northwest to southeast. (See Fig. 4.) The chief peculiarity about the contrasted erosion surfaces of the Natural Bridge area lies in the fact that one of the tributary streams flowed parallel with, but almost opposite to, the direction of the main stream. This is primarily responsible for the escarpment which runs parallel to the drainage lines. It is possible that the limestones underlying the escarpment may be a little more resistant than those farther west near the Plank Road. This factor is of minor significance as compared with the normal slopes of Harrisburg erosion surfaces as they are developed by master streams and their tributaries.

The depth of dissection of the higher basin west of James River in the Natural Bridge region is further testimony in support of the idea of two Harrisburg surfaces.[12] Within a distance of two miles from its mouth at Gilmore Mills, Cedar Creek has cut into the Harrisburg surface to a depth of at least 300 feet. At Natural Bridge, where Cedar Creek has an elevation of approximately 950 feet, the erosion surface on the surrounding hills is about 1,300 feet, giving a relief of 350 feet. Other streams such as Roaring Run and Rocky Run, which empty into the James between Natural Bridge and Buchanan, have impressive gorges in the margin of the upland to the west. These streams have younger valleys and are more deeply intrenched below the upland level than is common or expectable in this region. The writer has been unable to find other examples of such youthful valleys and such deep dissection in the Appalachian Valley except where piracy has occurred. The explanation for the above is apparently to be found in the capture by these streams of drainage territory which formerly belonged to streams flowing in another direction.

The last line of evidence against a single Harrisburg erosion surface and in favor of two, is found in the lower part of the basin

[12] See the topographic map of the Natural Bridge Special Quadrangle, published by the U. S. Geological Survey.

of Cedar Creek. The road leading from Natural Bridge to Gilmore Mills is a favorable route for a consideration of this feature. A short distance south of the Bridge, one descends from the higher Harrisburg basin to the lower basin, about 1,050 feet in elevation. One can see from this point the continuation of the lower surface toward the northeast and southwest. It is about 50 feet higher here than along the Harrisburg valley walls of the James. The contrast between the two levels is shown in Plate 7. From this point to Gilmore Mills, Cedar Creek is flowing through an area that was eroded down to the Harrisburg surface of the James River, while above this point the stream is flowing through country that was peneplaned at the same time but at an appreciably higher level. Thus Cedar Creek flows across an escarpment at least 250 feet high. This is entirely inconsistent with the theory that Cedar Creek had its present position in the Harrisburg cycle. Except where rocky barriers cross stream courses, there is always a *gradual* upstream rise of Harrisburg surfaces. As indicated elsewhere, the upper Harrisburg surface descends northeastward *across* the present course of Cedar Creek. Cedar Creek flows eastward, almost parallel with the Harrisburg divide between northeast-flowing and southwest-flowing streams, as shown by the profiles. (See Fig. 4.) The present position is apparently different from the one it had in the Harrisburg cycle.

If the above is true, it is obvious that previous theories of origin of Natural Bridge, based upon the early existence of Cedar Creek in its present position, are not tenable. It is barely possible, but wholly unlikely, that Cedar Creek took its present course late in the Harrisburg cycle. If Cedar Creek did not have its present position in the former cycle, it will be necessary to reconstruct an entirely new drainage history for the region as a whole and to develop a different theory of origin for Natural Bridge.

SUMMARY OF THE HARRISBURG EROSION RECORD IN THE NATURAL BRIDGE REGION

There are apparently two well-defined Harrisburg surfaces in this area. At Buchanan the two surfaces come together at an elevation of approximately 1,050 feet. The lower one slopes down the valley of James River to an elevation of approximately 1,000 feet in the vicinity of Natural Bridge Station, while the upper rises to the northeast along the valley of a former subsequent stream which flowed southwestward in the approximate position of the present Plank Road. The stream had its source a short distance north of the Botetourt-Rockbridge county line. Northeast of this

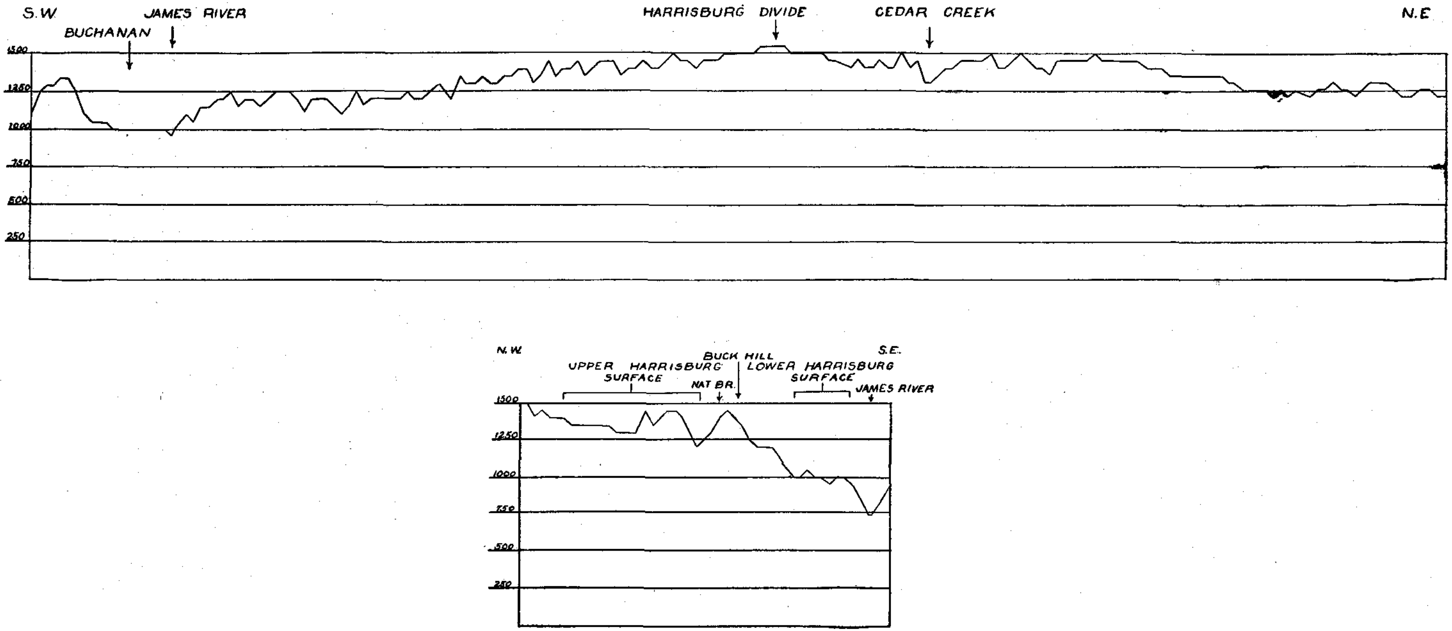


FIGURE 4.—Projected profiles across the basin of Cedar Creek. Each profile covers a belt of country a mile wide. Note that the Harrisburg surface slopes northeast and southwest from the "Harrisburg divide." The northeast-sloping surface in the longer profile cuts across the course of Cedar Creek, which trends to the southeast. Natural Bridge is not against a steep slope as shown in the short profile. The arrow merely indicates its position with reference to the escarpment. (Reprinted by permission from Denison University Bulletin, Journal of the Scientific Laboratories.)

divide the streams developed a surface which slopes towards Sallings Mountain. Near the head of this stream, the present elevation is approximately 1,400 feet, while the elevation just west of Sallings Mountain is slightly above 1,100 feet. The Harrisburg surface is very well developed in the northeastern part of the Natural Bridge Special quadrangle at elevations between 1,250 and 1,300 feet. Between Longwood and Fancy Hill, it seems to stand higher than it does in the region to the northeast, and also above its elevation in the area of the Poague Run basin between Fancy Hill and Rural Valley School. This indicates a possible position of a divide across the Valley in Harrisburg time. An especially good remnant of the Harrisburg peneplane is in the area south of Lexington. It is bounded by North River on the northeast and southeast, and Buffalo Creek on the southwest. The hilltops are quite accordant at an altitude of 1,200 feet.

Because of the depth of recent dissection and the prominence of Buck Hill and other erosion residuals, it is difficult to determine the exact elevation of the Harrisburg surface in the immediate vicinity of Natural Bridge. Malott and Shrock[13] estimate that, "In the interstream spaces [it] has an altitude of about 1,400 feet." This is a fair estimate of its height in the area near Highbridge Church, but the writer is of the opinion that it is a little too high for the area immediately surrounding Natural Bridge where the general accordance is more nearly 1,300 feet. Within a short distance to the west or southwest it approaches the figure given by Malott and Shrock. At the same time, as already explained, it is impossible to give a general estimate of the present elevation of the Harrisburg surface for the region as a whole because of the rather rapid downstream descent, particularly in the basins of the tributary subsequent streams.

DRAINAGE CHANGES

Assuming that the restoration of the Harrisburg surfaces as given above is essentially correct, we must still account for the changes in drainage which have taken place since the close of the Harrisburg cycle. It is obvious that with the uplift which

[13] These authors correctly refer to an error in statement by the present writer (Virginia Geol. Survey Bull. 11, 1925), where he says, "Successive elevations are about as follows: Natural Bridge, 1,100 feet; between Natural Bridge and Lexington, 1,200 feet; Fairfield, 1,600 to 1,700 feet; Middlebrook, 2,000 feet." The elevation of 1,100 feet should have been given for Natural Bridge Station instead of Natural Bridge. A sentence in the next paragraph of the same bulletin helps to clarify this point. "From Middlebrook to Balcony Falls the upland surface drops about 900 feet, while the fall in the present drainage is about 1,200 feet." From this statement it is clear that the same elevation is used for Balcony Falls as for Natural Bridge, which is obviously untrue. The estimate was meant for the area of Natural Bridge Station. After more study it is now found to be too high by approximately 100 feet.

brought the Harrisburg to a close, the streams of the region began to intrench themselves. Furthermore, short tributaries entering James River from the west began to gnaw vigorously into the escarpment which separated the upper and lower basins. Two of the most important streams, those which have secured for themselves the largest share of the upland drainage, enter the James at points where the master stream is undercutting the escarpment. The drainage area of Rocky Run formerly discharged toward the southwest along the Plank Road. This territory was captured by a stream working into the escarpment from the east. The same thing has happened in the case of Roaring Run. The tributaries of these streams which head against the Short Hills and flow eastward across the Valley, flowed formerly toward the southwest along the general direction of the Plank Road.

Another stream heads near Highbridge Church and flows southward, then southeastward into the James. The upper parts of these valleys are broadly open, but downstream they are extremely youthful and are characterized by rapids and local falls. It seems to be a case of an upland surface that is being rapidly dissected by vigorous pirate streams. As one travels from Buchanan northward along the Plank Road, now the Lee Highway, with map in hand, it is very easy to trace the upstream slope of the Harrisburg surface. Passing across the moderately flat area north of Purgatory Creek, where the word "Plank" in Plank Road is printed on the Natural Bridge Special map, he notices the more dissected terrain bordering Rocky Run, but the striking feature is the fact that the hills preserving the erosion surface rise uniformly northeastward across the valley of Rocky Run and its tributaries as well as across the valleys of the tributaries of Roaring Run. The erosion surface slopes southwestward, while the present streams flow in general southeastward, a fact difficult to explain except on the basis of piracy.

Following the Plank Road across the county line, one is impressed by the open character of the valley near the head of Roaring Run. It appears to have been very little modified since the Harrisburg cycle. The pirate stream has not yet had time to dissect deeply this part of the Valley. The stream flowing to the northeast on the opposite side of the divide has a steeper gradient and a notably younger valley. At present this tributary of Cedar Creek is gaining ground on Roaring Run. This is interesting, in view of the fact that Roaring Run has already captured this territory from a southwesterly flowing stream. It appears to be a case of stealing from a pirate.

A significant factor in this diversion of drainage to the southeast is the belt of limestone sinks which occurs along the eastern rim of this escarpment. A part of the run-off is at present being carried through subterranean channels, and it is likely that this was also true in the Harrisburg cycle. At any rate the sinks have certainly played a part in promoting the development of these southeast-flowing pirate streams.

Cedar Creek is the largest of the streams which have been led to take southeasterly courses since Harrisburg time. In view of its connection with Natural Bridge, however, the history of Cedar Creek will be reserved for later consideration.

The Harrisburg erosion surface can be identified in the Lexington-Buchanan area with reasonable certainty. It is as well developed and as well preserved here as in most parts of the Appalachian Valley. Its interpretation, however, rests upon the recognition of different Harrisburg surfaces with their upstream rise, and also upon the recognition of the deep dissection of the higher basin by pirate streams, especially in the vicinity of Natural Bridge and along the escarpment between Natural Bridge Station and Buchanan. In other parts of this region there is nothing peculiar or unusual about the development or preservation of the Harrisburg surface.

ORIGIN OF THE NATURAL BRIDGE

THEORIES PREVIOUSLY OFFERED

The theories of origin of the Natural Bridge of Virginia have been so carefully reviewed by Malott and Shrock[14] and also by Reeds[15] that it would seem unnecessary to go into detail. If the record of Harrisburg erosion has been correctly interpreted in the preceding pages, none of the published theories would be acceptable without serious modification. All of them have been based upon the supposition that Cedar Creek has long flowed in its present position and that its youthful characteristics are due to its rejuvenation through uplift.

The Walcott[16] theory is summarized on an earlier page. It is so plausible that its wide acceptance is easily understood.

Malott and Shrock point out an outstanding objection to the Walcott theory. If the Bridge, they say, really represents a remnant of the former floor of Cedar Creek, it should occupy the posi-

[14] Malott, C. A., and Shrock, R. R., op. cit.

[15] Reeds, C. A., The Natural Bridge of Virginia and its environs: New York, Nomad Publishing Co., Inc., 62 pp., (1927).

[16] Walcott, C. D., The Natural Bridge of Virginia: Nat. Geog. Mag. vol. 5, pp. 59-62, 1893.

tion of a valley bottom, whereas it is actually against a slope. The surface rises from the level on which the hotel is located southward across the Bridge up to the hills beyond. While it may be argued that later erosion has altered the topography in the vicinity of the Bridge, it is hardly likely that it would have changed the surface so markedly. At the same time, it would not seem necessary that the subterranean channel of Cedar Creek should have been located immediately beneath its abandoned surface course. All in all, there does not seem to be any serious weakness in Walcott's theory except, as previously stated, Cedar Creek in all probability did not flow in this position. Walcott assumed that, following the uplift at the end of the Harrisburg cycle, a fall formed at the mouth of Cedar Creek at Gilmore Mills. This fall retreated upstream toward the Bridge, when Cedar Creek, at some point above the Bridge, began to sink in its bed and to find a lower outlet at the base of the fall.

In the study of the region, Malott and Shrock find what they regard as wholly adequate support for the Gilmer theory. Their restatement of this very early theory of origin, accompanied by diagrams, is very convincing. They summarize the case in the following words: "The finding of the evidence which conclusively proves that Cedar Creek formerly followed a great meander curve or loop about a spur of nearly horizontally bedded limestone fully substantiates the Gilmer theory of the origin and development of Natural Bridge. It furnishes a perfect clue to the conditions which made sub-surface diversion possible. Cedar Creek did find a subterranean passage beneath the ridge (spur), and this passage was developed into a cavern tunnel. The roof-rock, especially at the ends and more particularly at the upper end, weakened and, lacking sufficient support, gradually fell into the deepening tunnel and was dissolved and washed away. A remnant of the roof-rock, however, still remains over this much shortened tunnel and forms the magnificent natural span over the steep-walled, cavern-born canyon. The Walcott theory of the origin of Natural Bridge necessarily becomes untenable, as it has no evidence to support it. The evidence is wholly and conclusively in support of the Gilmer theory. That this evidence had not been discovered long years ago, very probably is due to the facts that the canyon and the bridge are viewed almost wholly from below and that the little visited areas adjacent to the canyon are densely wooded. Moreover, the attractiveness of the theories of origin, and especially the completeness of the Walcott theory, may have discouraged the investigation of the field evidence which has awaited this long while."

The evidence referred to in the above quotation consists largely in the presence of what the authors call a meander loop which swings around to the north of the Bridge and unites with the valley of Cascades Creek. Distributed along this valley, but particularly at the wall of the canyon, there are boulders of sandstone and quartzite, believed by the authors to have been derived from the Short Hills to the west. In addition, the favorable structure at the Bridge and other possible contributing factors are mentioned.

The meander loop which is postulated by these writers consists of a swing of approximately a mile around the hill on which the hotel is situated. Assuming that the stream once occupied this position, it would hardly be possible to call it a meander in view of its great size as compared with the volume of the stream. This, however, does not argue against the theory. The present writer would raise a question as to the sufficiency of the evidence in support of the northward swinging course around the hill. The part of the supposed course between the point where it leaves the present valley and the old road leading westward from the Lee Highway is characterized by numerous sinks. In fact, this is really a sink hole basin without surface outlet. There is nothing especially significant about either the transverse or longitudinal profile of this depression which would indicate its former occupancy by a stream. An examination of the soil and gravels along the old road resulted in the finding of a few partly rounded sandstone pebbles and small boulders. The soil, however, is definitely residual and the number of gravels which might be interpreted as stream-worn is so small that no special significance can be attached to them. Similar gravels occur in other comparable situations in this locality.

Perhaps the greatest weight is attached by these authors to the discovery of a deposit of gravels and boulders on the rim of the gorge at the very point where Cedar Creek is supposed to have left its present valley for its northward swing around the spur. There are two crucial points in this unique boulder occurrence. The first has to do with the rounding, the other with the source of the material. Malott and Shrock say: "On the rim of the upland just north of the sharp meander turn of the stream in the gorge occur stream gravels and well rounded cobbles of quartzitic sandstone which have been very probably derived from the Massanutten sandstone in Short Hills Mountain at the headwaters of Cedar Creek. These gravels and cobbles in places are several feet in depth and lie considerably more than 200 feet above the bottom of the gorge of Cedar Creek." There are some fairly well rounded specimens, but many are partly rounded or angular.

As to the source of the boulders in the above locality, Malott and Shrock point to the Short Hills. If this can be demonstrated it is not necessary to consider even the degree of rounding. Several specimens from this deposit by the side of the canyon were submitted to Dr. Charles Butts[17] for examination. He identified the dark red specimens as definitely belonging to the Clinton formation which is exposed in the Short Hills. The Clinton does not occur between the Short Hills and Natural Bridge. The red specimens appear to be, in general, more rounded than the lighter-colored fragments. The latter may have been derived from local sources.

The topographic situation of this boulder and gravel deposit detracts from its trustworthiness as an indicator of an abandoned valley. It would seem possible to account for those boulders with Cedar Creek in its present position about as easily as by having it occupy the route proposed by Malott and Shrock. It is surprising that there are no good boulder deposits along this old "valley" except at the very point where it leaves the present valley. Rounded gravels and boulders of Clinton sandstone are widely distributed in the area surrounding Natural Bridge, and consequently their value in restoring former drainage lines is slight, except where supported by other evidence.

It seems impossible to fit the above theory into the regional history as outlined on earlier pages. If Cedar Creek took its present course as late as the close of the Harrisburg cycle, it would be hard to reconcile this fact with the subterranean cut-off of a meander route as required in the revised Gilmer theory. It seems more likely that the underground channel or outlet was developed by a concentration of sink drainage just west of the Bridge before Cedar Creek was there. In other words, Cedar Creek may never have had a surface course across the Bridge, as postulated by Walcott, or around the Bridge as stated by Malott and Shrock.

PROPOSED LIMESTONE SINK PIRACY THEORY

In attempting to find an adequate basis for an explanation of Natural Bridge and the gorge of Cedar Creek above and below the Bridge, a study has been made of the possible factors which could have been responsible for the piracy of Cedar Creek and its diversion to its present position under Natural Bridge. It seems to the writer that there were present in this locality the

[17] Butts, Charles, Personal communication.

very conditions which would make such a change not only possible but relatively easy. In short, the flow of surface drainage through sinks near the eastern margin of the escarpment to a stream gnawing into the upland, would provide favorable conditions for the development of a sink drainage basin on the upper level, with its outlet following a subterranean course to a stream on the lower level.

The steep gradient of this outlet stream would enable it to abstract drainage territory from the northeast-flowing tributaries of ancient Cedar Creek and finally to tap the waters of Cedar Creek itself. On the basis of this theory, the present Cedar Creek never flowed as a surface stream across the east-facing escarpment separating the upper and lower levels. It was led under the escarpment by a private stream developed from a large sink basin which had its subterranean outlet to the east.

Features of underground drainage near Natural Bridge.—There are several rather interesting features in the subterranean drainage of this locality. In general, it appears that the movement of underground water is chiefly to the east, as would be expected from the eastward-dipping structure above the Bridge and the location of the master stream to the east. In the following paragraphs some of the features of the underground drainage near the Bridge will be described briefly in order to show the possibility of an earlier diversion of Cedar Creek as suggested in the proposed sink piracy hypothesis.

A local feature of special interest is the small temporary stream which heads in springs about a half mile west of the Lee Highway and flows toward the valley of Cascades Creek. In fact, it is shown on the Natural Bridge Special map as flowing into Cascades Creek about two-thirds of a mile north of Natural Bridge, and to the casual observer it appears to be a normal tributary joining its master stream. As a matter of fact it empties into limestone sinks in the gardens of the Natural Bridge of Virginia, Inc., and has no surface connection with any stream, although there is a well-marked valley leading from the sinks northeastward to Cascades Creek. The rocks at the sink holes are dipping to the east and it is likely that the underground flow is in this direction, although tests with fluorescein have thus far given no clue to its outlet.

Almost a mile above the Bridge, the visitor finds one of the most interesting local attractions of the Natural Bridge area. In the valley wall of Cedar Creek, about 30 feet above the level of the stream, the limestone rocks have been blasted away to expose a swift, east-flowing, subsurface stream known as Lost River. According to Reeds the rocks at this point dip 20° toward the southeast and it is likely that the water follows the dip slope until it unites with Cedar Creek a few yards downstream.

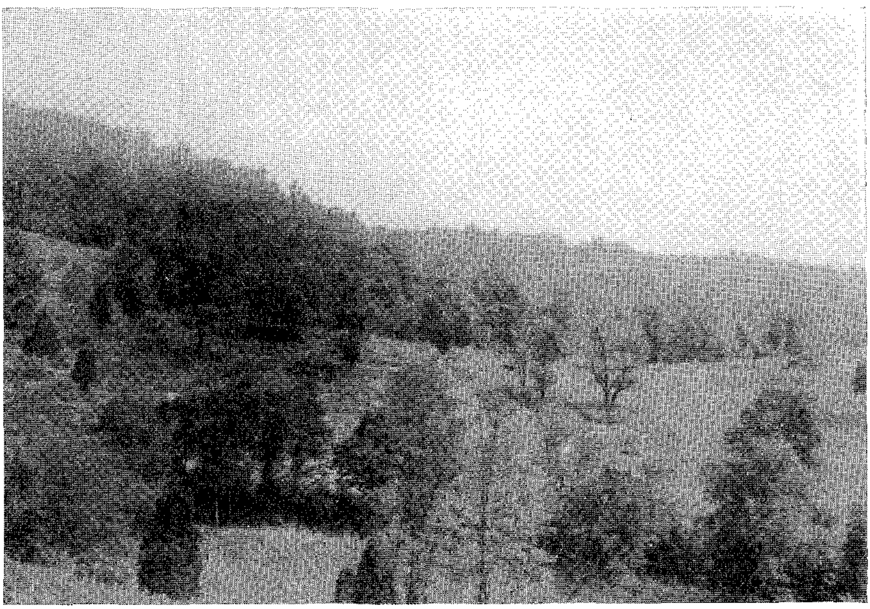
Buck Hill is a prominent topographic feature, just northeast of the Bridge, which rises to an elevation of 1,450 feet. The map shows a sink on the north side of the hill at a height of more than 1,400 feet. On the west side of the hill, there is a sink which leads into a rather large underground cavern. It is said to trend eastward for a distance of several thousand feet, and to be occupied in part by a small stream flowing in the same direction.

About a mile west of Natural Bridge the writer was shown an opening under a limestone ledge at the top of an east-sloping hill. The owner of the farm stated that after heavy rains the water which enters this opening, unless artificially prevented, empties into his well in the floor of the valley to the east.

Numerous sinks occur in the area under consideration. They are found, as previously stated, along the floor of the "abandoned valley" of Cedar Creek as described by Malott and Shrock. They also appear along the highway leading southwest from the Bridge, and again near Rockypoint and Indianrock. It will be seen that these sinks are in a belt trending northeast and southwest, just west of the escarpment. In the woods southeast of the Bridge, the surface in some places is pitted with them. Isabella's Stairway is particularly noteworthy. This is a sink which opens into an almost vertical shaft. By the use of a few artificial steps, people descend through this "Stairway" and come out at an opening not far above the level of Cedar Creek. The writer noted round river rocks tightly cemented in the ceiling and sides of the lower part of this nearly vertical passage. This feature is almost directly in line with the course of Cedar Creek just below the Bridge and illustrates how the surface drainage may have been carried through a number of different channels which later united in a single stream.

The development of sink drainage near the eastern rim of the escarpment before the piracy of Cedar Creek occurred would be similar to the drainage conditions which now prevail in the region called Little Levels near Hillsboro, as shown on the Marlinton, West Virginia, quadrangle. An area of 10 to 12 square miles has no surface drainage except streams which end in sinks. The area is several hundred feet above the level of Greenbrier River which borders it. Short tributaries of this stream are gnawing back into the upland, but as yet they have not gone far. There

A. Escarpment between upper and lower Harrisburg surfaces 1 mile east of Natural Bridge, Virginia. James River level in left middle ground, higher level on right.



B. Lower slope of escarpment separating Harrisburg surface of James River on right from higher Harrisburg surface on the left of photograph. Photographs by F. J. Wright. (From Denison University Bull., Journal Scientific Laboratories.)

A. Escarpment between upper and lower Harrisburg surfaces 1 mile east of Natural Bridge, Virginia. James River level in left middle ground, higher level on right.

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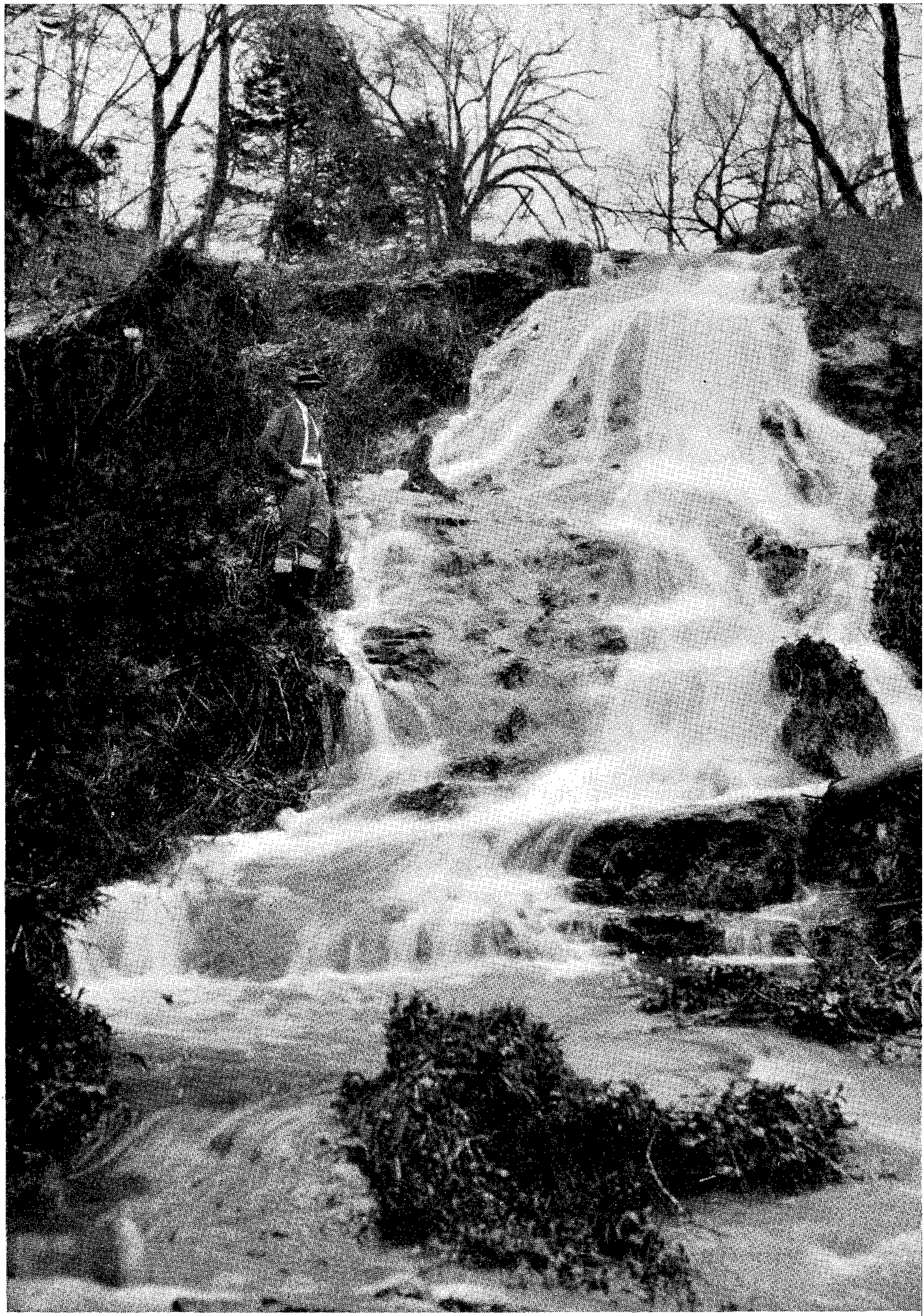
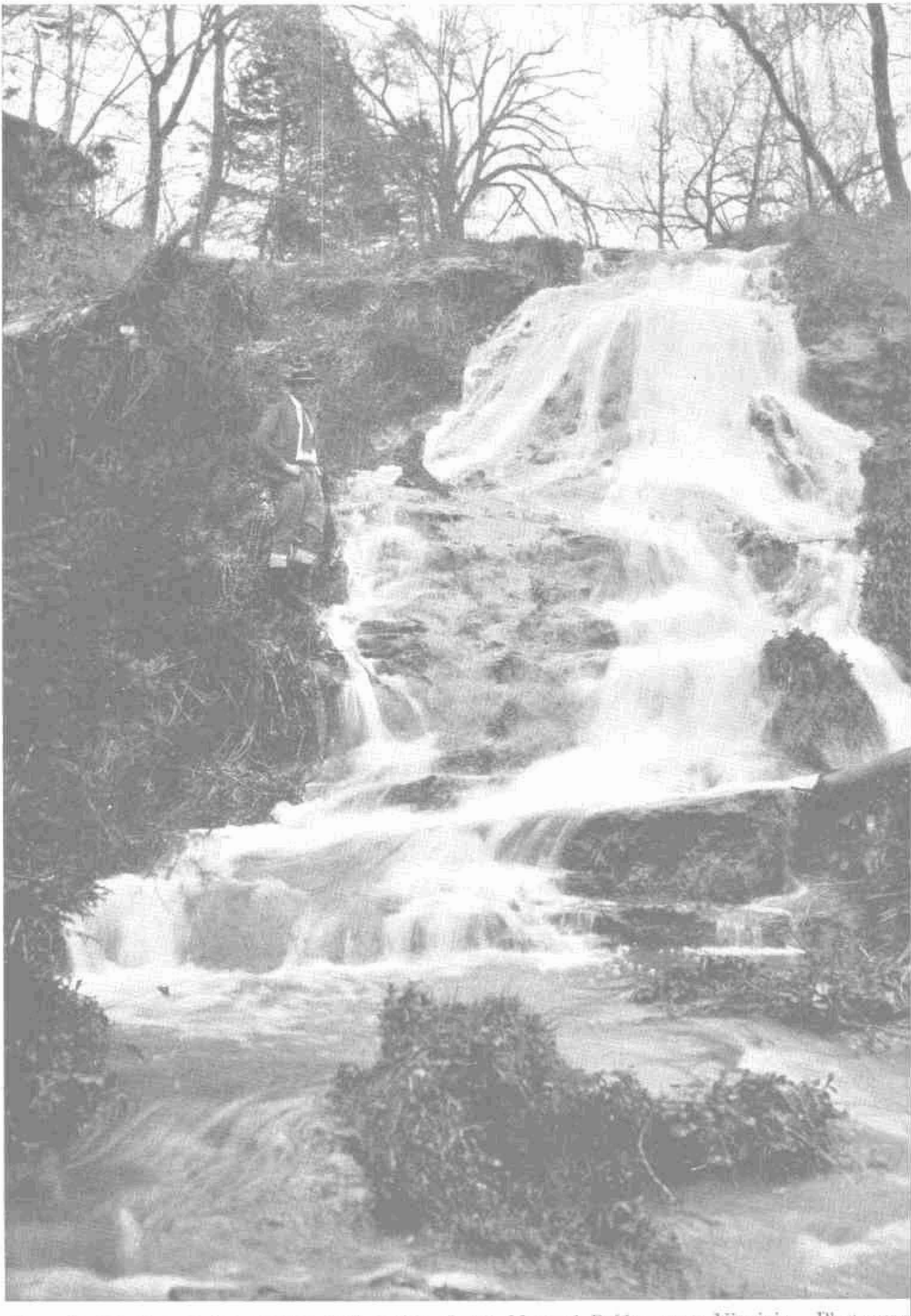


Cascades Creek near its junction with Cedar Creek, Natural Bridge area, Virginia. Photograp[h] by C. A. Reeds. (Courtesy of Natural Bridge of Virginia, Inc.)



Cascades Creek near its junction with Cedar Creek, Natural Bridge area, Virginia. Photograph by C. A. Reeds. (Courtesy of Natural Bridge of Virginia, Inc.)

appears to be no marked concentration of any of the upland drainage which would be necessary for the formation of a natural tunnel. This may be realized, however, when Millstone Creek, which drains a sink basin on the western margin of the Marlinton quadrangle and the eastern margin of the Lobelia quadrangle, finds its outlet in one of the surface streams flowing into the Greenbrier.

The conditions which perhaps most nearly correspond to those which are presumed to have existed in the Natural Bridge region near the close of the Harrisburg cycle are shown in the great sink basin which extends northeastward from the belt of sinks just west of the Bridge. The divide between this large area of interior drainage and the head of Cascades Creek is along the Lee Highway about two miles north of Natural Bridge. Turning eastward on a county road leading from this highway, one can travel for 2 miles along the side of a broad lowland which has no surface outlet. It has the appearance of a subsequent stream valley. The water passes out of the basin through various sinks distributed along its floor, and through a large subterranean outlet near the eastern end. After heavy rains, the outlets are not large enough to carry off the water, and a lake forms which sometimes covers acres of ground. Just east of this basin, on a slightly lower level, there is a large spring which flows throughout the year regardless of whether or not water enters the main outlet in the sink valley. Objects dropped into the stream in the sink basin come out in the spring on the other side. A valley or basin of this size is the product of the coalescence of a number of sinks, and it is this process which may have been responsible for the development of the initial drainage west of the Natural Bridge.

Evidence in support of the present theory.—The first feature which points toward piracy in the Natural Bridge region is the deep wind gap in Sallings Mountain west of Glasgow. The altitude of its floor is slightly above 1,100 feet, which is the approximate elevation of the Harrisburg surface west of the mountain. Another fact indicating its former occupancy by a stream is the occurrence of rounded boulders and gravels on both sides of the gap. They are much more abundant on the east than on the west. The possibility of their having been deposited on the east side of the gap by North River, is very remote in view of the topographic location of the boulders. Some of the boulders rest on the edges of deeply weathered shale and form a fairly well assorted layer dipping to the east.

The high degree of rounding exhibited by some of these boulders indicates stream wear. Their topographic situation and their rounded character point strongly toward their having been deposited by a stream flowing from west to east across the Valley. A crucial point is the question of their origin. Butts[18] has recently identified the rounded, red specimens as belonging to the Clinton formation whose nearest exposure is in the Short Hills. This formation does not occur in the Blue Ridge to the east, and hence the boulders must have been deposited by a stream which drained the Ridges to the west. North River, Buffalo Creek, and Cedar Creek are the only streams which could have occupied this position. There is no field evidence to indicate any post-Harrisburg changes in the courses of Buffalo Creek and North River. On the other hand, the evidence points strongly to Cedar Creek as the stream which formerly occupied the wind gap in Sallings Mountain.

A second line of evidence in favor of the piracy of Cedar Creek is it peculiar course. After leaving Short Hills, it swings southward along the Plank Road, then turns east across the Valley. That it should first turn southward rather than eastward is not expectable, but in itself is not specially significant. Of much greater importance is the low col near the head of Poague Run just opposite the point where Cedar Creek leaves the mountain. From this col, one can look down the valley of Poague Run across several local divides to the wind gap in Sallings Mountain. This alignment of features is distinctly suggestive of a former stream valley, although positive evidence is largely lacking due to the relatively rapid erosion of limestone.

The youthful characteristics of the present valley of Cedar Creek in the vicinity of Natural Bridge are difficult to overemphasize. The transverse profile is V-shaped and the walls are actually precipitous. The ungraded character of tributary valleys and Lace Falls are other indications of youth. These facts point to the recent shifting of Cedar Creek to its present position, or to a great increase in its volume, or both.

A somewhat careful search for stream gravels was made between the Sallings Mountain wind gap and the Short Hills. They were found on the shallow col on the first low ridge northwest of Sallings Mountain. Samples were taken which comprised well-rounded, red sandstone boulders and also light-colored specimens. The red material is more significant than the light because it indicates more definitely the Clinton formation which appears only in the mountains to the west.

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[18] Butts, Charles, Personal communication.

Another occurrence of boulders was found on the side of a hill on the road leading from the Lee Highway, 2 miles southwest of Fancy Hill, to Longwood. The boulders in this locality are numerous and apparently comprise the same types of materials as those found in the wind gap of Sallings Mountain. Light quartzites seem to predominate, but red specimens, well rounded, also occur.

On the low divide between the head of Poague Run and Broad Creek, there are abundant sandstone fragments, some partly rounded. They are decidedly less well-rounded than those observed in the wind gap in Sallings Mountain, but they are apparently the same material.

Samples of stream gravels and boulders, including fragments of the Clinton formation, were collected from the present stream bed of Cedar Creek along the Plank Road, and at points downstream as far as Natural Bridge.

The writer has found sandstone and quartzite gravels showing more or less rounding in several other situations in this region. Scattered boulders were found in the valley of a tributary of Poague Run about a half mile southwest of the larger occurrence on the road to Longwood, as previously described. They are abundant in the later terrace deposits of the James River between Natural Bridge Station and Glasgow as well as along the valley of North River near the base of the Blue Ridge. No material comparable to the reddish-colored sandstone was found in a search of a large deposit of boulders in the bed of a stream flowing from the Blue Ridge into North River. Some Clinton gravels were found on the hills near the southern end of the large sink basin northeast of Natural Bridge. Material exhibiting variable degrees of rounding occurs in quantity near the rim of the gorge of Cedar Creek a short distance above Natural Bridge, as described by Malott and Shrock. The boulders are not as well-rounded as those in the wind gap in Sallings Mountain but they have doubtless suffered stream wear. Part of the material in this deposit can be accounted for locally but there are some specimens of red sandstone from the Short Hills. Similar materials occur on the low divide northeast of Highbridge Church.

Assuming that the red material in these various gravel deposits has been derived from the Short Hills to the west, it is still not clear how we shall account for some of the above occurrences. The testimony of the boulders and gravels is not regarded by the writer as particularly helpful in tracing the exact positions of former streams, except, as in the case of Sallings Mountain, where the position of the stream is indicated by the wind gap. The gravels here definitely show that the source of the stream was in the Ridges to the west. The wind gap was clearly formed by a stream which occupied it until the close of the Harrisburg cycle. The most probable course of the stream which flowed across Sallings Mountain is outlined by several of the gravel occurrences referred to above and by the col at the head of Poague Run. The exact position, however, is unknown, and it may not have been related to any of the gravel occurrences previously described. In view of the fact that a former stream course is fairly well indicated by a wind gap, a col, rounded gravels, and the further fact that the present Cedar Creek has characteristics which clearly indicate that its present position has been acquired since the close of Harrisburg time, it would seem logical to conclude that the stream which cut the wind gap in Sallings Mountain was the ancestral Cedar Creek, which was later diverted to its present position. In fact, there is practically no alternative because no other stream has a position which could so easily have been taken as a result of diversion from a course across Sallings Mountain.

The cause of the piracy.—Postulating the above changes in the history of Cedar Creek, we must next seek an adequate cause. Perhaps the enlargement of a sink drainage basin, and the coalescence of smaller sinks into larger ones, in the area between Red Mills and Natural Bridge first provided a subterranean outlet for the surface discharge which joined a small stream at the eastern base of the escarpment. Through piracy, the drainage area west of Red Mills was diverted to this subterranean stream. Eventually the upper waters of Cedar Creek were captured near the base of Short Hills.

The writer would not attempt to trace step by step the series of subterranean and surface stream piracies which resulted in the development of the present Cedar Creek. Cols, and low divides between the heads of subsequent streams, are so common in limestone regions that they have little significance in tracing drainage changes. It is quite probable that a tributary of the ancestral Cedar Creek rose near Highbridge Church and flowed northeastward by Red Mills. There is an extremely low divide between the tributary which enters Cedar Creek from the north, at Red Mills and Poague Run. There is also a possibility of a former stream along the strike valley east of Natural Bridge and Buck Hill. In fact, there are many possibilities in the evolution of the present Cedar Creek system, and it would be extremely difficult to demonstrate the correctness of any detailed restoration. Cedar Creek and its upper tributaries have dissected the region in the present cycle to such a depth that the evidence of former stream courses has been destroyed.

The theory as outlined above seems to explain the features of the Natural Bridge locality and also fits into the regional history. Natural Bridge is accounted for in much the same way as explained by Gilmer and Walcott, as a remnant of the roof of an underground tunnel. Lace Falls represents an ungraded portion of a young valley. The gorge is the unroofed portion of a former tunnel which has been modified by weathering and erosion. The tunnel on this theory originally extended as far east as the margin of the escarpment. Cascades Creek (Pl. 8) at present discharges into Cedar Creek just below the Bridge, but in Harrisburg time it might have flowed northeastward along the well-marked subsequent valley which extends to the eastern margin of the Natural Bridge Special map. The little valley southwest of the Bridge along the Lee Highway might have been occupied by a tributary of Cascades Creek which crossed the present gorge just below Natural Bridge. In view of the fact that the tunnel of Cedar Creek extended as far east as the edge of the escarpment, Cascades Creek could not have entered Cedar Creek on the surface before the collapse of the tunnel roof at the present junction. It may have emptied, for a time, into a sink, such as the vertical sink described as Isabella's Stairway, and joined Cedar Creek underground. This possibility is indicated by the fact that the little garden stream, shown on the map as a surface tributary of Cascades Creek, actually plunges underground through a sink.

Within a mile of Gilmore Mills, Cedar Creek makes a pronounced eastward bend that has the appearance of an entrenched meander. The writer studied this feature as well as the somewhat less distinctive bend downstream. It should be remembered that these bends are on the Harrisburg surface of James River, and their only unusual characteristic is their great width. If a short stream flowed in this position during the earlier cycle, it is quite conceivable that it was winding leisurely in its course. Such a small stream would certainly have a very narrow meander belt. If these are true intrenched meanders it would appear that their great depth is due to the fact that there has been an enormous increase in volume. It is a well-known fact, however, that lateral cutting may greatly exceed downcutting in a rejuvenated meandering stream. If the stream had moderate meanders in the Harrisburg cycle, the increased volume following the piracy of Cedar Creek would serve to widen these meanders or bends.

The sink piracy theory for the origin of Natural Bridge is presented as a tentative explanation. If the regional history has been correctly interpreted, none of the theories of origin previously published would be acceptable without serious amendment. That being the case, the most plausible theory that the writer has considered involves the diversion of Cedar Creek from an ancestral course across Sallings Mountain to its present position under Natural Bridge. This may have been accomplished by the headward growth of a stream gnawing back into the escarpment, combined with the effects of sink hole drainage.

THE ORIGIN OF MOUNTAIN LAKE, VIRGINIA

BY

HENRY S. SHARP

STATE COMMISSION ON CONSERVATION AND DEVELOPMENT
VIRGINIA GEOLOGICAL SURVEY
Bulletin 46-H
UNIVERSITY, VIRGINIA
1936

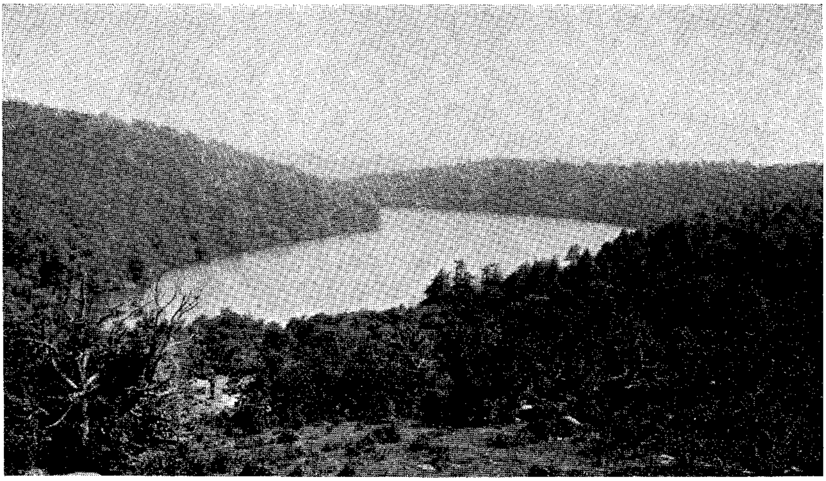
ILLUSTRATIONS

PLATE PAGE

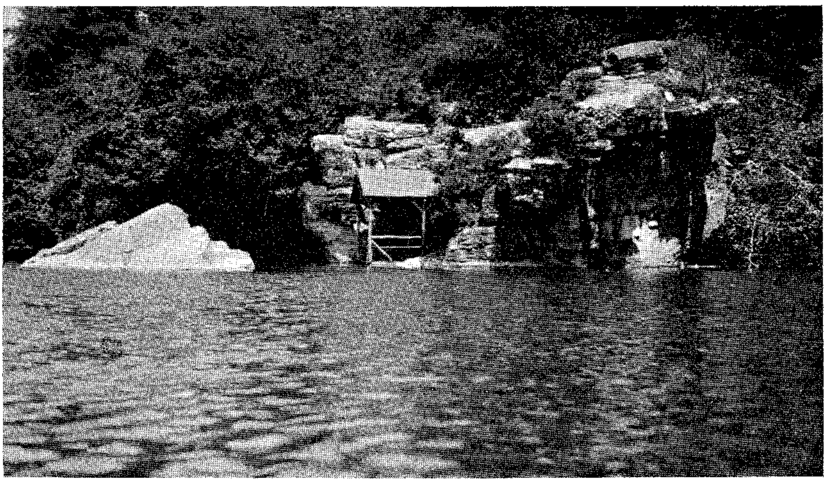
9. A, Mountain Lake, Virginia; B, Blocks of Clinch sandstone along southeast side of Mountain Lake 80

FIGURE PAGE

5. Block diagram of Mountain Lake and vicinity 82



A. Northward across Mountain Lake from Salt Pond Mountain. The outlet occupies the low sag but can not be seen because of the projecting point.



B. Blocks of Clinch sandstone about midway between parent ledge and lake bottom. (Both reprinted from the Journal of Geology, by permission of the University of Chicago Press.)

A. Northward across Mountain Lake from Salt Pond Mountain. The outlet occupies the low sag but can not be seen because of the projecting point.

B. Blocks of Clinch sandstone about midway between parent ledge and lake bottom. (Both reprinted from the Journal of Geology, by permission of the University of Chicago Press.)

The Origin of Mountain Lake, Virginia[1]

By Henry S. Sharp[2]

Lakes within the glaciated region of North America are such common features that their occurrence excites little notice unless they are of great size or of peculiar shape. Beyond the moraines, however, inland lakes other than those occurring in sinks or on the floodplains of mature streams are unusual, and, even when small, their origin is a source of speculation to layman as well as to geologist. When in addition to being extra-morainic the lake occupies a basin in a high valley surrounded by mountain ridges with whose development it is intimately related, the occurrence is unusual and invites explanation.

Such is Mountain Lake situated in Giles County 7 miles northeast of Pembroke in the Valley and Ridge section of western Virginia and shown on the Dublin, Virginia, topographic sheet.[3] It was first brought to the writer's attention in 1923 by Professor George D. Hubbard, of Oberlin College, but in spite of its interest apparently no discussion of its origin has been published. The lake (Pl. 9, A) is ¾ mile in length and ¼ mile wide, having a surface elevation of 3,873 feet. As these dimensions are essentially the same as those given by a party of surveyors which is said to have discovered the lake in 1751, an artificial origin need not be considered. The location is one of rare beauty and is now the site of a small summer resort, which fortunately has not destroyed the natural charm.

Figure 5 shows that the lake occupies the axis of a breached anticline from the trend of which its longer direction diverges slightly. East of the lake the anticline is maintained unbreached by Silurian sandstones, of which the extremely resistant Clinch[4] is most important and forms the anticlinal Salt Pond Mountain, here about 4,300 feet in elevation. At the lake the resistant arch of sandstone has been breached, and Salt Pond Mountain divides, becoming Doe Mountain and Bald Knob, homoclinal ridges whose steeper scarp slopes oppose each other. The anticlinal valley thus formed is opened upon the Sevier shales,[5] a formation here believed to be well over 1,000 feet in thickness and varying from calcareous shale at the bottom to sandy shale at the top. Due

[1] Reprinted from the Journal of Geology, vol. 41, no. 6, pp. 636-641, 1933; by permission of the University of Chicago Press.

[2] Department of Geology, Columbia University.

[3] The area containing Mountain Lake has been resurveyed as part of the Pearisburg sheet on a scale of 1:62,500. [Ed.]

[4] G. D. Hubbard and Carey Croneis, Notes on the Geology of Giles County, Virginia, Denison Univ. Bull. Jour. Sci. Labs., vol. 20, pp. 307-77, 1924. All stratigraphic information is from this paper.

[5] Now known to be the Martinsburg shale and so termed by the Virginia Geological Survey. [Ed.]

to the northeastward plunge of the anticline the two homoclinal ridges diverge toward the southwest and the intervening shale valley opens in that direction, where it is occupied by Doe Creek. The latter is a subsequent stream heading in a steep gully at a divide about 60 feet above the surface of the lake and about 600 feet from it. The lake occupies the anticlinal valley northeast of this divide and has no permanent tributaries except small spring rills. It does not parallel the anticlinal axis, but extends more to the north, appearing to fall in line with the outlet stream, a tributary of Little Stony Creek. Since the lake clearly lies within the anticlinal arch of Clinch, the outlet flows through and down a notch cut in this formation just north of the lake. The stream is resequent and is structurally superposed upon the Clinch. It has a much lower gradient and less imposing valley than Doe Creek, which is a noteworthy feature extending to the divide at the opposite end of the lake. The anticline is more widely breached at the lake than at the divide, where the two ridge crests of Clinch approach each other somewhat more closely.

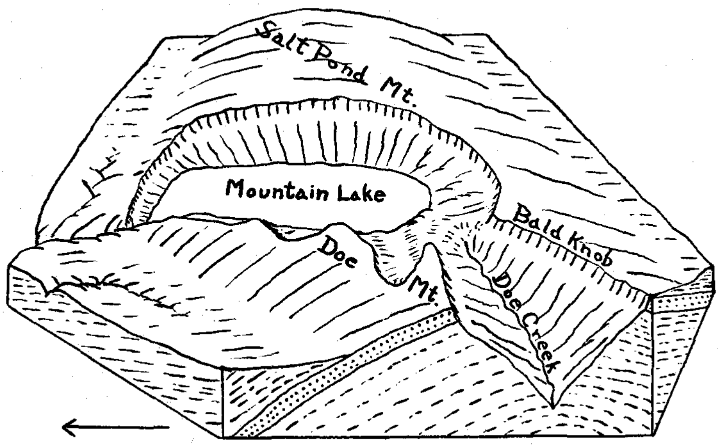


FIGURE 5.—Block diagram of Mountain Lake and vicinity. (Reprinted from the Journal of Geology, by permission of the University of Chicago Press.)

Sixty-five soundings showing a maximum depth of 75 feet were made, and it is probable that this is approximately the greatest depth, although depths of over 100 feet were reported to the author by local inhabitants, none of whom had ever sounded the lake. The author's soundings indicate the head of the lake to be shallow, the depth to increase gradually northward reaching 75 feet within a few hundred feet of the outlet, and then to decrease rapidly until the outlet is reached. Near the outlet, within the area of decreasing depth, the bottom is composed of immense blocks of Clinch; the depth here may vary several feet within a horizontal distance of a few inches according to whether the lead strikes or just misses the edge of one of these great blocks. These blocks in the lake are continuous in occurrence with those above water near the eastern side of the outlet, where a veritable rock city of tremendous Clinch blocks is found. Some of these, half submerged, may be dimly seen at the edge of the lake in Plate 9, A, although their great size is better indicated in Plate 9, B. These are several hundred feet from the parent ledge forming the wooded mountain ridge. Blocks of importance do not occur west of the outlet, but on the east they can be traced in unbroken procession from ledge to lake bottom.

For the origin of this lake basin several hypotheses may be entertained. If the lake occurred in New York, it would undoubtedly be attributed to glaciation without further study; in that state Lake Minnewaska occupying an anticlinal ripple in the resistant conglomerate of Shawangunk Mountain seems to possess several features analogous to Mountain Lake. Minnewaska has been explained as the result of glaciation, but the possibility arises that in part at least it is not glacial, when it is seen that this origin need not be considered for Mountain Lake.

The possibility that the lake occupies a solution basin must be considered; two important limestones, the Shenandoah[6] and the Chickamauga,[6] underlie the Sevier[6] shale in which the lake basin is formed, and the valley areas where these limestones outcrop are pitted with sinks indicating a high degree of solubility. Serious objections to this theory of origin, however, must lead to its rejection. The lake basin is larger than any limestone sink in the area, most of which are small circular basins. Furthermore their bottoms are mostly very uneven, containing minor sinks and knobs, and their sides are very ragged and upon submergence would form an irregular shoreline. Both of these features are lacking at Mountain Lake where the bottom slope is notably regular, and the shoreline very even. It must also be noted that no sinks in the limestone area contain lakes of any considerable size. Perhaps the strongest evidence that the lake does not occupy a limestone sink is its situation near the top of the Sevier [Martinsburg] with approximately 1,000 feet of slightly soluble or insoluble shale between it and the top of the limestone. It seems impossible that limestone solution could have any effect at the surface through such a thickness of shale.

All the features noted by the author are consistent with an origin of the lake basin as a normal stream valley subsequently dammed. The longitudinal profile of the basin with its gradual descent down valley to a point of sudden ascent is that of a stream valley dammed by debris,

[6] These names have been abandoned by the Virginia Geological Survey. See Geologic Map of Virginia (1928) and Bulletins 34 (1932) and 42 (1933). [Ed.]

the dam causing the reversal in slope. The genetic history seems to have been as follows: A resequent stream, tributary to Little Stony Creek, flowing down the flank of the Salt Pond Mountain anticline cut through the Clinch forming the mountain arch. With the exposure of the underlying Sevier [Martinsburg] this stream developed a short subsequent anticlinal valley more or less parallel to the trend of the fold and now the site of the lake. At the same time Doe Creek was working headward along the axis of the anticline, and the headwaters of the two streams approaching each other entirely breached the anticline, leaving only a low divide on the Sevier. As longer slopes of Sevier [Martinsburg] were exposed just south of the notch cut in the Clinch, great blocks of this formation crept downward over the shale slopes, gradually filling the valley bottom just above the notch. The Clinch may also have fallen as talus, or as a rockslide, although there is no evidence of the latter. Weathered particles and organic material filling the interstices made a water-tight dam impounding the lake. The source of the blocks is clearly the ledge above the outlet on the east, and the outlet stream is crowded over to the west edge of the gap with no important blocks farther west of it. The bottom of the gap is paved with smaller irregular Clinch boulders and sand.

Stumps rooted 1 and 2 feet below the surface of the lake indicate a fairly recent increase in depth. There are no indications that this rise in waterlevel is due to artificial causes, and it may be attributed to a more thorough sealing of the interstices of the block dam.

Comparison of the gradients and the situations of the outlet stream and of Doe Creek indicate that the latter with its much steeper gradient is encroaching upon the area of the former, which has the disadvantage of superposition across the Clinch. Thus the divide, now about 60 feet above the lake and 600 feet southwest of it, is being pushed lakeward by Doe Creek which may eventually tap the lake and establish a new divide at the gap occupied by the present outlet.

STRATIGRAPHY OF ORDOVICIAN BENTONITE BEDS IN SOUTHWESTERN VIRGINIA

BY

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STATE COMMISSION ON CONSERVATION AND DEVELOPMENT

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Stratigraphy of Ordovician Bentonite Beds in Southwestern Virginia[1]

By R. R. Rosenkrans[2]

"Beds of volcanic materials record periods of volcanic activity and where interbedded with ordinary sediments they form key strata that are being used more and more by those engaged in stratigraphic studies."

Clarence S. Ross.

INTRODUCTION

The presence of beds of altered volcanic materials or bentonite in strata of Middle Ordovician age in Virginia was first reported by Nelson[3] in 1926. The rather widespread occurrence of such materials in Virginia has since been noted by others including Ross,[4] Kay,[5] Butts,[6] Woodward,[7] and Mathews.[8] Their investigations have shown that there are many Ordovician bentonite horizons in this region.

Because stratigraphers recognize that such bentonite beds form ideal key horizons for use in precise stratigraphic correlations, it has seemed desirable to investigate the occurrence with a view to their possible utilization in precise stratigraphic work. In this paper is presented a discussion of the occurrence and stratigraphy of 14 bentonite beds found in southwestern Virginia. The stratigraphy of several bentonite beds found in northern Virginia has been previously discussed by the writer.[9]

As the term is used in this paper, bentonite may be defined as: "A rock composed essentially of a crystalline claylike mineral formed by the devitrification and accompanying chemical alteration of a glassy, igneous material, usually a tuff or volcanic ash; and it often contains variable proportions of accessory crystal grains that were originally phenocrysts

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[1] This paper is a part, slightly revised, of a dissertation, entitled "The geographic distribution and stratigraphic occurrence of Ordovician altered volcanic materials in Eastern North America," submitted to the faculty of Princeton University in partial fulfillment of the requirements for the degree of doctor of philosophy.

[2] Department of Geology, Princeton University.

[3] Nelson, W. A., Volcanic ash deposit in the Ordovician of Virginia (abstract): Geol. Soc. America Bull., vol. 37, no. 1, pp. 149-150, 1926.

[4] Ross, C. S. Altered Paleozoic volcanic materials and their recognition: Am. Assoc. Petroleum Geologists, vol. 12, no. 2, pp. 143-164, 1928.

[5] Kay, G. M., Distribution of Ordovician altered volcanic materials and related clays: Geol. Soc. America Bull., vol. 46, no. 2, pp. 225-244, 1935.

[6] Butts, Charles, Southern Appalachian region: Internat. Geol. Cong., XVI, Guidebook no. 3, p. 16, 1933; Geologic map of the Appalachian Valley in Virginia with explanatory text: Virginia Geol. Survey Bull. 42, pp. 19, 21, 1933.

[7] Woodward, H. P., Geology and mineral resources of the Roanoke area, Virginia: Virginia Geol. Survey Bull. 34, pp. 51-52, 1932.

[8] Mathews, A. A. L., Marble prospects in Giles County, Virginia: Virginia Geol. Survey Bull. 40, p. 11, 1934.

[9] Rosenkrans, R. R., Bentonite in northern Virginia, Jour. Washington Acad. Sci., vol. 23, no. 9, pp. 413-419, 1933.

in the volcanic glass . . . The characteristic claylike mineral has a micaceous habit and facile cleavage, high birefringence, and a texture inherited from volcanic tuff or ash." This usage is somewhat broader than that of Ross,[10] but it seems desirable in view of recent discoveries relative to the chemical and physical properties of the Paleozoic bentonites.

The use of bentonite beds as key horizons in stratigraphic studies depends upon the fact that a bentonite bed represents a volcanic eruption and ash fall that occurred in a very brief interval of time. Although a bentonite bed generally represents but a single eruption and concomitant ash fall, there are some beds which represent several successive, almost contemporaneous, eruptions. Thin shaly partings are to be found between successive layers of such bentonite beds or else textural differences are noted. Whether a given bentonite horizon is the product of a single or composite eruption, its stratrigraphic value is unimpaired so long as it is identifiable, for it represents a deposit whose distribution would be independent of any land barriers separating disconnected basins of sedimentation. As a result, a bentonite bed is a horizon marker which may extend over a wide area and which is independent of faunal and lithographic variations of the enclosing or adjacent strata.

There are two important limitations to what might be termed "bentonite stratigraphy." It is necessary that there be one or more (preferably several) readily distinguishable bentonite beds in the stratigraphic series under investigation. It is also necessary that the exposures of the strata containing bentonite be good; otherwise, the soft and easily eroded bentonite beds may not be found. In these respects the Middle Ordovician strata of the Appalachian region, and of Virginia in particular, have proved to be an exceptionally favorable field for study.

No detailed laboratory investigation of the bentonites in Virginia has been made. It is not possible, therefore, to determine accurately their present economic value, though it is believed to be slight. Bentonite finds wide application in many industrial processes, such as oil refining, paper manufacture, and production of ceramic ware. Most of the bentonite now used comes from the western part of the United States where there is a large available supply of low-cost material. In view of the thinness of the deposits in Virginia, their relative inaccessibility, structural relations, overburden, and their greater compactness, it would seem that their commercial value is at present negligible.

BENTONITE BEDS IN SOUTHWESTERN VIRGINIA

In Virginia outcrops of strata of recognized Ordovician age are largely confined to the Appalachian Valley, or the Valley and Ridge province. In Virginia the "Valley" is delimited on the northwest by

[10] Ross, C. S. op. cit.

the combined Cumberland-Allegheny escarpment, and on the southeast it is delimited by the Blue Ridge.

In order to understand the stratigraphy of Ordovician formations in the Valley one must clearly appreciate its structural and erosional history. These formations were deposited in a sinking trough—the Appalachian geosyncline. Following sedimentation through most of the Paleozoic era, the region was subjected to orgenic movements which are collectively designated the Appalachian Revolution. During this disturbance the strata which had accumulated in the geosyncline were folded and faulted by deforming forces acting from the east and southeast.

The folds and faults which were developed at this time trend more or less parallel to the present elongation of the Valley and extend for great distances. Many of the folds were broken and the rocks overthrust toward the northwest. Along some of these low-angle overthrusts there was horizontal displacement amounting to several miles. Typical examples of such overthrusts are the Pulaski and Saltville overthrusts. The resulting structure of the region has been aptly described as a series of overlapping "shingle blocks," all of which are bounded by major fault zones and dip toward the southeast.

Following deformation and elevation of the region, subsequent differential erosion has stripped away the less resistant strata so that the Valley now consists of a series of linear more or less monoclinal ridges, developed on the more resistant formations, and a parallel series of intermontane valleys separating these "valley ridges."

The areal distribution of outcrops of Middle Ordovician formations in southwestern and central Virginia is shown in Figures 6 and 7, respectively. These narrow, linear belts are found chiefly along the western flanks of the eastward-dipping valley ridges. They extend southwestward into Tennessee, where essentially the same stratigraphic sequence is found in the more northern portion of the Valley in that State.

Numerous excellent road-cut exposures are found in the region. These offer unexcelled opportunities for studying the lower Paleozoic strata in a region where a rather complete sedimentary record is present. Some of the earlier workers in this area noted that the faunal and lithologic sequences of some of the adjacent parallel belts of the same formations are unlike. According to the views advanced by Ulrich[11] these observed variations are to be attributed to deposition in distinct, parallel "troughs of sedimentation" separated by "barriers." This view has not gained general acceptance and there is a tendency in the more recent literature to ascribe the observed variations in sequence, in part at least, to facies variations dependent on distance from the shoreline

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

and the source of the sediments. Not all observed variations can be explained in this manner and the concept of "barriers" in the Appalachian geosyncline can not be completely discarded. Nevertheless, some of the apparently marked differences between adjacent belts are to be explained through the juxtaposition by overthrusting of strata originally deposited in more widely separated areas. A particularly illustrative case of such facies variation is the Lowville—Moccasin—Bays sequence.[12]

In the more westerly belts of Ordovician strata, as in the Cumberland Gap region in Lee County, more than 1,000 feet of medium thick-bedded, dove-colored to bluish limestones of Lowville age occur. These grade eastward, in the middle belts, into a thick series of red argillaceous limestones or calcareous mudrock to which Campbell in 1895 applied the name Moccasin formation. The Moccasin in turn grades eastward into a more clastic phase consisting of a thick series of brown and red sandstone of Black River age known as the Bays sandstone.

These beds are overlain by a thick series of shales and arenaceous limestones, the Martinsburg formation. In the more westerly belts the lower Martinsburg becomes more calcareous and apparently grades westward into the limestones of equivalent age found in Kentucky. In Virginia the Martinsburg is subdivided in the more westerly belts into two formations. The lower of these is termed the Trenton limestone, while the upper, shaly member is termed the Reedsville shale.[13] It is believed that the Trenton and Reedsville of this area are essentially syntaxial with the formations of the same name in New York and Pennsylvania, respectively.

Apparently there was only slight interruption of sedimentation in this region between Black River and Trenton time. The Moccasin formation, a term largely restricted to the red calcareous mudrock facies of the Lowville, grades upward through a transitional series of argillaceous limestones into the lower Trenton. At the section (Sec. 93) in the Narrows of New River, where these beds are particularly well exposed, they consist of greenish mudrock not unlike the red Moccasin except for color, blue-gray impure limestones, and greenish drab shales. These beds are also well exposed near Tazewell (Sec. 153).

The Moccasin is largely unfossiliferous, such fossils as have been found in it being restricted to the lower portion, and in particular, to the interbedded dove-colored or blue limestone beds. The exact age and correlation of the upper Moccasin and of the succeeding transitional series of shales and shaly unfossiliferous limestones are therefore subject to question. Inasmuch as the lower Moccasin is of Lowville age and the overlying formation is Trenton these beds are termed Black River.

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[12] Butts, Charles, Variations in Appalachian stratigraphy: Washington Acad. Sci. Jour., vol. 18, no. 13, pp. 357-380, 1928.

[13] Butts, Charles, Geologic map of the Appalachian Valley of Virginia with explanatory text: Virginia Geol. Survey Bull. 42, pp. 19-21, 1933.

The precise boundary between the Trenton and the underlying Moccasin has been difficult to draw. One section only, the Narrows section, in southwestern Virginia has been studied and described in detail in the literature. In this section Hubbard and Croneis[14] locate this boundary at the base of an 18-inch bed of massive, non-fossiliferous, blocky, bluish-gray limestone which is found 40 feet below the first of the gray, coarsely crystalline, very fossiliferous, limestones of undoubted Trenton age. As so conceived, this boundary is placed 100 feet above the upper limit of the red calcareous mudrock (Moccasin) facies. The transitional zone, in this section, is therefore 140 feet thick. Kay[15] places the Moccasin-Martinsburg boundary at the top of the red Moccasin facies and puts all of the transitional beds in the Martinsburg.

The suggestion is made by Mathews[16] that the transitional beds should be mapped as a new formation, the Eggleston, lying between the Moccasin and the Trenton. He says:

> "The Eggleston limestone includes the beds of upper Black River age which are younger than the upper red Moccasin member (Lowville) and older than the Trenton limestone. Although a good section of the formation occurs 1.1 miles south of Eggleston, Va., the best section is along State Highway 8, one mile north of Narrows, Va. This will be considered the type locality and will be described in detail in the comprehensive report on Giles County now in preparation. As the name Narrows has been preoccupied and as there are no suitable local names for the formation, the name Eggleston limestone has been selected and approved.
>
> "In general the Eggleston is thin- to thick-bedded, fine-grained, argillaceous, dark-buff to light-brown limestone which upon fracturing forms cuneiform blocks with the jointing perpendicular to the bedding. It contains many thin beds and a few thicker beds of bentonite, and its peculiarities may be due to this material. The formation is widely distributed in the Valley and Ridge province. In the type locality it is more than 150 feet thick. The fossils are of the upper Black River type."

It is to be noted that the views of Hubbard and Croneis[17] differ from the views of Mathews as to the delimitation of the base of the Martinsburg and the top of the Moccasin. Their interpretations are based on the Narrows section.

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[14] Hubbard, G. D., and Croneis, C. G., Notes on the geology of Giles County, Virginia: Denison Univ. Bull., Sci. Lab. Jour., vol. 20, pp. 307-377, 1924.

[15] Kay, G. M., Distribution of Ordovician altered volcanic materials and related clays: Geol. Soc. America Bull., vol. 46, no. 2, pp. 225-234, 1935.

[16] Mathews, A. A. L., Marble prospects in Giles County, Virginia: Virginia Geol. Survey Bull. 40, p. 11, 1934.

[17] Op. cit.

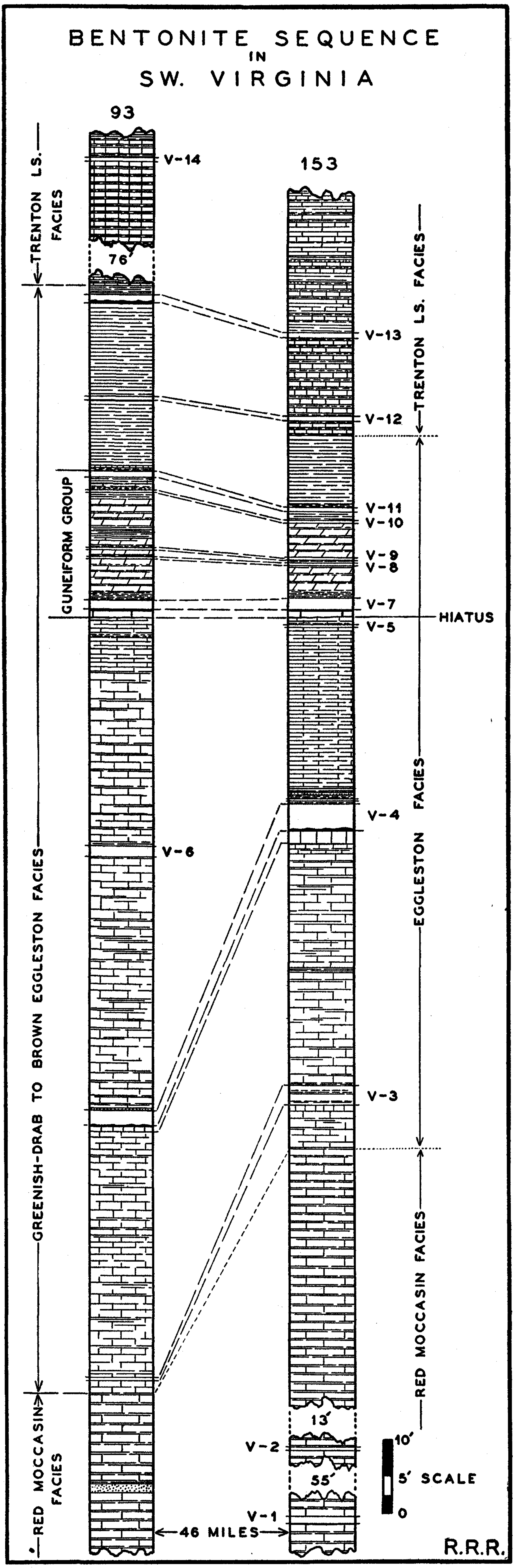
The value of the Eggleston as a distinct formation, and of the various proposed boundaries (Moccasin-Martinsburg, Moccasin-Eggleston, and Eggleston-Martinsburg) depends not upon a single section, but upon their usefulness in correlation with other sections in the region. If the Moccasin-Martinsburg boundary used by Hubbard and Croneis represents a disconformity and is traceable throughout the region, then the Eggleston is of doubtful validity as a distinct formation, and particularly so if either or both the Moccasin-Eggleston boundary and the Eggleston-Martinsburg boundary are of different ages in different localities.

In the solution of the problem of the delimitation of the Moccasin and Martinsburg formations and the determination of the value of the Eggleston as a formation fossils play only a minor part because most of the beds in question are unfossiliferous. Moreover, all are presumably of Black River or upper Black River age and it is questionable whether the meager faunas would serve in drawing fine distinctions, particularly when the problem is further complicated by the known facies variations in this region.

Correlation of bentonite beds seems, however, to offer a means of attacking the stratigraphic problems of the Black River beds in this area. Eleven bentonite horizons are found in the Narrows section, ten of which occur in the Eggleston beds. Without discussing here the evidence for his conclusions, the writer believes, as a result of his studies of the bentonite beds, that: The Eggleston is but a facies whose upper and lower limits vary according to locality, and that the Moccasin-Martinsburg contact as established by Hubbard and Croneis is a readily recognizable horizon throughout southwestern Virginia and also is a horizon of disconformity, the value of this hiatus varying from locality to locality.

Probably the best exposure of the bentonite sequence found in southwestern Virginia is that seen in the section designated as section 153, and located 3 miles south of Tazewell, in Tazewell County. At this locality at least 200 feet of the upper Moccasin and more than 200 feet of the overlying beds are continuously exposed. A complete section is obtainable on each limb of a small syncline so that in reality two sections are available and may be used to check against each other. A detailed correlation of this section with the Narrows section is presented as Plate 10. The bentonite sequence established in these two "type" sections has been recognized throughout southwestern Virginia.

In order to facilitate a discussion of the bentonite beds found in this region they have been designated as beds V-1, V-2, V-3, etc. Of these, bed V-1 is the oldest. The relationships of these beds are indicated on Plate 10. This nomenclature has been adopted as a matter of convenience only as it is not to be expected that this exact sequence will be found in other areas; in fact, it is not feasible at present to



Standard sequence of bentonite beds in southwestern Virginia.

correlate the bentonite beds of this area with those of neighboring geologic provinces.

The bentonite bed designated as V-1 occurs in the Moccasin formation approximately 125 feet below the upper limit of the typical red mudrock Moccasin facies. It has been observed in but a few localities and its presence elsewhere cannot be readily established because this portion of the stratigraphic section in places is much folded and faulted. Strictly speaking, this bed is a greenish-white bentonitic shale overlain by a few inches of green shale. It is best exposed in the Tazewell section (Sec. 153) where it caps a small anticline (Pl. 11, A). At this locality its thickness is approximately 12 inches and it immediately overlies a two-inch layer of cherty green mudrock. As a key horizon for stratigraphic correlation this bed is of little value because it is difficult to recognize.

Bed V-2 is a 3-inch bed of greenish-white bentonitic shale lithologically similar to bed V-1 and occurring 65 feet above that horizon. It is not readily recognizable and has been identified in but two localities.

In contrast to the two preceding beds, bentonite bed V-3, or rather, bentonite zone V-3, is quite readily recognizable and a valuable horizon marker. It has been found from Catawba Mountain in Virginia (Sec. 102) to Thorn Hill P. O. in Tennessee (Sec. 75), a distance of 200 miles along the strike. More than 16 outcrops of this zone have been studied. All have shown that it represents several successive penecontemporaneous volcanic eruptions and ash falls. A characteristic feature of the zone is a five-fold division, there being commonly three layers of yellow bentonite separated by two thin layers of red to purple shale. The thickness of the entire zone is generally a little less than 2 feet.

The outcrop of this bed in section 102 has been described by Ross[18]. His measurements of this bed at that locality and comparative measurements of this bed at three other localities, respectively 80, 110, and 150 miles distant, are given in Table 1.

TABLE 1.—*Typical sections of bentonite zone V-3 in southwestern Virginia*

Section 102,[a] near Catawba, Roanoke County, Virginia

	Inches
Yellow arkosic bentonite	6¾
Red shale	1¼
Yellow micaceous bentonite	5½
Red and yellow bentonite	2½
Dark-red sandy shale	5

[18] Ross, C. S., Altered Paleozoic volcanic materials and their recognition: Am. Assoc. Petroleum Geologists Bull., vol. 12, no. 2, p. 157, 1928.
[a] Ross, C. S., op. cit.

Section 153, southwest of Tazewell, Virginia

	Inches
Yellow bentonite	4
Drab limestone	1
Yellow bentonite	1
Red shale	2
Yellow bentonite with some red shaly material near base	19
Gray-green chert	1–2

Section 88, near Old Rosedale, Russell County, Virginia

	Inches
Yellow bentonite	5
Drab limestone	1
Yellow bentonite	1
Red shale	2
Yellow bentonite	8
Red shale	5
Yellow bentonite	2
Gray-green chert	1

Section 82, in Big Moccasin Gap, near Gate City, Virginia

	Inches
Yellow bentonite	2+
Drab limestone	1
Yellow bentonite	2
Red shale	2
Yellow bentonite	6
Red shale	5
Yellow bentonite	2
Gray-green chert	1+

Distance from section 102 to section 153 is 80 miles; section 153 to section 88, 30 miles; section 88 to 82, 42 miles.

The remarkable uniformity of this bed over a wide area is clearly shown. Many outcrops of the zone have been so badly disturbed by local squeezing and folding that it is impossible to determine the exact thickness of the individual members. It is, however, always possible to recognize that this zone consists of alternating layers of yellowish white bentonite and thin red shale. Moreover, this zone is always recognizable by the following features. It generally rests on a bed of blocky, gray to dove-colored limestone 10-12 inches thick that is capped by a green chert 1 to 2 inches thick. This chert weathers with a very smooth white surface immediately beneath the bentonite. This zone is commonly found from 2 to 10 feet above the upper limit of the red Moccasin facies. There are a few exceptions located either east of the Saltville thrust fault or in the extreme southern sections. The upper limit of the red mudrock is not marked by a hiatus, for it grades into a greenish mudrock whose lithology is similar and from which it differs only in color. This transitional zone is usually but a few feet thick and as noted above, everywhere (with the noted exceptions) occurs a few feet below the bentonite zone V-3. Its position is approximately 35 feet stratigraphically below the readily recognizable bentonite bed V-4.

The bentonite bed designated as V-4 is the thickest bentonite bed in the region. Measurements on at least 20 outcrops of this bed show that it varies in thickness from 1 to 4 feet or more and that the average thickness is approximately 3 feet. It rests on a very smooth, white, ripple-marked chert which caps a blocky dove-colored limestone 1 foot thick. This bed occurs from 30 to 35 feet stratigraphically above bentonite zone V-3. The intervening strata are greenish drab mudrock and thin, dove-colored sublithographic limestones. The bentonite of this bed has a pronounced lemon-yellow color and is quite talcose. At the top of this bed, or slightly higher, are found two 1-inch beds of blocky drab sandstone. Although not present everywhere, these sandstone beds have been noted in most of the sections where bed V-4 has been found.

From 1 to 2 feet of greenish to drab calcareous shale succeed bentonite bed V-4. In some sections an additional thin bentonite bed is found in this interval. An outcrop of bentonite bed V-4 near Tazewell is shown in Plate 11, B. Its widespread occurrence and easy identification make this bentonite bed one of the most useful horizon markers in the region.

The bentonite bed designated as V-6 is 18 inches thick and has been observed only in the Narrows (Sec. 93) section. It is doubtfully present in one additional section (Sec. 97 near Staffordsville), though here the stratigraphic sequence has been somewhat confused by local faulting. Bentonite bed V-6 rests on 6 to 7 inches of brown cherty limestone, the upper 2 inches of which are very dark-colored. It was thought at first that the presence of this "extra" bentonite bed in the Narrows section is due to faulting with the repetition of some other bentonite horizon. This is apparently not the case and this bed is therefore interpreted as indicating deposition of strata at this locality which are not recorded elsewhere in the region. This view is substantiated by the fact that the stratigraphic interval between the readily recognizable bentonite bed V-4 and the equally easily identified bentonite bed V-7 is some 35 feet greater in this section than in any other. The interval between this bed and V-7 is also 35 feet. These relationships seem most readily explained as the result of a hiatus in other sections that is equivalent to approximately 35 feet of strata (including 18 inches of bentonite, V-6) in the Narrows section. This interpretation is indicated in Plate 13. If there was interruption of sedimentation at Narrows during this time, it would seem to occur at a horizon 2 feet below bentonite bed V-7. A lithologic change is found at this point in the section, and in fact this is the horizon at which Hubbard and Croneis[19] placed the Moccasin-Martinsburg boundary in this section. It may be noted in passing that this falls within the limits of the proposed Eggleston formation of Mathews.[20]

Elsewhere in southwestern Virginia a lithologic break and a 4-inch mud zone are found 2 feet below the easily recognized bentonite bed V-7. These are believed to be the physical evidence of the hiatus noted above; the value of this hiatus being greater in the sections other than that at Narrows. In some sections a thin bentonite bed, of only local occurrence and designated as bentonite bed V-5, is found either at or a few inches below this mud zone. It has not been found in the Narrows section, but it is presumably older than bentonite V-6. Where it has been observed, this bentonite is less than 4 inches thick and in places is light green, as in section 153. It is the only light-green bentonite in the region and may possibly be the same as the thick green bentonite bed that has a widespread occurrence in Kentucky, Tennessee, and Alabama. If so, it represents but the thin edge of the ash fall which formed that bed.

Overlying the horizon of the mud zone noted above is found an 18-inch to 2-foot bed of massive, dense, bluish, non-fossiliferous limestone capped by a bed of chert 2 to 3 inches thick. This bed of chert is blocky and readily becomes detached from the subjacent limestone bed. The lithology of this bed is quite distinct from that of the underlying impure, cobbly, dove-colored limestones and similar to that of some of the overlying "Trenton" strata. This is the bed termed S-1 by Hubbard and Croneis.[21] Overlying this chert is found the 18-inch bentonite which has been termed V-7. This bed has been recognized in more than 20 sections. It is rather dark yellow and it grades upward into from 9 to 18 inches of thin, hard, hackly, olive-green, arenaceous shales which delimit the base of the so-called "cuneiform beds."

These "cuneiform beds" are a series of brown-weathering, bluish-gray to drab, impure, non-fossiliferous limestones characterized by a peculiar type of jointing and weathering. These beds show many vertical joints at right angles to the bedding. On weathering, angular fragments break out along these joint planes and the resultant pitted surface resembles a clay tablet covered with cuneiform inscriptions. The term "cuneiform" for these beds has been used by several writers and seems aptly to describe them. (See Pl. 12, A.)

The total thickness of this group of beds is approximately 20 feet. Associated with these beds are found the 5 bentonite beds (V-7, V-8,

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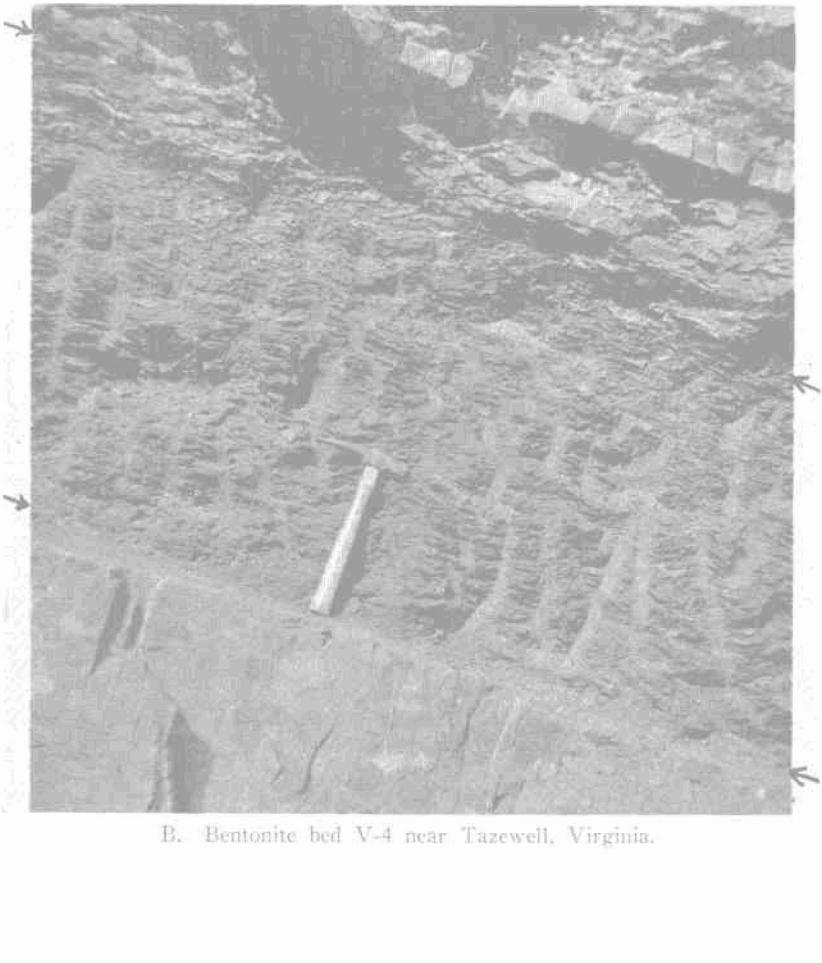
[19] Op. cit.
[20] Op. cit.
[21] Op. cit.

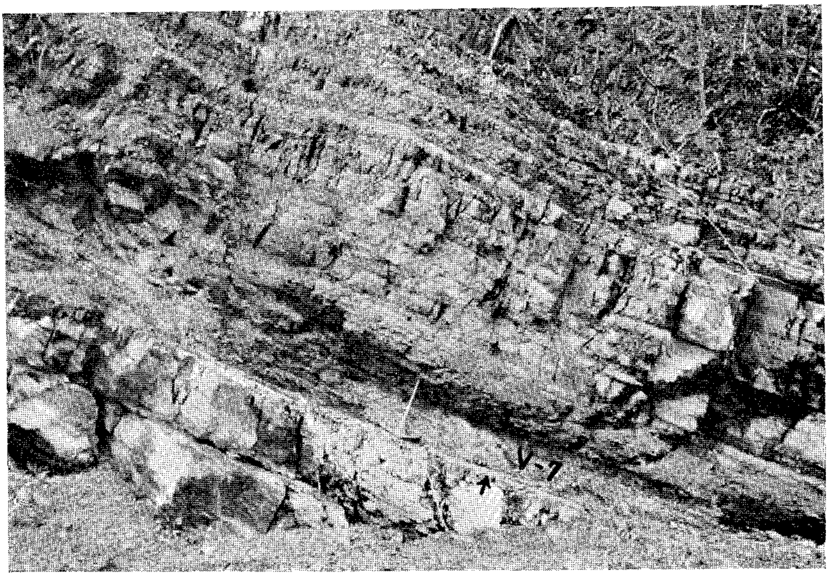
A. Small anticline in Moccasin formation near Tazewell, Virginia.

B. Bentonite bed V-4 near Tazewell, Virginia.

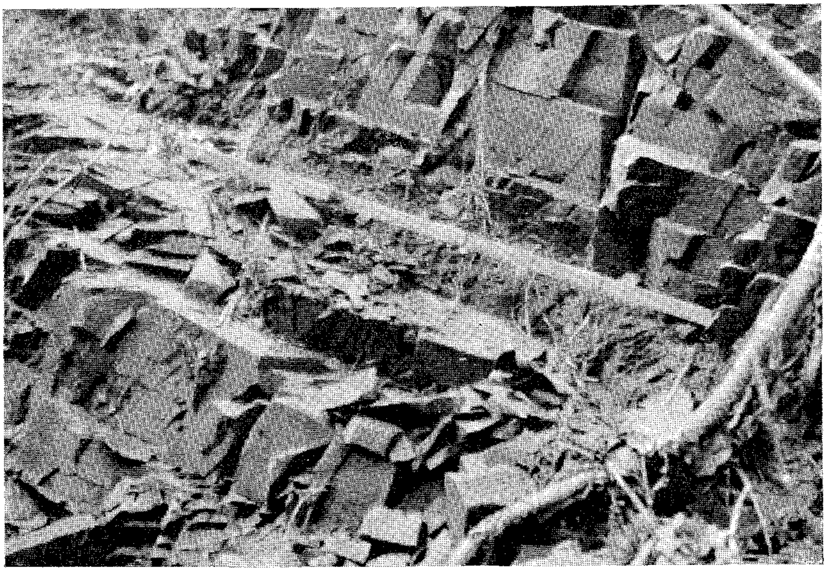
A. Small anticline in Moccasin formation near Tazewell, Virginia.



B. Bentonite bed V-4 near Tazewell, Virginia.



A. "Cuneiform" beds in the Narrows section. Hammer rests on chert at base of bentonite V-7.



B. Characteristic jointing of the "cuneiform" beds.

A. "Cuneiform" beds in the Narrows section. Hammer rests on chert at base of bentonite V-7.

B. Characteristic jointing of the "cuneiform" beds.

V-9, V-10, and V-11). The group consisting of these 5 bentonite beds, the "cuneiform" beds, and the thick limestone bed found beneath bentonite V-7, are grouped together in the present paper as the cuneiform group. It forms a zone that has been traced widely in southwestern Virginia and northeastern Tennessee. A generalized sequence of it is given in Table 2.

TABLE 2.—*Generalized sequence of "cuneiform" group in southwestern Virginia*

	Thickness Ft.	Thickness In.
Bentonite (V-11), with a distinctive orange color		8
Shale, green, calcareous		11
Shale, green to drab, very soft		2
Bentonite (V-10), light yellow		2
Limestone, blocky, cuneiform	5–8	
Shale, green, very soft		2
Bentonite (V-9)		.5–1
Limestone, blocky, cuneiform		6–9
Shale, green, soft		1–2
Bentonite (V-8)		.5–1
Limestone, blocky, cuneiform	4	
Shale, olive-green, hackly, transitional from the overlying cuneiform beds to the underlying bentonite	1	8
Bentonite (V-7)	1	6
Chert, dark brown, blocky, detachable from subjacent bed		2–3
Limestone, a single bluish gray, non-fossiliferous bed	1	6

One of the most remarkable features of this group of strata is its persistence and uniformity of character over a wide region, a fact that is clearly shown in Plate 13. This fact, combined with the distinctive nature of these beds, makes them one of the most readily recognizable and useful horizons in the section.

Bentonite beds V-8 and V-9 are distinctive only by virtue of the fact that they form a pair of very thin (1/8 to 1½ inches) beds that are commonly present near the middle of the cuneiform group. They thus add further value to this group as a horizon marker.

Bentonite bed V-10 consists of 1 to 2 inches of light-yellow bentonite in the upper part of the cuneiform group. It is most readily recognized from its stratigraphic position relative to bentonite V-11. The latter is 8 inches of bentonite characterized by a pronounced orange color and its position at the top of the beds with the characteristic "cuneiform" jointing and weathering. It has been observed at more than 10 localities. That it has not been seen elsewhere is attributable to poor and incompletely exposed sections rather than to its absence.

A light lemon-yellow bentonite, from 4 to 10 inches thick, found approximately 10 feet above bentonite V-11, has been designated as bed V-

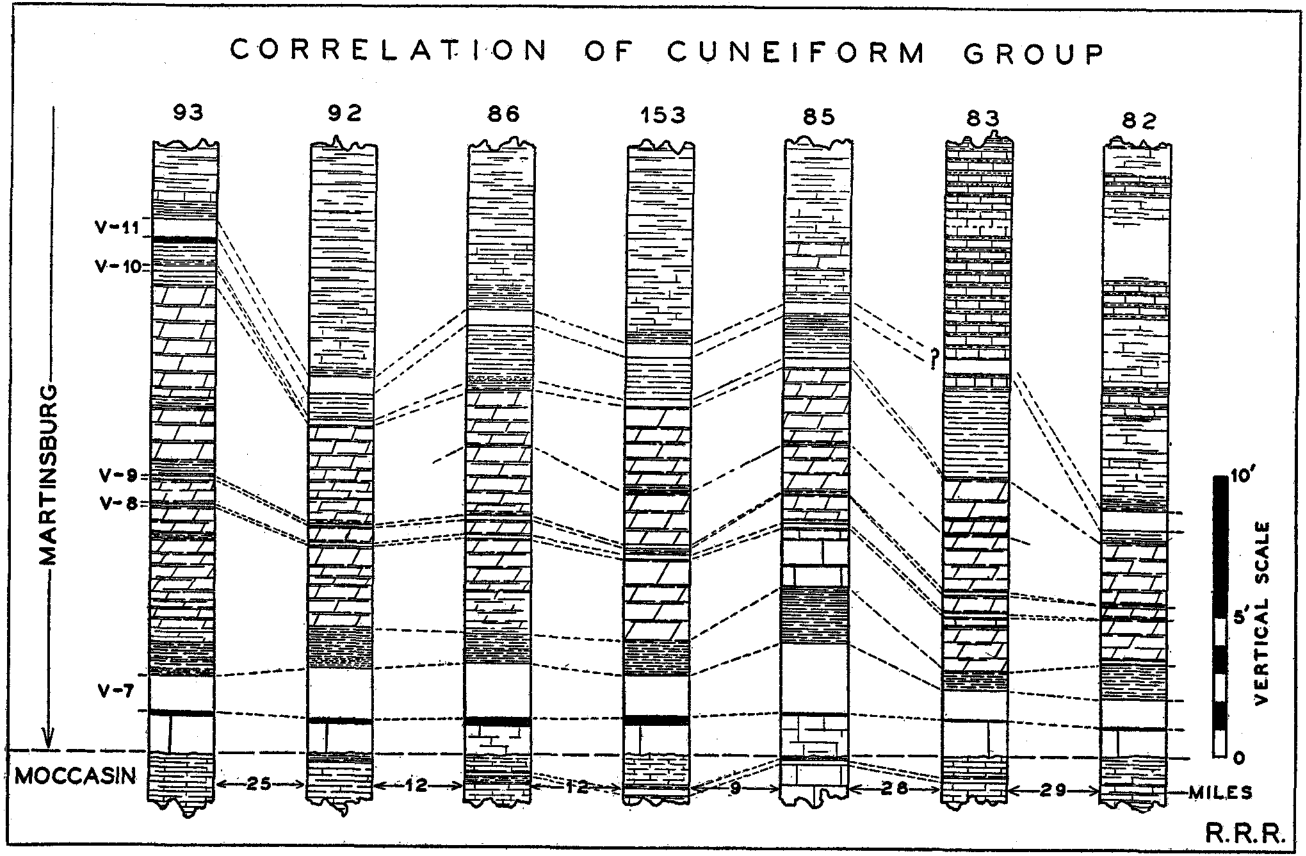
12. Its color contrasts markedly with that of the preceding bentonite bed and this sequence of an orange-colored bed and a lemon-colored bed has been particularly useful in the correlation of many sections. The stratigraphic position of this horizon within a few feet of the top of the cuneiform group has also tended to make its identification comparatively easy.

Approximately 15 feet higher in the section is found 12 to 14 inches of bentonite (V-13) whose color in most sections is a very dark greenish drab. The strata between beds V-11 and V-12 and between V-12 and V-13 in the Narrows section are largely brown to drab calcareous shales. Here, the first appearance of the light-gray, very fossiliferous, coarsely crystalline "Trenton" limestone facies occurs 1 foot above bed V-13. At other localities, and particularly in the more southerly sections, beds of this lithology appear below bed V-13, and although the evidence is not conclusive, because of too few well-exposed sections, it seems to indicate that the change from the deposition of greenish-drab calcareous shales and bluish-gray limestones (Eggleston facies) to deposition of the characteristic Trenton limestone facies was transitional and began earlier in the more southern sections. This would seem to indicate that the upper boundary of the Eggleston facies which separates it from the Trenton facies varies in age from locality to locality. A similar case was noted in the boundary between the Eggleston and the underlying red Moccasin facies.

A dark-colored, ripple-marked chert is found immediately beneath bentonite bed V-13 in the Narrows section. It has also been noted in the section near Staffordsville (Sec. 97).

Bentonite bed V-14 is characterized by its stratigraphic position approximately 100 feet above the base of the Trenton facies. At Narrows this bed is very thin and almost white. At Rosedale (Sec. 88) and in some of the other southern sections a bed of bentonite 10 inches thick rests on 7 inches of brown chert with "cuneiform" jointing at this approximate horizon. These are believed to be the same bed, though it is possible that two separate beds have been confused.

The most complete sections showing the sequence described above are those found in the belts of outcrop west of the Saltville and Saltville-Bland faults. To the east of these faults one or more of the bentonite beds are absent and it is believed that this area may have been emergent during a part of Moccasin-Lowville time. This is an area in which the Moccasin is markedly arenaceous. According to Butts, it contains one or more beds of sandstone up to 4 feet thick, and at the south end of Walker Mountain as much as 15 feet thick (Bays facies). Possibly the absence of some of the bentonite beds in this area may be attributed to destruction of the ash beds by agitation on the bottom. Similar sections occur in northeastern Tennessee, though there the apparent absence of



Correlation of the "cuneiform" group of beds in southwestern Virginia.

some of the bentonite beds is possibly due to very poor exposures of the sections.

A number of sections in the belts of outcrop east of the Saltville and Saltville-Bland thrust faults have been studied. One feature that is brought out in these sections is the fact that the upper limit of the red Moccasin facies is no longer constant with respect to the bentonite beds. In these eastern sections this red coloration is in places found above bentonite bed V-3 and even above bed V-4. This is interpreted as indicating that the conditions of sedimentation favoring the development of the red Moccasin facies persisted in the more easterly and southerly areas after deposition of a greenish mudrock facies had begun in the more westerly areas. If this is true, the upper limit of the red Moccasin facies varies in age from locality to locality and is therefore less satisfactory as a boundary for delimiting the Moccasin formation.

The Eggleston has been regarded as a distinct formation overlying the Moccasin. The present study indicates that there are two facies in the region—a red mudrock (Moccasin) facies and the greenish mudrock facies which has been termed the Eggleston formation. It seems to be more correctly spoken of as the Eggleston facies. Deposition of it followed deposition of the red Moccasin facies and in general began earlier in the more westerly areas. On Wallen Ridge in Lee County (one of the most westerly belts of outcrop studied) no red Moccasin facies has been found though there is a considerable development of the greenish Eggleston facies. There is, however, a thick development of the Lowville limestone facies. This area seems, therefore, to be related to the central Kentucky, central Tennessee, and Chattanooga areas. If the bentonite beds are to prove useful in establishing closer correlations of the strata of Black River age in these states with those of Virginia, they should be present in this area. It seems to be one of critical importance because the sediments are transitional between the great limestone deposits of the interior and the clastic rocks in the eastern part of the Appalachian Valley.

Although good sections in Lee County are rare, several have been found which show a number of bentonite beds. These seem to correlate more closely with the bentonite sequence found farther to the east and northeast in Virginia than with that found in Kentucky and Tennessee. There are some similarities between the bentonite sequence of this area and that found in the Chattanooga area, which may afford a basis for close correlation with that area. As the Chattanooga area can be closely correlated with the central Kentucky and central Tennessee areas by means of bentonite beds, it is felt that further study may make possible a close correlation of all of these areas by means of the bentonite beds. For the present, a statement of such correlations seems unwarranted by the available evidence.

A tentative correlation of sections found in Lee County with sections farther east on Powell and Clinch mountains (successive overlapping "shingle blocks" in the latter in which the red Moccasin is typically developed) seems to indicate the presence in this area of a hiatus that accounts for the absence of bentonite beds V-1 to V-6. This hiatus occurs 2 feet below a bentonite bed that has been interpreted as bed V-7. If this interpretation is correct, this hiatus occurs at the same horizon as that noted in the sections farther to the northeast. The amount of strata missing because of this hiatus is greater, however, than in the sections numbered 82 to 100 and section 153.

CONCLUSIONS

There has been presented the writer's interpretation of the stratigraphy of the bentonite beds found in southwestern Virginia. The conclusions reached from a study of these beds and the correlation of the many sections measured may be summarized as follows:

In southwestern Virginia there are present four distinct facies of strata of Black River age. From west to east they are the Lowville limestone facies, red Moccasin mudrock facies, and Bays sandstone facies. The fourth, or Eggleston greenish mudrock facies, is transitional between the red Moccasin facies and the overlying Trenton limestone facies of the Martinsburg. Although the greenish Eggleston facies generally overlies the red Moccasin facies it also replaces the uppermost part of the red Moccasin in the more westerly belts. In Lee County, in the extreme southwest portion of the region, this greenish facies is present to the exclusion of the red Moccasin facies and is itself found interfingering with the bluish-gray limestones termed the Lowville limestone facies. It is probable that these limestones in turn grade westward into the very pure "birdseye" limestones of Lowville age that are called the Tyrone formation in central Kentucky and Tennessee. Were it possible to obtain sections in the intervening area this probably could be demonstrated. All of the observed changes in facies seem to be attributable to distance from shoreline and source of sediments rather than to deposition in distinct "troughs of sedimentation." The study of the bentonite beds and associated strata therefore verifies the concept of the Lowville-Moccasin-Bays sequence as advanced by Butts in 1928.

As both the upper and lower limits of the Eggleston formation as found in the type section have been found to vary in age from locality to locality within the region it seems better to use this as the name of a facies rather than of a formation. The status of the Eggleston as a formation is further weakened by the fact that a considerable disconformity is present within this formation throughout the region. This disconformity occurs a few feet below the bentonite bed herein designated as bed V-7 and is a readily recognizable horizon throughout the region. For this reason this seems the most useful and logical position in the section to draw the boundary between the Moccasin and the Martinsburg formations, that is, the Black River-Trenton boundary. This is the boundary used by Hubbard and Croneis in the Narrows section and also by Butts[22] in the section in Little Moccasin Gap. The value of this hiatus is greater in the more southerly and southwesterly sections and there is a possibility that there was no interruption of sedimentation in the Narrows area. Apparently the restriction of the Black River sea began earlier in the southwest and the sea withdrew to the northeast. Evidence found during a study of the bentonite beds of central Tennessee and central Kentucky also pointed to the withdrawal of the Lowville sea in a northerly and northeasterly direction.

It is a significant fact that the period of greatest volcanism, as indicated by more numerous bentonite beds, occurred at the same time that this withdrawal of the sea was taking place, or slightly thereafter. There is thus suggested a correlation between volcanic eruptions and other crustal disturbances which are evidenced by the shifting and restriction of the areas of marine sedimentation.

VALUE OF BENTONITE BEDS IN INTERPROVINCIAL CORRELATION

The value of bentonite beds in correlations over single geologic provinces of more or less limited area has been adequately demonstrated. The correlations in southwestern Virginia which have been discussed in this paper afford an excellent example of such intraprovincial correlation. It is but natural to inquire if these bentonite beds are equally useful in interprovincial studies and correlations. Theoretically they should prove of great value in the solution of stratigraphic problems involving such correlations, but practically, however, they have not proved to be extremely useful.

Many of the correlations which have been made have depended on the recognition and identification of sequences of bentonite beds rather than of individual horizons. In practice it has frequently proved impossible to establish the identity, beyond all possible doubt, of a given bentonite bed outside a single geologic province. Close correlation even between adjacent provinces has in many instances been difficult or impossible. Especially is this true where there apparently has been interfingering of bentonite beds between the provinces. A specific example may be cited.

[22] Butts, Charles, Geologic map of the Appalachian Valley of Virginia with explanatory text: Virginia Geol. Survey Bull. 42, pp. 19-21, map, 1933.

Bentonite beds have been found in northern Virginia. (See Fig. 8.) They occur in the Chambersburg formation and in the basal part of the Martinsburg formation. They are, therefore, of essentially the same age as those found in southwestern Virginia, yet exact correlation between the two areas is not yet possible. It is hoped that additional study of the heavy minerals of the bentonite beds may make possible the precise identification of individual beds by means of their petrographic characters. Until this is feasible it must be admitted that with certain noteworthy exceptions the greatest usefulness of the bentonite beds is in intraprovincial correlations such as those in southwestern Virginia.[23]

DETAILED SECTIONS

The present study of the Ordovician bentonite beds has made possible detailed correlations of a large number of stratigraphic sections. Many of these sections have not been previously described. Owing to lack of space only a few of these sections are given in this paper. Detailed measurements of all the sections mentioned or shown in Figs. 6-8 are on file in the library of Princeton University.[24]

Section (No. 153) of the bentonite sequence in the Trenton member of the Martinsburg formation and in the Moccasin formation near Tazewell, Virginia

This section is one of the two best, if not the best, sections of the lower Trenton and upper Moccasin to be found in southwestern Virginia. The exposure is at the side of the road leading along Plum Creek into Thompson Valley, approximately 3 miles south-southwest of Tazewell, Tazewell County, Virginia. A continuous exposure of nearly 400 feet is at hand and one-quarter mile to the west this sequence is repeated in reverse order as the strata are again exposed in the western limb of a shallow syncline.

	Thickness Ft.	In.
Martinsburg formation, Trenton member:		
Limestone, gray, shaly, in beds 2 to 5 inches thick, commonly very fossiliferous, separated by brown shaly partings. In the upper portion of the section the shaly partings become thicker and more numerous, whereas the limestone beds become thinner and less numerous. Some of the shale beds become black and slaty in this portion of the section..........	60+	

[23] These remarks are to be construed as a recognition of the limitations of "correlation by means of bentonite beds" rather than as an attempt to minimize the usefulness of this method in stratigraphic studies.

[24] In the writer's dissertation on "The geographic distribution and stratigraphic occurrence of Ordovician altered volcanic materials in eastern North America."

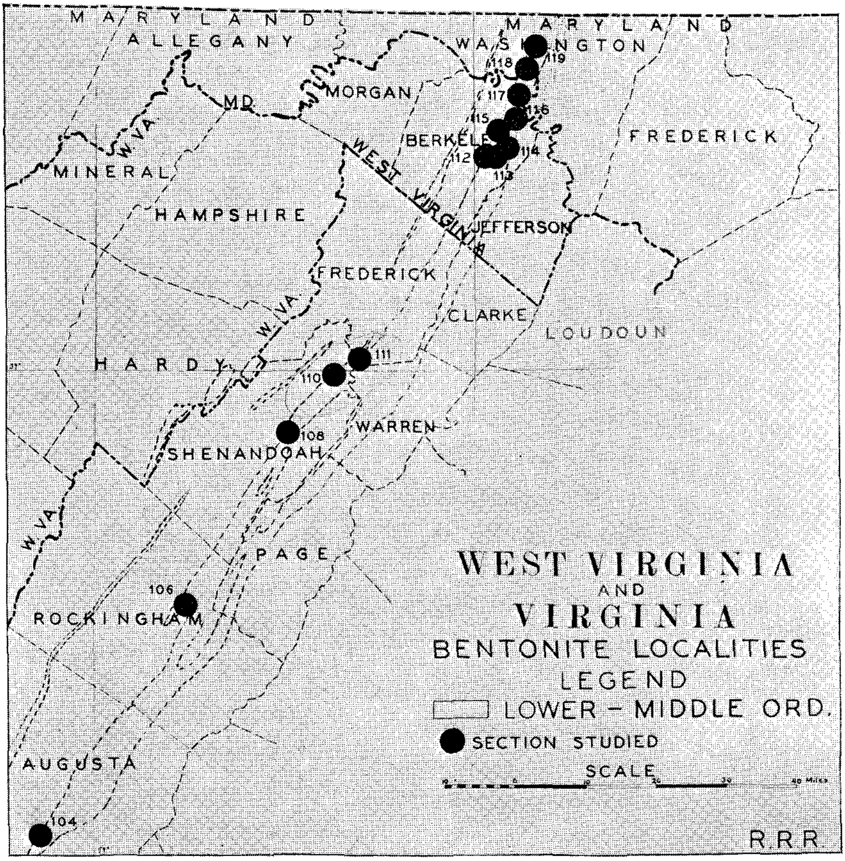


FIGURE 8.—Index map showing bentonite localities in northern Virginia and adjacent parts of West Virginia and Maryland. Numbers refer to described sections, as follows: 104, beside U. S. Highway 11, 5 miles south of Staunton; 106, about 7 miles south and one-fourth mile east of New Market; 108, in creek bed at east edge of Woodstock; 109 and 110, Tumbling Run, Fishers Hill section, about 1.5 miles south-southwest of Strasburg; 111, beside U. S. Highway 11, 3 miles north of Strasburg; 112, beside State Highway 9 just east of bridge at southeast edge of Martinsburg, W. Va.; 113, beside State Highway 9, half a mile east of section 112; 114, east bank of Opequon Creek near road forks half a mile south of Blairton, W. Va.; 115, quarry of the North American Cement Corp., 3 miles northeast of Martinsburg, W. Va.; 116, one-fourth mile west of Bedington, W. Va.; 117, beside U. S. Highway 11 at Falling Waters, W. Va.; 118, at Pinesburg Station, Md.; and 119 at Wilson, Md.

	Thickness Ft.	In.
Limestone, gray to black, slaty, thin bedded, non-fossiliferous	12	
Bentonite (V-13), arkosic; contains numerous molds of *Rafinesquina, Plectambonites,* and abundant *Dalmanella*		7
Limestone, typical Trenton facies, light gray, coarsely crystalline, very fossiliferous, in beds, 4 to 8 inches thick, with very abundant *Dalmanella;* weathered surfaces show many silicified fossil fragments in relief	11	
Bentonite (V-12)		6–8
Limestone, as above, typical Trenton facies	2	
Shale, brown, calcareous, in part covered (not exposed on eastern limb of the syncline)	10±	
Shale, dark green, hackly		4
Bentonite (V-11), strong orange color		6
Shale, drab to dark green, calcareous	1	6
Bentonite (V-10)		3
Limestone, dark blue to drab, weathering brown, with characteristic vertical jointing, a typical "cuneiform" bed		9
Limestone, typical "cuneiform" bed	2	
Shale, dark green, soft		1
Limestone		1
Shale, dark green, soft		1
Limestone, typical "cuneiform" bed	1	10
Bentonite (V-9)		½
Shale, dark green, calcareous		1½
Bentonite (V-8)		1½
Limestone, massive, blocky, typical "cuneiform" bed		10
Limestone, massive, blocky, typical "cuneiform" bed	2	1
Shale, olive-green, hackly	1	2
Bentonite (V-7), lemon-yellow	1	6
Chert, dark brown, blocky, separates readily from limestone below		2–3
Limestone, massive, dense, bluish gray, unfossiliferous, with marked slickensiding *within the bed*	1	1
Moccasin formation:		
Limestone, impure, dark bluish gray, cobbly	1	
Bentonite (V-5), light green to greenish gray, locally thickened by movement along this bed, and with a		

	Thickness Ft.	In.
thin layer of slickensided calcite at the base of the bed		2–3
Limestone, bluish gray, cobbly, thin bedded	15	
Mud zone		10
Limestone, thin bedded, bluish gray, cobbly	6	
Limestone, shaly, with 2 inches of blocky, arenaceous limestone at the base	1	
Shale, calcareous		8
Bentonite		1
Shale, brown, calcareous		2
Bentonite (V-4), light lemon-yellow, locally thickened by squeezing; sheared, with very waxy luster	3	6±
Limestone, dense, gray, upper surface silicified to a brown chert which has a smooth white upper surface. On this chert are preserved gentle ripple marks whose wave length is 25 inches and whose amplitude is 1½ inches	1	10
Limestone, gray to bluish, thin bedded	16	
Limestone, argillaceous and shaly		10
Mudrock, greenish drab to gray, calcareous, pinkish upper beds	15	
Shale, gray to drab		4
Bentonite (V-3) consists of several layers of light-colored bentonite alternating with reddish soapy shale that may be bentonitic. The exposure of this bed on the western limb of the syncline shows it to consist of:		
Yellow bentonite ... 4 inches		
Drab, bentonitic limestone ... 1 "		
Yellow bentonite ... 1 "		
Red shale ... 2 "		
Yellow bentonite that is colored red a few inches above the base ... 19 "		
	2	3±
Limestone, massive, dove-colored, with the upper surface silicified to a green chert 1 foot thick		11
Limestone, in beds 3 to 5 inches thick, dove-colored to gray, some bluish gray; typical Lowville facies in Virginia	5	
Mudrock, a red argillaceous limestone with interbedded red shale. Typical Moccasin facies at the base of the member, but much lighter in color in upper		

	Thickness Ft.	In.
portion where there is a transition from the red earthy mudrock to pink and dove-colored limestones	44	6
Shale, red, very soft		3
Mudrock, red, calcareous, typical Moccasin facies	11	
Bentonitic shale (V-2), pink to greenish white		3
Mudrock, red, calcareous, typical Moccasin facies	37	
Shale, red, very soft		3
Mudrock, red, calcareous, typical Moccasin facies	26	6
Bentonite (V-1), pink to greenish white, mixed with overlying 3 inches of green shale; this bed caps the small local anticline	1	1
Mudrock, red, calcareous, typical Moccasin facies	12+	

Section (No. 93) of the Trenton member of the Martinsburg formation and of the Moccasin formation in the Narrows of New River, Giles County, Virginia

Probably one of the most complete sections of the middle Paleozoic strata to be found in Virginia is that exposed along New River in the "Narrows," a deep gorge which it has cut through East River Mountain. A new State highway (No. 8) which has been built along the northeast side of New River exposes a continuous section, a portion of which is described in the following section. This locality is 1.7 miles north of Narrows, Giles County, Virginia.

		Thickness Ft.	In.	
	Martinsburg formation, Trenton member: 142'			
58	Limestone, thin bedded, gray, fossiliferous, with shaly partings			
57	*Bentonite,* very white		1–2	142 1/4
56	Limestone, coarsely crystalline, in beds 1 to 8 inches thick; rather impure, at places very fossiliferous	22		142
55	Shale, black, fissile		4	120
54	Limestone, coarsely crystalline, in beds 1 to 8 inches thick; rather impure, at places quite fossiliferous	37	6	119 3/4
53	Limestone, single bed, somewhat arenaceous	1	6	81 1/4
→ 52	Limestone, very fossiliferous, almost a coquina; weathered surfaces show abundant silicified fossil fragments in relief	6	6	79 3/4
→ 51	Limestone, very shaly	17		73 1/4
50	Limestone, a single bed, gray, dense, non-fossiliferous	1		56 1/4

	Thickness Ft.	In.
Limestone, coarsely crystalline, gray, blocky, in beds 2 to 6 inches thick; fossils scarce; interstratified with 2-inch beds of blocky, calcareous shale	8	
Shale, drab to black, deeply weathered	1	
Bentonite	1	
Chert, ripple marked; wave length of the ripples is 26 inches and amplitude is from 2 to 3 inches		2–3
Shale, calcareous, thin, blocky	15	6
Bentonite		6
Shale, brown, weathered	9	
Limestone, gray, coarsely crystalline		4
Shale, greenish to drab		8
Bentonite, dark greenish yellow		8
Chert, much weathered		2–4
Shale, green		8
Mud zone		2
Bentonite		1–2
Shale, greenish yellow		9
Limestone, blocky, typical "cuneiform" bed	4	
Shale, thin, blocky, brown		6
Limestone, blocky, typical "cuneiform" bed	1	10
Shale, green		7
Bentonite		¾
Shale, greenish to drab, weathers, brown, calcareous, "cuneiform"		11
Bentonite		½
Limestone, shaly, in part showing "cuneiform" jointing	1	
Shale, thin, hackly		2
Limestone, very shaly; upper part has typical "cuneiform" jointing; lower part is a blocky calcareous shale	3	8
Shale, olive-green, hackly	1	3
Bentonite (V-7)	1	3
Limestone, gray, dense, non-fossiliferous bed capped by 2 inches of chert	1	6

Moccasin formation:

	Ft.	In.
Limestone, gray to dove-colored, cobbly	2	4
Shale		4
Limestone, gray, thin bedded, shaly	5	
Mudrock, calcareous, greenish; similar to the red facies	24	

	Thickness Ft.	In.
Bentonite	1	6
Chert, in 1-inch layers		2
Shale, green to yellow, arenaceous, possibly a deeply weathered mudrock; some beds are a bright lemon-yellow when deeply weathered	1	6
Limestone, gray, coarsely crystalline		5
Shale, greenish yellow, soft	4	
Greenish mudrock, deeply weathered	18	
Shale or mudrock, weathered, partly covered	10	6
Sandstone, blocky, in 2 layers		2
Bentonite, lemon-yellow, waxy, talcose	1	10
Chert, upper surface very smooth and very white, ripple marked; wave length of ripples is 13 to 14 inches		2
Limestone, massive, drab	1	
Mudrock; greenish, impure argillaceous limestone that weathers to a soft greenish-yellow mud	34	
Bentonite		4
Limestone, deeply weathered, argillaceous, drab to greenish	1	
Mudrock, red, calcareous, typical red facies grading upward through a transitional zone 1 foot thick into the overlying greenish phase	14	6
Sandstone, greenish to olive	1	
Mudrock, typical red facies	10+	

Section (No. 86) of the Trenton member of the Martinsburg formation and of the Moccasin formation on west slope of Rich Mountain, Tazewell County, Virginia

The following section is found on the west side of Rich Mountain at the side of highway No. 136 which leads from Five Oaks to Burkes Garden, approximately half a mile east of Cox's Store, which is located at the junction of State Highways No. 87 and No. 61.

	Thickness Ft.	In.
Martinsburg formation, Trenton member:		
Shale, drab, weathers to brown mud	6	
Bentonite, light lemon yellow		3–4
Shale, calcareous, and thin shaly limestones	9	6
Shale, very thin and fissile	1	

	Thickness Ft.	In.
Bentonite, distinct orange, thickness varies because of local squeezing		2–11
Shale, bluish green	1	10
Shale, blocky and arenaceous		2½
Shale, dark gray		5
Limestone, argillaceous, blocky	2	
Limestone, drab, argillaceous, typical "cuneiform" jointing	2	4
Shale, green		2
Bentonite, squeezed		2–4
Limestone, blocky, "cuneiform" jointing		7
Bentonite		¾
Limestone, blocky, "cuneiform" jointing	2	
Shale, bluish gray	1	6
Shale, greenish, hackly	1	
Bentonite	1	11
Chert bed with ripple marks; wave length of ripples is 25 inches		4
Moccasin formation:		
Shale, blocky, green, calcareous	2	
Bentonite		2±
Shale, green, blocky		6±
Shale, calcareous	1	
Limestone, gray, shaly		3
Shale	1	
Limestone, greenish drab, argillaceous, a mudrock	17	
Bentonite		11
Limestone, a massive, blocky bed capped by 2 inches or more of chert. This chert has a very smooth, white, ripple-marked upper surface	1	
Shale	3	
Covered interval.		
Mudrock, typical red facies	50+	

Section (No. 82) of the Trenton member of the Martinsburg formation and of the Moccasin formation near Gate City, Scott County, Virginia

The type locality for the Moccasin formation is Big Moccasin Gap, 1 mile east of Gate City, Scott County, Virginia. The following section was measured at the side of the Southern Railroad through the gap.

	Thickness Ft.	In.
Martinsburg formation, Trenton member:		
Shale, calcareous and slaty, with interbedded impure, thin limestones		
Bentonite	1	
Limestone, greenish gray, capped by a chert bed 2 inches thick	6	
Covered interval showing some ledges of shaly limestone	33±	
Bentonite, orange-colored		10
Limestone, brown to drab		4
Limestone, with typical "cuneiform" jointing	2	2
Shale		1
Limestone, blocky		3
Shale		1
Limestone, with typical "cuneiform" jointing	1	5
Bentonite		1
Limestone, "cuneiform" jointing, grading downward into a green, hackly shale	1	3
Bentonite, very light creamy yellow	1+	
Chert		1
Limestone, greenish drab	1	
Moccasin formation:		
Mudrock, greenish, calcareous, crumbly	7±	
Bentonite, light yellow	2±	
Chert, dark gray, with many fractures filled with pink calcite		6
Mudrock, a greenish, crumbly, impure, argillaceous limestone	15±	
Bentonite, consists of several distinct layers of alternating red and yellow materials; undoubtedly the bed which has been designated as V-3:		
Yellow bentonite .... 2+ inches		
Drab limestone 1		
Yellow bentonite 2		
Red shale 2		
Yellow bentonite 6		
Red shale 5		
Yellow bentonite 2		
——————	1	8+

	Thickness Ft.	In.
Limestone, blocky bed, rather shaly at base; capped by 1 inch of gray-green chert	2	
Shale		1
Mudrock, red, calcareous, typical Moccasin facies	35	
Fault.		

Section (No. 80) of the Trenton member of the Martinsburg formation and of the Lowville formation, near Jonesville, Lee County, Virginia

The following section is exposed along State Highway No. 64, where it crosses Wallen Ridge, approximately 3 miles southeast of Jonesville, Lee County, Virginia. Section measured from east to west.

	Thickness Ft.	In.
Martinsburg formation, Trenton member:		
Limestone, a thick series of thin-bedded, gray, fossiliferous, shaly limestones		
Bentonite	1	
Chert		2
Limestone, gray, shaly, partly covered	30±	
Limestone, gray, coarsely crystalline, abundantly fossiliferous, with *Dalmanella fertilis, Rhyncotrema increbescens, Herbertella* sp., *Plectambonites,* etc. Upper portion more shaly and thin bedded than lower; typical Trenton facies for this area	65	
Mud zone, possibly a fault		3
*Limestone, cobbly, shaly	2	
*Limestone, massive, gray	1	6
*Shale, greenish	1	9
*Limestone, very cobbly	3	
*Limestone, drab, dense, massive	3	8
*Shale	3	6
**Bentonite*	1	10
*Chert		4
*Limestone, dove-colored, massive	3	
Mud zone, possibly a fault		10
Mudrock, greenish, calcareous	33	
Shale, greenish		6

*In this section those beds marked with an asterisk may be a repetition of beds found near the base of the Martinsburg as used above. The similiarity between the bentonite bed so marked and the bed found in the gully is quite notable. The section needs further study in order to check this resemblance.

	Thickness Ft.	In.
Mudrock, greenish drab, massive	1	8
Limestone, gray, dense, in 1-inch beds alternating with beds of drab, fissile shale 2 to 3 inches thick	2	
Limestone, lenticular bed		2–3
Shale, drab, fissile, calcareous		8
Limestone, coarse, gray, fossiliferous		2
Shale, brown to drab, with a few thin limestone lenses		10
Limestone, very siliceous, abundant *Rafinesquina* sp.		1½
Bentonite, eroded to form gully	1	11
Chert, blocky, brown, upper surface checked; exposed on west side of small gully		4
Limestone, single bed	1	4
Lowville formation:		
Limestone, dove-colored, thin bedded, with numerous fucoids, crinoid rings, small gastropods, etc.	10	
Limestone, very thin and shaly, bluish gray	2	
Limestone, dove-colored, in beds 8 to 10 inches thick, fossiliferous; typical Lowville for this area	30	
Limestone, dove-colored, blocky, single bed	2	
Limestone, blue gray, thin bedded, somewhat shaly in upper portion	20	
Mudrock, greenish drab, calcareous, non-fossiliferous	40	
Limestone, massive, bluish gray	2+	

MINERALOGY OF TWO VIRGINIA MARBLES

BY

JANE KESSLER

STATE COMMISSION ON CONSERVATION AND DEVELOPMENT
VIRGINIA GEOLOGICAL SURVEY
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Mineralogy of Two Virginia Marbles[1]

By Jane Kessler[2]

In Grayson County, about a mile and a half southwest of Grant, there is a marble which is cut by a number of pegmatite dikes. The location is shown on the geological map of Virginia, published by the Virginia Geological Survey in 1928. It appears to underlie an area of about half a mile in diameter, but the outcrops are few and the mapping is uncertain. It is surrounded chiefly by pre-Cambrian granite-gneiss and some greenstone. The best exposure is in a quarry, the face of which is approximately 30 feet across by 15 feet high. The marble mass inclines about 30° SE. and is overlain by 3 feet of slightly metamorphosed and very much weathered shale. The dikes, which are sharply defined and range from a few to 18 inches in thickness, show what appear to be definite contact effects on the limestone through a width of 1 to 9 inches. The pegmatites shown in the quarry in general maintain a fairly uniform width for their entire length although there are some which have irregular swellings and pinchings.

The pegmatite consists essentially of albite, microcline, microperthite, orthoclase, and quartz with accessory diopside, titanite, and pyrite. The feldspars show good cleavage and are light pink, with the exception of the albite which is white. The quartz is gray and has a glassy luster. The feldspars and quartz are not in distinct crystals but are intergrown and seem to represent the same period of crystallization. The diopside occurs in green prismatic crystals up to half an inch in length. The titanite is in minute crystals and grains easily distinguished with a hand lens. A small amount of pyrite is present in grains and striated cubes. Since the diopside, titanite, and pyrite are in fairly well formed crystals and occur imbedded in the feldspars, it appears that they are early crystallizations.

The contact zone contains, as secondary minerals in the calcite, diopside, clinochlore, tremolite, both the columnar and fibrous varieties, titanite and pyrite. The calcite, which is light gray and coarse grained, some of the rhombs being an inch and a half in length, shows secondary twinning in the hand specimen. Diopside and tremolite are abundant in small, distinct, but incomplete crystals. The two varieties of tremolite seem to indicate two modes of origin. The white, fibrous variety consists chiefly of slip fibers although there is some cross fiber present.

[1] Read before the Virginia Academy of Science, Section of Geology, Lexington meeting, May 1, 1936.
[2] Department of Geology, Virginia Polytechnic Institute.

The chlorite is in small plates, and the titanite and pyrite are present in greater quantity than in the pegmatite.

Outside of the contact zone the texture of the marble is variable, being fine to coarse grained, but nowhere as coarse as that at the contact. The color varies from pink to white. The minerals other than calcite are chiefly clinochlore, phlogopite, and diopside and locally titanite, pyrite, and tremolite. The clinochlore, which occurs in green transparent plates, larger than those at the contact, appears to be not an alteration of a previous mineral but an original crystallization as clinochlore. The diopside is in small, light green, transparent to translucent crystals. Phlogopite is the only mineral conspicuous in the outside marble which is absent in the contact zone.

The mineral differences in the two zones are chiefly in character and relative abundance rather than in species. Tremolite and diopside are more abundant in the contact zone. It would appear then, that regional metamorphism and contact metamorphism have produced similar minerals, or that contact metamorphism has only slightly modified the regional metamorphic effects. Part of the regional metamorphism occurred later than the contact metamorphism. This is indicated by the character of the quartz and feldspars in the pegmatite and the calcite at the contact, all of which show strain effects under the microscope.

In contrast to the Grayson marble there is a marble in Patrick County, several miles south of Woolwine, with no associated intrusive rocks, which shows quite a different mineralogy. This marble, which is not shown on the geological map of Virginia, is surrounded by pre-Cambrian gneiss and schist. Regional metamorphism in the marble has produced a marked banding which gives it the appearance of a gneiss. The dark bands carry biotite, orthoclase, quartz, albite, pyrrhotite, and titanite. The feldspars, quartz, and titanite can be distinguished only in thin section. The light bands are dominantly white and pink, medium-grained calcite, locally containing pink garnet, pyrrhotite, and titanite.

It is interesting to note in these two marbles that aside from secondary calcite there are no metamorphic minerals in common. If the minerals outside the supposed contact zone of the Grayson marble have not been affected by the intrusions, the difference in the minerals in the two marbles might be explained by a difference in impurities of the original limestones or to different conditions during metamorphism.

Both of these marbles are quarried and ground for agricultural lime which is sold locally.

VIRGINIA'S MINERAL CONTRIBUTION TO THE CONFEDERACY

BY

ROCKWELL S. BOYLE

STATE COMMISSION ON CONSERVATION AND DEVELOPMENT
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Virginia's Mineral Contribution to the Confederacy[1]

By Rockwell S. Boyle[2]

Following the election of Lincoln to the presidency in 1860, considerable agitation developed in the states south of the Potomac, to start a movement that had been fostered in the event of that election. There was much concern in regard to the part that Virginia would take in this movement if it should be started. There were many reasons for this concern. In 1860, Virginia had political power, man power, and industrial power scarcely rivalled by other Southern States. Mineral resources played a large part in this superior industrial power. Virginia produced relatively large amounts of iron, lead and coal. The other Southern States looked to Virginia, partly because of her wealth of natural resources. In many ways, the support of Virginia was indispensable to the states that contemplated the forming of a new republic.

A strange thing about the secession is the fact that few men thought that war was pending. They had an implicit faith in peaceful secession, so did not make preparations until the war clouds actually began to gather. The John Brown raid was the first incentive for fortification. Then some of the states began to make preparations. Strangely enough it was the government at Washington that began to make reinforcements in the arsenals of the South, but the guns sent were of old types, most of which had been discarded and replaced in Northern arsenals. The governments of several Southern States began to make some preparations and foreign importation of some war materials was made. The Bellona and Tredegar iron works in Richmond had been engaged to some extent in the making of arms. The government factories at Harper's Ferry had been used for the reconditioning of arms. Hence, the South had some munitions when hostilities broke out, so that their manufacture was not of immediate importance.

Almost unprepared, the South was thrown into the conflict. Iron to manufacture arms did not become important until late in the war. The great need of iron was for railroads. This need for iron was made more critical by the fact that the furnaces of the South had depended on charcoal to the extent that wood readily accessible to the furnaces had been exhausted and charcoal or wood had to be brought

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[1] Read before the Virginia Academy of Science, Section of Geology, Lexington meeting, May 1, 1936.

[2] *Washington and Lee University.*

long distances. Coal had been so sparsely used that it was thought too expensive to spare men and money to mine it. Mining conditions in the coal fields near Richmond were also difficult. Consequently, at the outbreak of the war coal mining in the Richmond Basin was practically stopped. Moreover, transportation had been so poorly developed that even where much iron was found there was scarcely a way of producing it and where good furnaces were located, deposits of iron had been exhausted so that the ores had to be hauled long distances in wagons.

Had transportation been adequately developed along James River, vast areas of coal, wood, iron, lead, and food materials would have been available for manufacture and distribution at Richmond. Unfortunately such was not the case, and with the scarcity of man-power and money, the South was unable to undertake at this late hour the building of railroads. Every effort was made to keep the railroads in condition, both from depredations of the enemy and from ordinary depreciation. For this use came the great need of iron.

It was estimated that the South would need 50,000 tons of rolled steel a year to keep the railroads in repair and to make extensions. How was this need to be met? Georgia, Tennessee, Alabama and Virginia were the only iron-producing states in the Confederacy. By the early part of 1864 the inroads of the enemy had almost entirely stopped production in Georgia and Tennessee. Despite harassment by the enemy, Virginia still had, as late as November, 1864, 18 furnaces in operation.

Although the railroads needed annually 50,000 tons of iron, the combined operations of the Southern furnaces could make only 20,000 tons, exclusive of all other work. The mills of Augusta, Georgia, could produce 12,000 tons, but they were also occupied in the manufacture of brass, and thus did not have a capacity production of iron. The Tredegar Iron Works in Richmond produced almost 8,000 tons annually.

To what extent did Virginia aid the Confederacy with iron? Plans were made at one time for people to collect scrap iron from their premises and allow the government to ship it to the furnaces at Richmond. The furnaces were working to capacity on iron ore, the railroads were fully engaged, and so the plan did not materialize. There was some production of iron in Alabama, but this was not very helpful, as the iron had to be shipped a long distance to rolling mills.

The Tredegar Iron Works, which played a large part in the history of Richmond, was able to make Virginia the leader in iron production. In the first year of the war it made and put into service 165 heavy guns of first quality. It kept up production through the war, although the Confederacy often had difficulty in placing the guns where needed.

The Tredegar Iron Works outfitted in the first year of the war, the first iron-clad vessel of American navies, the Merrimac. The heroic efforts of the Tredegar works, fraught with many exciting episodes, continued through the war. Hence, during the war Virginia was almost the sole producer and manufacturer of iron.

Virginia had been mining lead, not wholly for shot, since 1750 when the Chiswell mines at Austinville were opened. Oddly enough the Chiswell mines were acquired by the Union Lead Mining Company in March, 1860. This company produced shot for the Confederacy to fight "The Union."

For the decade 1858-1868 the lead mines of Wythe County produced about 6,750,000 pounds of lead. During the four years of the war these mines produced nearly 2,350,000 pounds of lead for the Confederacy.

As the Faber lead deposits in Albemarle County, discovered in 1849, were not worked regularly, the Confederate Government took charge of operations on a royalty basis. Royalty was paid to the owners of the land on slightly more than 7,000 pounds of lead.

Both the Faber and Wythe County mines were operated until 1864. When Sheridan crossed the Blue Ridge from the Valley, in the raid of 1864, the miners at Faber promptly abandoned the mine, and it was severely damaged. The mines in Wythe County were put out of commission by a Union raid in December of the same year. This was so close to the end of the war that neither resumed operations before the surrender at Appomattox.

Even this great amount of lead was insufficient and many means were taken to obtain more. Aside from the lead that had been brought into the South before the war and smuggled lead, Virginia was the only lead producer in the Confederacy. With crippled transportation, one wonders why the government smelted lead and manufactured bullets at Petersburg when it apparently would have been easier to transport shot than the ore from the mines.

In 1862, there occurred somewhat of a salt famine in the South. Great amounts of salt were needed for the preservation of food for the army as well as for the home. With the shortage of labor as a result of the demands of the army, the production of salt in the maritime areas was almost stopped. Then the supply of salt gave out. Finally the brine springs and wells of the North Holston Valley in southwestern Virginia were developed by the Confederate Government. Distribution was carefully regulated, and thus the need was met in part until some of the other Southern States could develop salt wells. Virginia continued to be the most extensive producer. These salt deposits had been known since 1666 and had been worked sporadically through the 18th century until regular mining was begun in 1836.

A substance essential in making gun powder is nitrate. An alarming shortage of it soon developed. Mills at Augusta, Georgia, were producing powder with sulphur and saltpeter which at first were well supplied, principally from stores that were in the South. Since long before the Revolution nitrates had been known and mined in some of the limestone caves of the Appalachian Valley. Most of the best deposits had been mined before the outbreak of the War between the States.

Smuggling of saltpeter through the ports of Florida was attempted, though that was precarious. From this source the South was able to obtain about half the needed amount. More had to be found and Virginia again came to the rescue, although not by herself. The Confederate Government set up, for the emergency, the Niter and Mining Bureau to apply new methods and to make extensive search to obtain more nitrate from known cave deposits as well as from new deposits that might be found. Although not chemically the same as saltpeter, the substance found in the caves was a calcium nitrate in sufficient concentration to be used for gunpowder. This meager source supplied the remainder of the needed nitrate, and for the short period to 1865 the supply of gun powder was adequate. This supply would not have lasted indefinitely.

It has been noted that the mining of coal practically ceased during hostilities. In 1861 and 1862, the annual production of coal in Virginia reached a new height of 445,000 short tons, but from 1863 through 1866 production dropped to 40,000 tons, or to about 10 per cent of the former output. The Merrimac was chiefly a coal-burning vessel and it was reported that the supply of coal for its encounter with the Monitor came from new mines in Montgomery County. Most of the meager coal supply of Virginia during these years was for use on railroads, although a little was used in the iron mills.

In summary, lead and iron were the greatest mineral contributions of Virginia to the Confederacy. Lead was indispensable, not being obtainable elsewhere. Virginia's supply of salt, nitrate, and coal were very important contributions, but they were not indispensable. Other mineral industries were developed in Virginia during the war, but as the chemistry of warfare then did not involve much more than the manufacture of gun powder, there was little need for the other mineral resources.

Slightly more encouraging than recording what Virginia did to prolong the war with the above-mentioned resources, is to note what the war did for mineral resources of Virginia besides destroying mines, furnaces, and mills. At the end of hostilities the South was as destitute of money as a section could be. The first result of this financial distress was to reduce the price of property almost beyond belief. This naturally brought about much speculation by foreign capital. It was known that

Virginia contained considerable mineral wealth and it was to this field that much capital was attracted.

The mining of zinc in Virginia is one industry that can be dated from the War between the States. Since 1750 lead had been mined along New River; zinc had been neglected or discarded. During the war the Confederate Government asked for a shipment of the "new" mineral to be sent to the lead furnaces at Petersburg. Several tons were sent and smelted and then nothing more was heard of it. After the war, arrangements were made to ship zinc ores from the Austinville mines to the Lehigh Zinc Works at Bethlehem, Pennsylvania, and to the Mercer Zinc Works at Trenton, New Jersey.

In 1866 David S. Forney, an artist, came from Pennsylvania to southwestern Virginia. Being an amateur mineralogist, he began to look for zinc ores in association with the lead ores. He found them at Bertha, but development was slow. Finally, in 1879 some of the ore was shipped to Providence, Rhode Island. Almost at once, due to the high grade of the ores, extensive developments were begun at Bertha and a furnace was built at Pulaski by Northern interests. This resulted in the origin and development of the Bertha Mineral Company.

In 1834 the gossan of the pyrite deposits in Louisa County was first worked, mostly for iron and to a less extent for copper. By 1861 the limonite at the Sulphur mines was exhausted. Some limonite was obtained at the Arminius mine during the war. In 1865 a New York concern bought the Arminius mine and began to work it extensively for sulphur and copper. This development, due in large part to the devaluation of property, led to speculation and resulted in the development of some of the largest pyrite mines in America.

The rapid progress in the mining of coal and iron and the growth of commerce and transportation were also direct results of the war. A renewed interest in the gold deposits also stimulated important commerce in parts of the Piedmont area. Then followed interest in many phases of mineral development in the State.

STRATIGRAPHY AND STRUCTURE OF THE MARION AREA, VIRGINIA

BY

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STATE COMMISSION ON CONSERVATION AND DEVELOPMENT

VIRGINIA GEOLOGICAL SURVEY

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Stratigraphy and Structure of the Marion Area, Virginia[1]

By Byron N. Cooper[2]

ABSTRACT

The Marion area, in southwestern Virginia, contains sedimentary rocks ranging in age from Lower Cambrian to Upper Devonian, inclusive. Seventeen formations are recognized and stratigraphic breaks of major and minor importance are noted. The most notable hiatus involves uppermost Ordovician, Silurian, and Lower Devonian beds, all of which are missing in the Marion area. As a guide to stratigraphic interpretation, the paleontology of the formations is given consideration and the common guide fossils of each division are listed.

The structure of the rocks in this area is very complex. The region has suffered intense folding and overthrust faulting of the type particularly characteristic of southern Appalachian structures, but differing from the latter chiefly in containing a series of intersecting overthrusts and folds which have no definite orientation to the typical trend of regional structures. The structure of the region is discussed in detail and structure sections are included.

INTRODUCTION

LOCATION OF THE AREA

The Marion area lies in the geographic center of Smyth County, Virginia. (See Fig. 9.) It is bounded on the east and west by the 81° 30′ and 81° 40′ meridians, respectively. The northern boundary of the mapped area extends west of Mollies Knob[3] for a distance of 3½ miles and then turns southwest following along the lower slopes of the southeast flank of Walker Mountain. The southern boundary extends east and west along a line just north of Adwolf. The area mapped consists of a hexagonal plot of 58 square miles. The chief city is Marion, which is located in the east central portion of the area. Hungry Mother State Park is situated in the northeastern part of the area. The area is well drained by small streams that flow to the south-

[1] A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in the Department of Geology in the Graduate College of the State University of Iowa, June, 1935.

[2] Temporary assistant, Virginia Geological Survey.

[3] Mollies Knob used in this report refers to "Marleys Top" as shown on the topographic map of the Abingdon quadrangle and vice versa. Mollies Knob is the prominent peak in Hungry Mother State Park, about 3½ miles north of Marion. (See Pl. 16, A.)

west into the middle and north forks of Holston River. The Lee Highway, U. S. 11, extends westward across this area toward Bristol, Virginia, 47 miles to the southwest. The Bristol branch of the Norfolk and Western Railroad parallels the Lee Highway on its south side.

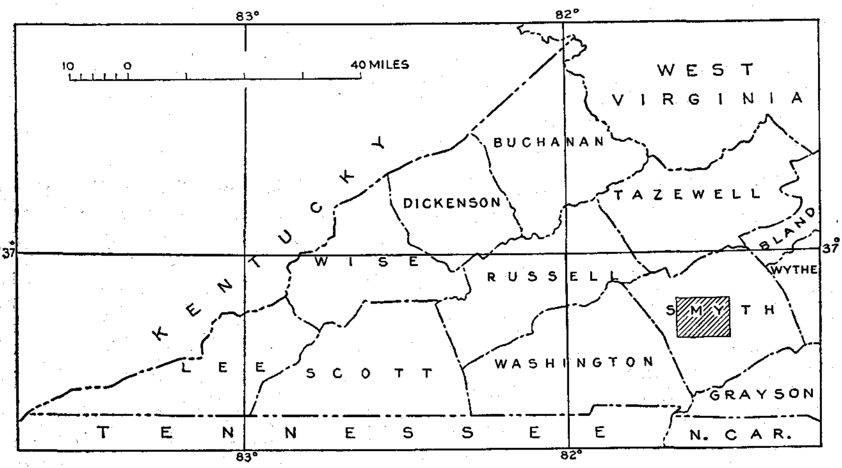

FIGURE 9.—Index map of the Marion area, Virginia.

SCOPE OF THE REPORT

The chief work on this project consisted of the making of an areal geologic map of the area. The stratigraphy and paleontology of the formations were given considerable attention with a view toward working out a geologic section for the region. The paleontology of the formations was studied and recorded only in an elementary way. The majority of the fossils collected by the writer has not been identified, because of the lack of facilities and because of the confused status of the paleontology of the Paleozoic rocks of the Appalachian region.

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The writer is greatly indebted to Dr. Charles Butts, for the generous help which he gave during the field work and during the preparation of the report. Without his assistance the present paper would not have been possible. The writer wishes to express his appreciation also for the help and the cooperation of Dr. Arthur Bevan, State Geologist, who through the Virginia Geological Survey, supplied the writer with the necessary equipment for field work. The writer is indebted to Drs. A. C. Trowbridge, J. J. Runner, and A. K. Miller, of the geology department of the State University of Iowa, for many

valuable suggestions given during the preparation of the report. Finally the writer is grateful to the people of Marion and vicinity for their hospitality and interest in the work.

STRATIGRAPHY

GENERAL STATEMENT

The sedimentary rocks mapped by the writer range in age from Middle Cambrian to Upper Devonian and comprise 17 formations. (See Pl. 14.) Metamorphism has not seriously affected the rocks, but, locally, shales have become talcose and limestones have been recrystallized. An igneous dike of questionable stratigraphic relation cuts shales and dolomites of Upper Cambrian age in a small area north of Marion. The rocks in the Marion area have an aggregate thickness of more than 10,000 feet. The Cambrian, Ozarkian, and Canadian rocks are chiefly shales and dolomites. The Ordovician system comprises a thick series of calcareous sediments with pure limestones at the base and calcareous sandstone at the top. A major stratigraphic break is indicated by the absence of uppermost Ordovician, Silurian, and Lower Devonian rocks in this area. Above this unconformity, the rocks are mainly fine clastics.

Conforming to the present usage of the Virginia Geological Survey, the writer recognizes the Ozarkian and Canadian systems and uses the terms Cambrian and Ordovician in a restricted sense. While many geologists object to the proposed rank of the terms, Ozarkian and Canadian, the writer believes that it is advisable that they be used until a more satisfactory classification is proposed.

CAMBRIAN SYSTEM

Paleozoic rocks older than the Rome shale crop out in a small area in the southeast corner of the Marion area. These rocks are the basal quartzites and the Shady dolomite of the Cambrian system. Because they are not involved in the particular structures of the Marion area, they are not discussed in this report.

ROME FORMATION

Name.—The Rome shale and equivalent beds with different names are known from Cumberland Valley in Pennsylvania to Georgia and Alabama. Rome was first designated as a formation name by Hayes[4] for this formation in Floyd county, Georgia. Prior to 1915, correlation of formations in the Appalachian region was not generally made.

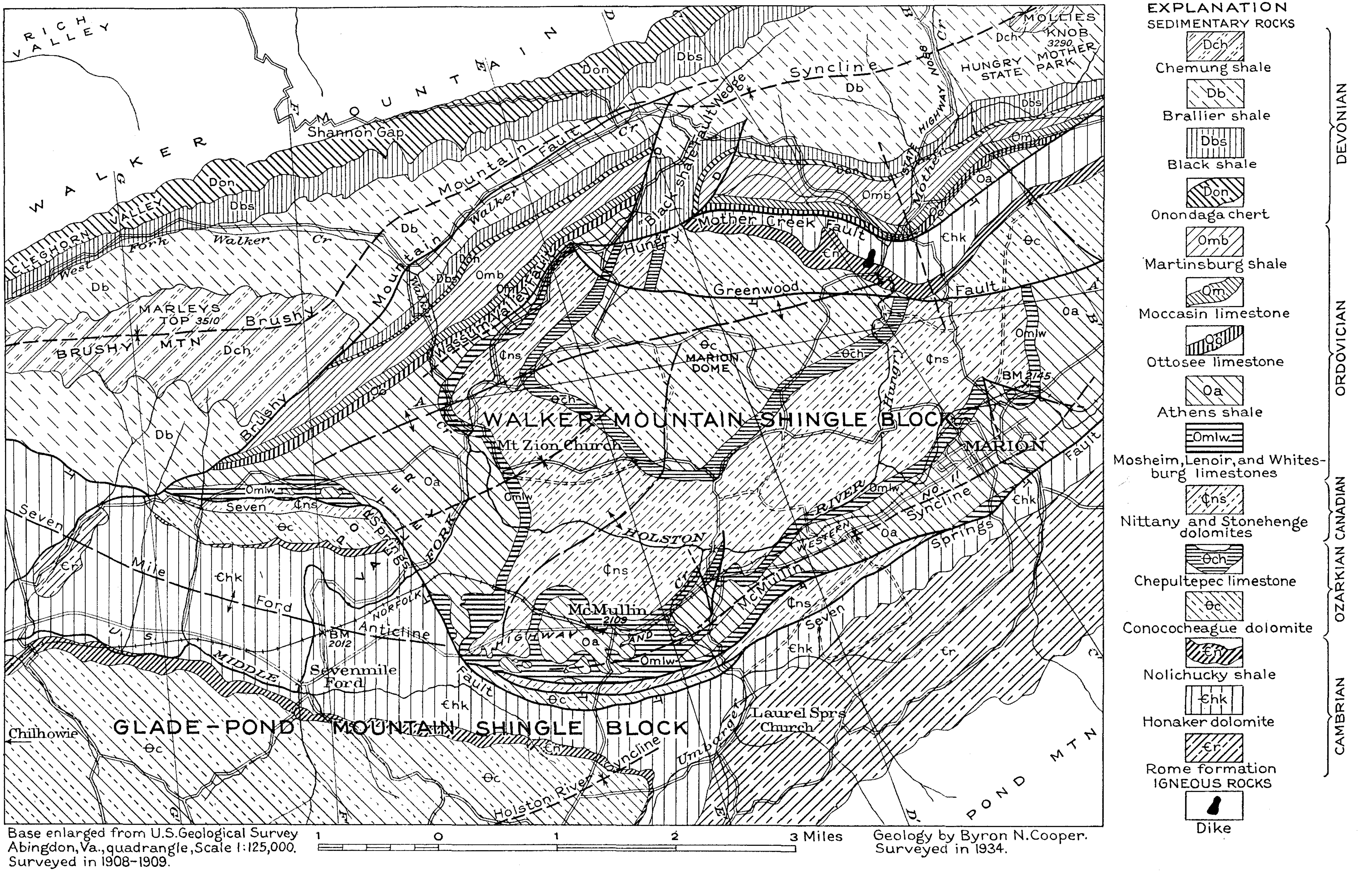
[4] Hayes, C. W., The overthrust faults of the southern Appalachians: Geol. Soc. America Bull., vol. 2, p. 143, 1891.

Each time a new area was studied formation synonyms were coined unknowingly. Of the many names which have been applied to the Rome formation, all but two, Rome and Watauga,[5] are now in disuse. The name Rome has priority over Watauga and, therefore, the latter should also be abandoned.[6] Butts[7] has suggested that the formation be called Waynesboro in belts northeast of Roanoke, and Rome in belts southwest of Roanoke. The writer conforms to this idea and calls the formation in the Marion area the Rome shale.

Description.—The Rome is everywhere a heterogeneous formation. In the Marion area, as in other areas, it is chiefly composed of red mudrock and sericitic green shales. (See Pl. 15, B.) The lower half of the formation is composed of red to chocolate-colored shales, siltstones, and thin sandstones and less commonly of green shales. The sandstone beds are calcareous and their thickness ranges from 1 to 18 inches. The predominance of red beds obscures the green shales on weathered outcrops. Near the bottom of the formation there is a distinct zone of buff-colored, calcareous shales and thin sandstone beds, about 60 feet thick. In the red and green shales the zones of red are from 6 inches to 40 feet in thickness, and the green zones are rarely more than 4 feet thick and are commonly less than 1 foot thick. Except for the upper 200 feet, the remainder of the Rome is very similar to the lower part; however, the green shales are more common and, in the upper 200 feet, there are two definite zones of buff-colored shale, each about 40 feet thick. The upper part of the formation is more calcareous than the lower part. Associated with the green shales are numerous thin bands of dense, blue-gray limestone and buff dolomite. The dolomite beds are easily mistaken for sandstone beds on weathered outcrops. Fine-grained sandstones, common in the lower part, are rare in the upper part, but where present they are much thicker and possess a singular rusty-brown color. Invariably associated with the limestone and dolomite bands in the upper 100 feet of the formation, are small nodules of pink chert which appear to be syngenetic concretions. The whole formation is thoroughly fractured. The beds have been minutely folded and locally thrust over one another. Metamorphism has been sufficient to develop schistose structures in many places.

Topography.—The Rome lends itself readily to the development of a knobby topography. Butts commonly refers to these knobs as "Rome hills." The second line of hills at the foot of Pond Mountain is developed on the Rome formation. Such knobs occur at the northwest foot of the Blue Ridge from Abingdon to Roanoke.

[5] Keith, Arthur, U. S. Geol. Survey Geol. Atlas, Cranberry folio (no. 90), p. 3, 1903.
[6] Woodward, H. P., The age and nomenclature of the Rome ("Watauga") formation of the Appalachian Valley: Jour. Geology, vol. 37, no. 6, pp. 594-595, 1929.
[7] Butts, Charles, Geologic map of the Appalachian Valley of Virginia with explanatory text: Virginia Geol. Survey Bull. 42, p. 4, 1933.



GEOLOGIC MAP OF THE MARION AREA, VIRGINIA.

Thickness.—Lack of continuous exposures makes it difficult to determine the thickness of the Rome formation. Innumerable reversals of dip, the results of erratic folding and faulting, further complicate the problem. Woodward[8] states that the Rome in the Marion area has been reported as 420 feet thick. This figure is undoubtedly in error. The Rome is fully 1,400 feet thick.

Stratigraphic relations.—The contacts between the Rome and the underlying Shady dolomite and between the Rome and the overlying Honaker are conformable.

Paleontology and correlation.—Fossils are not abundant in the Rome in any locality. The few forms found in the Marion area came from the southeastern belt of the Rome and from the lower portion of the formation. The species are as follows:

Obolus cf. O. smithi Walcott.
Acrotreta kutorgai Walcott.
Wimanella shelbyensis Walcott.
Olenellus romensis Resser.
Ptychoparia sp.
Cryptozoon sp.

Of these species, *Olenellus romensis* is the most nearly diagnostic in the formation. It has been found in several localities in Virginia.[9] Based upon the early work of Walcott[10] and the later work of Ulrich, the Rome is designated by the United States Geological Survey as Lower and Middle Cambrian in age. On the basis of paleontology and lithology, the Rome of this general region has been correlated by others with the Montevallo shale of central Alabama, the Rome shale of Georgia, the Watauga shale of western North Carolina, and the Waynesboro shale of northern Virginia, Maryland, and Pennsylvania.

HONAKER FORMATION

Name.—The Honaker formation was named by Campbell[11] from well-exposed sections south of Honaker, Russell County, Virginia.

Description.—The Honaker is a gray shaly dolomite. Its thickness in the Marion area is estimated to be 1,000 feet. The lower portion is composed of thin-bedded, gray, earthy dolomite and dolomitic shale. Some of the shale bands are highly carbonaceous and form conspicuous black bands on outcrops. The upper part of the Honaker consists of

[8] Woodward, H. P., Geology and mineral resources of the Roanoke area, Virginia: Virginia Geol. Survey Bull. 34, p. 33, 1932.
[9] Woodward, H. P., op. cit., p. 34.
[10] Walcott, C. D., Notes on the Cambrian rocks of Virginia and the southern Appalachians: Am. Jour. Sci.. 3d ser., vol. 44, pp. 52-55, 1892.
[11] Campbell, M. R., U. S. Geol. Survey Geol. Atlas, Tazewell folio (No. 44), p. 2, 1894.

dull- to dark-gray, crystalline dolomite. These beds appear to be thick bedded, but weathering brings out true thin bedding which is similar to that in the lower part of the formation. The beds vary greatly in thickness and local diastems add to the irregularity of the bedding planes. The rock weathers to a dull rusty gray, and the beds break down into a shaly rubble. Beds and nodules of black chert are present but are not common. The chert appears to be developed during weathering of the rock. The Honaker can be distinguished from dolomites above it by its darker color and its irregular, thin beds.

Paleontology and correlation.—A few fragments of Cryptozoon heads from the lower part of the formation comprise the fossils collected from the Honaker. Wherever the Honaker is known it contains few fossils. A belt of Honaker, extending southwest from the type locality at the town of Honaker, grades laterally into the Maryville and Rutledge limestones in the vicinity of Castlewood, Russell county, Virginia. The age of these formations is probably Middle Cambrian.[12] The Honaker is known in western North Carolina and adjacent parts of Tennessee and as far north as Giles County, Virginia. North of this county it forms a part of the Elbrook formation which is recognized in northern Virginia, Maryland, and southern Pennsylvania. It is equivalent to the Rutledge-Rodgersville-Maryville sequence in parts of southwestern Virginia and Tennessee. The Honaker is also correlated with the lower part of the Conasauga ("Coosa") formation in Alabama.

NOLICHUCKY FORMATION

Name.—The name Nolichucky was first published by Campbell[13] in a report on an area in Virginia. The type section of the formation is, however, along Nolichucky River in Green County, Tennessee.

Description.—The Nolichucky formation is composed of greenish-gray to yellow-drab shales and blue-gray, finely crystalline limestone. Butts[14] states that the Nolichucky is typically a shale at the base of the formation and grades upward into limestone. In the Marion area the upper beds of the Nolichucky are shale. Between the Greenwood school house and Hungry Mother Creek, along the wagon road, the Nolichucky is well exposed, and the limestone facies is particularly well developed. The formation weathers to a yellowish brown, rich soil. A section in this area is given below.

[12] Butts, Charles, op. cit. pp. 7-8.
[13] Campbell, M. R., U. S. Geol. Survey Geol. Atlas, Estillville folio (No. 12), p. 2, 1894.
[14] Butts, Charles, Geologic map of the Appalachian Valley of Virginia with explanatory text: Virginia Geol. Survey Bull. 42, p. 8, 1933.

Section of the Nolichucky shale along the road east of Greenwood School House, north of Marion, Virginia

	Thickness Feet
Conococheague formation:	
Gray cherty dolomite with beds of sandstone	
Nolichucky formation:	
11. Greenish-gray to drab-yellow, calcareous shales, weather mealy	80
10. Medium-bedded, ribbon-like layers of blue crystalline limestone, shale partings and lenses carrying *Acrotreta, Dicellomus,* and *Obolus*	25
9. Thin-bedded, shaly limestone, with *Crepicephalus*	20
8. Massive, blue-gray limestone	2
7. Gray, ropy shale, carrying nodules of blue limestone	2
6. Finely crystalline, blue limestone	1
5. Dark-gray shale and thin, wavy, nodular limestone beds carrying *Lingulella* and *Obolus*	20
4. Massive, blue-gray limestone	3
3. Blue-gray shale carrying *Cedaria* and *Crepicephalus*	2
2. Massive, blue-gray, fine-grained limestone, with thin scattered beds of blue shale, *Cedaria, Lingulella,* and *Obolus*	78
1. Covered interval, mostly blue to greenish-gray shale	15
	248

Honaker formation.

Paleontology and correlation.—The Nolichucky formation is not very fossiliferous in this area, and few forms except the trilobites are diagnostic. The following species were collected and identified by the writer:

Obolus cf. lamborni s. s. (Meek).
Lingulella buttsi Walcott.
Lingulella desiderate (Walcott).
Dicellomus appalachia Walcott.
Acrotreta kutorgai Walcott.
Crepicephalus texanus Shumard.
Cedaria sp.

The Nolichucky is known in western North Carolina, adjacent parts of Tennessee, and in Virginia, as far north as Giles County. Northeast of Giles County the Nolichucky forms the upper part of the Elbrook formation of northern Virginia, Maryland, and southern Pennsylvania. It corresponds to the upper part of the Conasauga ("Coosa") formation of Alabama and southeastern Tennessee. The Nolichucky is the uppermost Cambrian formation in this area.

UNCONFORMITY

The unconformity between the Nolichucky and the Conococheague formations is indicated by an erosion surface developed on the Nolichucky and by the absence of the Brierfield, Ketona, and Bibb dolomites of lower Ozarkian age which are represented by 2,500 feet of beds in Alabama and adjacent sections of Tennessee. Near the southern boundary of the Marion area, just north of Adwolf, the upper shales of the Nolichucky formation, which are present at other localities in the area, are missing. A thin development of the limestone beds only occurs here. The shales at the top have been eroded away. It is doubtful whether the lower Ozarkian dolomites were ever deposited within the Marion area. Following the deposition of the Nolichucky, the Marion area, at least, was uplifted above the sea and subjected to erosion during early Ozarkian time. Before Conococheague time, the region again was submerged.

OZARKIAN SYSTEM

CONOCOCHEAGUE FORMATION

Name.—Middle Ozarkian beds in the southern Appalachian region are composed of limestone and dolomite. The belts on the southeast side of the Valley are composed of limestone and the belts on the northwest side are composed of dolomite. The limestone is called Conococheague and the dolomite is called Copper Ridge as defined by Ulrich.[15] The Marion area lies in line with the belts of limestone called Conococheague by Butts. It should be noted, however, that the middle Ozarkian beds of the Marion area are not entirely limestone; in fact, most of the Conococheague in the area is either a dolomite or a magnesian limestone. Hence, there is in the Marion area an interfingering of the Conococheague limestone and the Copper Ridge dolomite which makes the use of either name somewhat anomalous. The name Conococheague, however, is used to designate the formation in this area.

Description.—The Conococheague in this area is chiefly a thick-bedded, coarsely crystalline, gray, cherty dolomite, but it contains characteristic beds of limestone, sandstone and edgewise conglomerate. Its thickness here is approximately 1,200 feet. It weathers to a yellowish-brown color, and long exposed surfaces are gritty. This grit is not made up of sand grains but of unweathered rhombs of dolomite. The formation weathers to a deep copper-red soil which is very fertile.

The Conococheague is characterized by a number of horizons of medium-bedded, brown, quartz sandstone. These beds are found throughout the formation and are not confined to particular zones. They

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

are not laterally persistent and few can be traced along the strike as far as half a mile. Along the road east of Greenwood School, north of Marion, there is an excellent exposure of one of these horizons. At this locality, sandstone beds total 11 feet in thickness.

The formation contains beds of intraformational dolomite conglomerate. Although there are a few beds of this type in the lower portions of the formation, by far the larger number occurs in the upper 200 feet. Most of the pebbles are lighter in color than the matrix, which is generally sandy. The pebbles weather more rapidly than the matrix and weathered surfaces are pitted. These beds are similar to the edgewise conglomerates described by Eaton.[16]

Another characteristic feature of the formation is the abundance of chert. It forms whole beds on weathered outcrops but not on fresh exposures. This suggests that it is of epigenetic origin. Blocks of these beds break off upon weathering and litter surfaces beneath the formation. There are also several beds of chert oölite. Along the banks of Hungry Mother Creek, north of Marion, there is an excellent display of this oölite. Two of the beds grade laterally into oölitic dolomite within a few feet. The chert contains no fossils except *Cryptozoon* heads. The base of the formation exposed along the Adwolf road, south of McMullin, carries several beds or lenses of dense, black, nodular chert, but this variety is not common.

Paleontology and correlation.—Except for fragments of *Cryptozoon* heads, the formation appears to contain no fossils. The age is middle Ozarkian.

That the Conococheague and Copper Ridge are stratigraphically equivalent is shown by the change of facies from typical Conococheague to typical Copper Ridge in the belt northeast of Tinker Mountain, north of Roanoke.

CHEPULTEPEC FORMATION

Name.—The name Chepultepec was designated as a formation name by Ulrich[17] from Murfrees Valley, Blount County, Alabama. Its present usage restricts it to include only beds above the Conococheague and below the Stonehenge.

Description.—The Chepultepec is a medium-bedded, fine-grained, blue-gray limestone. (See Pl. 16, A.) It is sufficiently pure to be suitable for lime burning. Several beds at the base of the formation are mud breccias and these beds upon weathering are mottled with small brown pits. Thin partings of mud give the beds a finely laminated ap-

[16] Eaton, H. N., Notes on certain conglomeratic structures in limestones in central Pennsylvania: Science, new ser., vol. 49, p. 474, 1919.
[17] Ulrich, E. O., op. cit. p. 638.

pearance on the weathered surface. Nodules and irregular lenses of black chert are present but not common. The formation weathers to a dusty gray color and exposed surfaces are rounded and fluted. The thickness of the Chepultepec is approximately 315 feet. Forty feet above the base of the formation there is a layer of massive oölitic limestone. The fresh rock is fine grained, but weathered surfaces are gritty.

The Chepultepec is conformable with the Conococheague formation.

Paleontology and correlation.—The Chepultepec contains few fossils whose preservation is sufficiently perfect to warrant specific identification. The following forms were identified in the Marion area:

Clarkoceras sp.
Dakeoceras subcurvatum ? Ulrich and Foerste.
Levisoceras sp.
Helicotoma uniangulata (Hall).
Sinuopea vera Ulrich and Bridge.

These forms are definitely Upper Ozarkian. The Chepultepec is also recognized in eastern Tennessee and in central Alabama.

CANADIAN SYSTEM

STONEHENGE FORMATION

Name.—The Stonehenge limestone was named by Stose[18] from Stonehenge, Guilford County, Pennsylvania.

Description.—The Stonehenge is a dove-gray, massive vaughanite. It is easily distinguished from the overlying dolomites on the basis of color. It differs from the underlying Chepultepec in being finer grained and slightly lighter in color. The beds are not laminated with mud partings as are the beds of the Chepultepec. The rock weathers a lighter color, and is carved into fluted, rounded patterns like those of the underlying formation. The beds are uniformly high in calcium carbonate and the rock is suitable for lime burning. The Stonehenge is approximately 25 feet thick.

Stratigraphic relations.—The Stonehenge is conformable with the Chepultepec and in some localities, particularly in Wassum Valley, the contact is "welded" in a single bed. The absence of an unconformity between the Canadian and the Ozarkian indicates that, at least in this area, sedimentation was not interrupted.

Paleontology and correlation.—The Stonehenge is characterized by *Eccyliopterus, Syntrophina,* and *Ophileta complanata.* The writer col-

[18] Stose, G. W., U. S. Geol. Survey Geologic Atlas, Mercersburg-Chambersburg folio (No. 170), p. 6, 1909.

lected and identified these forms, but he is not positive that his specific identification of the *Ophileta* is correct. The Stonehenge has been recognized in many parts of northern Virginia and Maryland, and more recently in eastern Tennessee. It is of lower Canadian age and is correlated with the Tribes Hill of New York.

NITTANY DOLOMITE

Definition.—The Nittany dolomite was named by Ulrich[19] from Nittany Valley in central Pennsylvania.

Description.—The Nittany formation is composed of light-gray, thick-bedded, crystalline, cherty dolomite. It is approximately 1,200 feet thick in the Marion area. In spite of its thickness, a uniform lithology is present throughout. The beds are very hard, but on weathering they become mealy. The formation weathers to a color lighter than the fresh rock.

The Nittany dolomite is characterized by an abundance of chert. Weathered areas underlain by the Nittany are strewn with great quantities of large angular blocks of this material. The beds of chert from which these fragments are derived are found in almost every weathered outcrop, but are conspicuously absent from every fresh exposure. Some of these beds attain a thickness of 2 feet. The beds are not persistent but grade laterally into dolomite. Such conditions suggest that the chert is epigenetic, and that it is developed during the process of weathering of the dolomite. The chert possesses all of the textural characteristics of the dolomite from which it is derived. The Nittany chert is fossiliferous and thus can be distinguished from the Conococheague chert.

Barite occurs as a vein and pocket-filling material in two localities in this area. In Wassum Valley where the Nittany is faulted up against the Athens shale, there are numerous veins and pockets which run parallel to the fault on the north. Some of these pockets were worked in the early years of this century.[20] In the eastern part of the area, near the fault which brings the Nittany in contact with the Conococheague, another series of veins and pockets of barite are present. These two zones represent part of a highly fractured belt of dolomite which originated at the time of the faulting on the north. Subsequently these cracks and fissures were filled by barite precipitated apparently from shallow circulating meteoric waters. In future years these deposits may prove of some economic value.

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[19] Ulrich, E. O., op. cit., p. 658.
[20] Watson, T. L., Mineral resources of Virginia: Virginia-Jamestown Exposition Commission, Lynchburg, Va., J. P. Bell Co., pp. 321-322, 1907.

Paleontology and correlation.—The Nittany is sparingly fossiliferous. One or more species of *Lecanospira* associated with a somewhat less common form resembling the genus, *Sinuopea,* were found at several horizons in the formation. The fossils are almost never found in the dolomite but in the fragmental chert derived from it. The top of the formation in Wassum Valley carries *Lecanospira* and this is of stratigraphic importance. The Nittany is recognized in Pennsylvania, Maryland, Virginia, West Virginia, and Tennessee. In Alabama the Longview limestone is its equivalent. The Nittany is of middle Canadian age.

UNCONFORMITY

The presence of *Lecanospira* at the top of the Nittany indicates that there is a hiatus between it and the overlying Mosheim limestone. The Bellefonte which carries the distinctive genus, *Ceratopea,* and numerous species of nautiloid cephalopods is absent. Also the basal Stones River (Ordovician) formation, the Murfreesboro limestone is absent. The contact between the Nittany and the Mosheim is marked by a gently undulating, wave-marked surface developed on the Nittany. In all eastern belts in the Valley of Virginia south of Roanoke, the Bellefonte and the Murfreesboro are reported to be either thin or absent. This indicates that the Marion area, like belts both northeast and southwest of it, was possibly a low lying land area during this time. Following this rather uniform shifting of the eastern border of the Appalachian sea during the close of the Canadian and beginning of the Ordovician, sedimentation in this general region continued almost without interruption until the later part of the Ordovician period.

ORDOVICIAN SYSTEM

STONES RIVER GROUP

MOSHEIM FORMATION

Name.—The name Mosheim was first applied to this formation by Ulrich[21] at Mosheim, Tennessee.

Description.—The Mosheim is everywhere a medium-bedded, compact, dove-colored vaughanite. The rock is very hard and possesses a characteristic splintery fracture. It weathers a light gray. In the western part of the Marion area, near McMullin, it is poorly developed. In the Marion quarry, east of Marion, the maximum thickness of 35 feet is exposed. The formation is very pure and makes an excellent stone for lime burning. The uniform texture and color, bedding, and

[21] Ulrich, E. O., Revision of the Paleozoic systems: Geol. Soc. America Bull., vol. 22, pp. 413-414, 1911.

jointing permit its commercial use as a marble. The thinness of the formation, however, restricts its economic possibilities.

Paleontology and correlation.—Fossils are rare in the Mosheim. The compactness of the rock is not suitable for preservation. Most of the fossils appear as etched outlines on the weathered surface. The Marion quarry exposures of the Mosheim yielded the following forms:

Tetradium syringoporoides Ulrich.
Unidentified Bryozoa.
Liospira americana Billings.
Helicotoma sp.
Euconia sp.
Lophospira bicincta Hall.
Gonioceras sp.
Leperditia cf. L. fabulites Conrad.
Pterygometopus troosti Safford.

Many large gastropods have been identified from the Mosheim by Ulrich from other localities. According to Woodward,[22] the Mosheim is middle Chazyan in age. The Mosheim is well known in the Appalachian region, south of Roanoke. In the northwestern belts of the Appalachian Valley, it forms a part of the Stones River but not the basal part as it does in the southeastern belts. The Mosheim is correlated with the basal Chickamauga of Alabama.

LENOIR FORMATION

Name.—Lenoir was first used as a formation name by Safford and Killebrew[23] for Lenoir City, Loudon County, Tennessee.

Description.—The Lenoir is a gray to black impure limestone 60 to 90 feet thick. The lower third of the formation is composed of medium-bedded, coarsely crystalline limestone containing scattered aggregates and stringers of pyrite. These beds vary greatly in lithology. North of Seven Mile Ford, this portion is composed largely of pinkish and black mottled limestone conglomerates. In Wassum Valley these conglomerates are absent, and there is a local development of dense carbonaceous marble beds. In the Marion quarry east of Marion, the lower Lenoir is lighter in color and more finely crystalline, and there are no beds of marble or conglomerate. The upper part of the formation is composed of thin-bedded earthy limestones containing nodules of purer limestone. These beds decay rapidly and the nodules weather

[22] Woodward, H. P., Geology and mineral resources of the Roanoke area, Virginia: Virginia Geol. Survey Bull. 34, pp. 43-44, 1932.

[23] Safford, J. M., and Killebrew, J. B., The elementary geology of Tennessee, Nashville, pp. 108, 130-131. 1876.

out, forming a rubble on the outcrop. The upper portion varies in thickness locally. Its best development is in the Marion quarry. Black chert, so characteristic of the Lenoir in other sections, is absent in the Marion area. The formation contains considerable organic matter and yields a characteristic odor when struck with a hammer.

Paleontology and correlation.—The Marion quarry exposures of the Lenoir yield many fossils. Many species are new, but in this report the writer makes no attempt to give a full account of the fossils. The identifications given below include only a small part of the Lenoir fauna from this locality.

Anthaspidella sp.??
Receptaculites biconstrictus? Ulrich.
Cheirocrinus sp.? (separate plates).
Hindia parva? Ulrich.
Nicholsonella sp.?
Rhinidictya trentonensis (Ulrich).
Monotrypa sp.
Glauconome n. sp.
Mesotrypa sp. undescribed.
Batostoma sp. und.
Chasmotopora sp. und.
Christiania aff. C. lamellosa Bassler.
Crytonotella sp.
Glyptorthis cf. G. bellarugosa.
Hesperorthis aff. H. tricenaria (Conrad).
Multicostella platys (Billings).
Hebertella sp.
Plectorthis exfoliata (Raymond).
Productorthis n. sp.
Sowerbyella n. sp.
Maclurea magna Emmons.
Trochonema sp.?
Bumastus sp.
Illaenus sp.
Ceraurus sp.
Encrinurus sp.
Pliomera canadensis Billings.
Pterygometopus cf. P. mercurius Ulrich Ms.
Remopleurides panderi? Billings.
Aparchites sp.

The Lenoir beds are of late Stones River age. The presence of *Maclurea magna* indicates that the formation is equivalent to the Crown

Point division of the Chazy limestone of New York State. The Lenoir is well known throughout Virginia and the formation extends northeastward into Pennsylvania where it is known as the Lemont limestone. The Lenoir is also known in eastern Tennessee, Maryland, and Alabama.

BLOUNT GROUP

UNCONFORMITY

Between the Lenoir and the overlying Whitesburg there is an unconformity with the Holston marble absent. The pinkish marble beds in Wassum Valley resemble the Holston marble beds of Tennessee. They are, however, not Holston but Ottosee, which is indicated by more than 100 feet of fossiliferous Ottosee beds below the pink marble beds.

WHITESBURG FORMATION

Name.—The Whitesburg was first recognized as a formation by Ulrich[24] at Whitesburg, Tennessee. The presence of a persistent limestone zone at the base of the Athens shale in the southern Appalachians has been known for a long time. Butts[25] recognized this zone as a "basal limestone member" in the Athens formation in Alabama. Paleontological study of the basal limestone member in the Athens in other areas will doubtless reveal further occurrences of the Whitesburg.

Description.—The Whitesburg formation is an impure crystalline limestone which is rather sharply marked off from the underlying nodular Lenoir. The beds are gray to brownish-gray and their thickness ranges from 8 to 15 inches. The beds weather to a brownish-gray which is darker than the fresh rock. In Wassum Valley, where the Whitesburg has its maximum development in this area, the formation is 23 feet thick. The basal layer is composed of a mud and limestone breccia and this bed can be recognized in all places where the contact is exposed. The Whitesburg appears to be absent in the Marion quarry. Probably during the deposition of this bed the weathered debris of the upper Lenoir, derived during the post-Lenoir- pre-Whitesburg hiatus, was incorporated into the Whitesburg.

Paleontology.—The following fossils were collected from the beds in Wassum Valley:

Christiania aff. C. lamellosa Bassler.
Hebertella bursa Raymond.
Orthis disparilis Conrad.
Pterygometopus transsectus? Raymond.

[24] Ulrich, E. O., *in* Gordon, C. H., History, occurrence, and distribution of the marbles of east Tennessee: Tennessee Dept. Educ., Div. Geology, Bull. 28, p. 34, 1924.

[25] Butts, Charles, Geology of Alabama: The Paleozoic rocks: Alabama Geol. Survey Spec. Rept. No. 14, pp. 111-112, 1926.

These fossils are not known to be diagnostic of the Whitesburg, but a rare indicative agnostid, *Arthrocachis elspethi* Raymond has been collected and identified from the same beds southwest of Marion. Ulrich has identified more than 150 species from this formation in other localities from Alabama to central Virginia.

ATHENS FORMATION

Name.—The term Athens was first applied as a formation name by Hayes[26] at Athens, Tennessee.

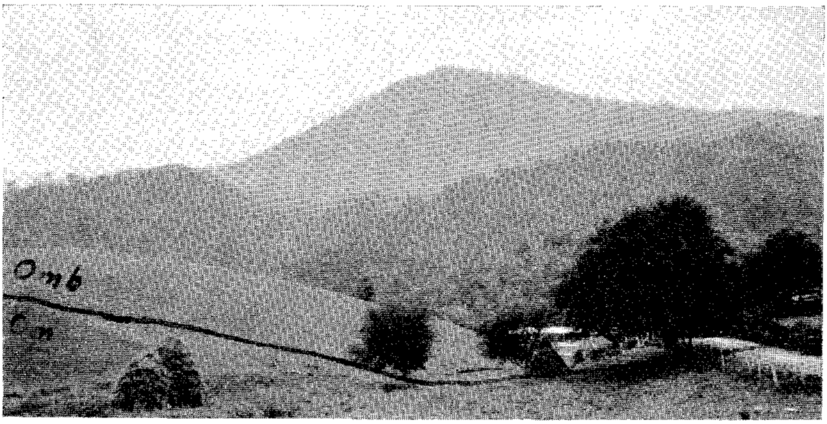
Description.—The Athens formation is composed of brownish-gray to black shales and thin-bedded, flaggy, gray limestones. The formation is approximately 850 feet thick. The lower 325 feet of the formation is composed of brownish-gray, fissile shale and the upper part of gray to black limestones interbedded with and often grading laterally into black shales. The limestone upon weathering reveals a shaly bedding which is not noticed on fresh outcrops. The Athens is intimately fractured and fresh outcrops are strewn with shoe pegs of shale. It carries considerable organic matter, yielding an odor when struck with a hammer. Weathered outcrops of the limestone are much lighter than the fresh rock. In the Marion area, the Athens changes facies. In areas to the southwest, it is predominantly a shale and contains many beds of arkosic sandstone. Half a mile east of McMullin, in Norfolk and Western Railroad cuts, the limestone facies of the formation is well displayed. In Porter Valley many of the limestone beds are lenslike and grade laterally into black shales. In Wassum Valley the Athens is only 60 feet thick, due to the faulting out of the remainder of the formation.

The Athens lies conformably upon the Whitesburg.

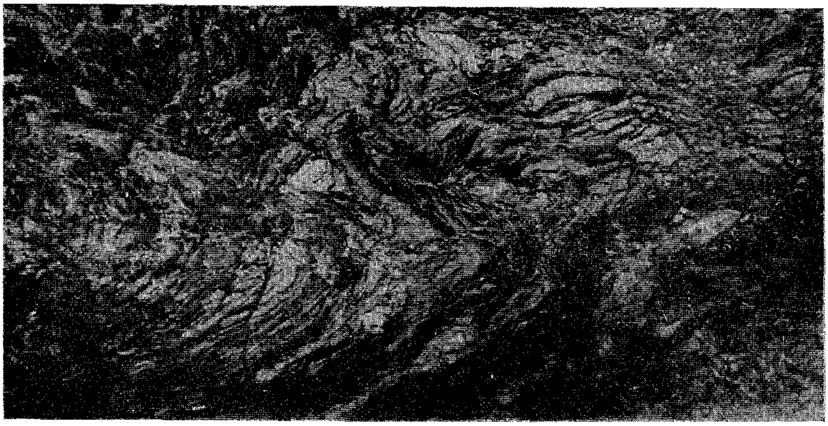
Paleontology and correlation.—The basal shales exposed in Wassum Valley and at the top of the Marion quarry yield an abundant fauna of graptolites and a few other fossils. The following forms were identified:

Climacograptus bicornis Hall.
Climacograptus scharenbergi Lapworth.
Dicellograptus sextans Hall.
Dicellograptus gurleyi Lapworth.
Dictyonema obovatum Gurley.
Dictyonema spiniferum Ruedemann.
Nemagraptus gracilis? Hall.
Trilobites fragments.

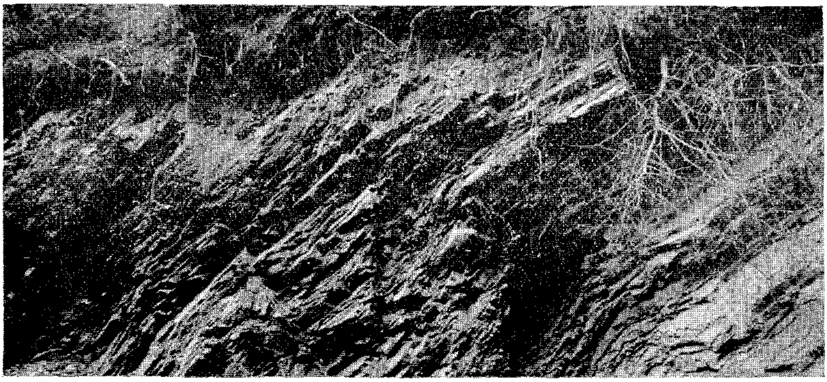
[26] Hayes, C. W., U. S. Geol. Survey Geol. Atlas, Kingston folio (No. 4), p. 2, 1894.



A. Mollies Knob in Hungry Mother State Park, near Marion, Virginia. It is capped by an isolated remnant of Chemung beds. Elevation, 3,290 feet.



B. Contorted beds in the Rome formation northeast of Chilhowie, Virginia.



C. Shale in the Trenton division of the Martinsburg formation in Hungry Mother State Park.

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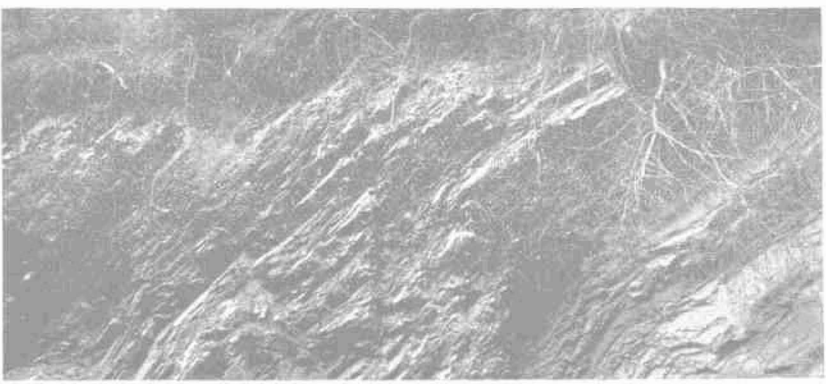
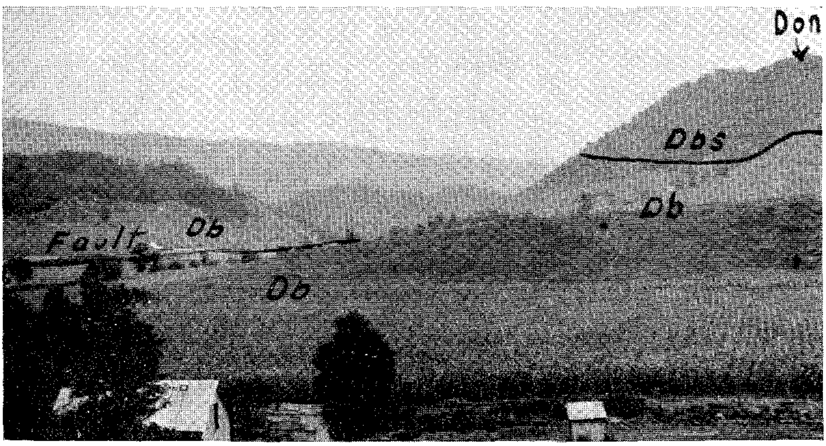
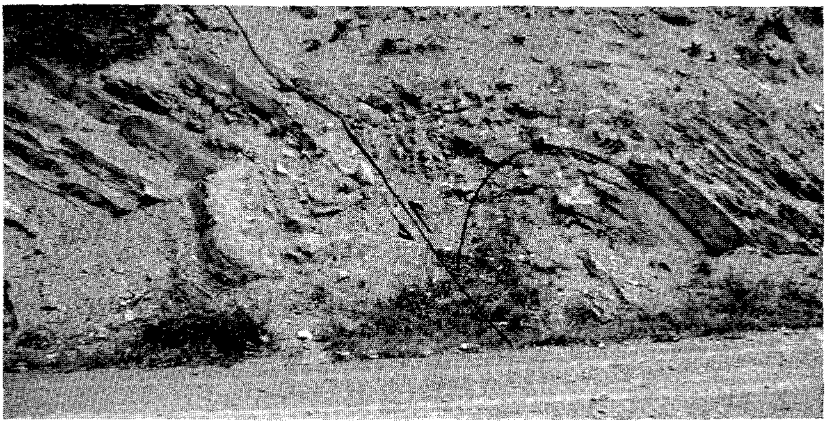


C. Shale in the Trenton division of the Martinsburg formation in Hungry Mother State Park.

A. Chepultepec limestone along the road 1½ miles northeast of McMullin

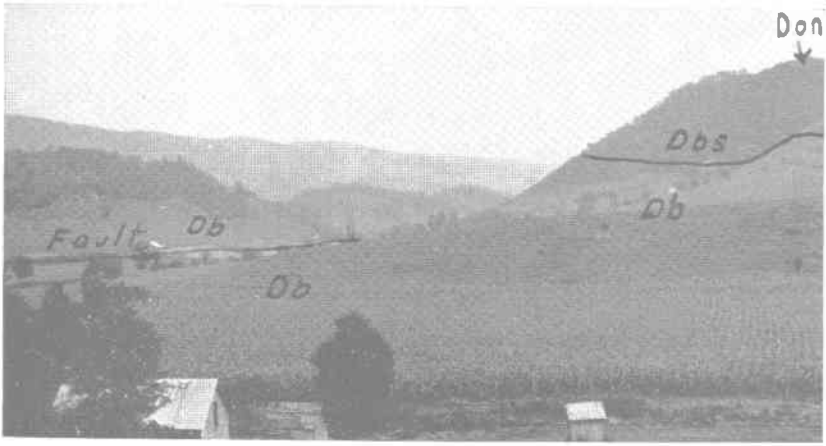


B. Cleghorn Valley between Brushy Mountain (on right) and Walker Mountain (in background). Looking northeast from the road below Marleys Top. The fault indicated is the Brushy Mountain overthrust.

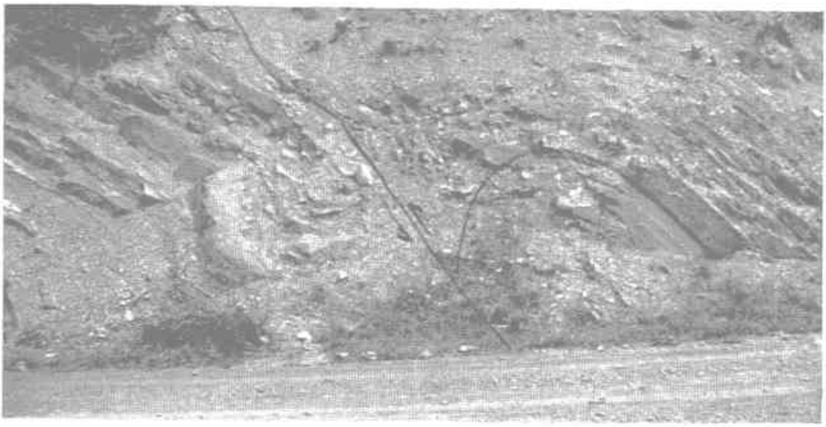


C. The Brushy Mountain overthrust northeast of Marleys Top. The fault is in the Brallier shale. Note difference in strike of beds near the fault.

A. Chepultepec limestone along the road 1½ miles northeast of McMullin



B. Cleghorn Valley between Brushy Mountain (on right) and Walker Mountain (in background). Looking northeast from the road below Marleys Top. The fault indicated is the Brushy Mountain overthrust.



C. The Brushy Mountain overthrust northeast of Marleys Top. The fault is in the Brallier shale. Note difference in strike of beds near the fault.

The graptolite fauna is identical in many respects with that of the *Nemagraptus gracilis* zone of the Normanskill shale of New York. The latter has been correlated with other Appalachian formations and with the basal zone of the Viola limestone of Oklahoma and Arkansas. According to Butts,[27] the same fauna is found in the Glen Kiln shale of Scotland.

OTTOSEE FORMATION

Name.—Ottosee was made a formation name by Ulrich for a redefined portion of the Sevier shales in eastern Tennessee. In the type locality at Ottosee Lake in Chilhowie Park, Knoxville, Tenn., the Ottosee overlies the Tellico sandstone, but in Virginia the Tellico is not recognized.

Description.—The Ottosee varies greatly in lithology within the Marion area, and the general lithology can scarcely be described. Because of its horizontal lithologic variation and because of the reputed economic significance of the upper Ottosee the following sections are included:

Section of the Ottosee limestone on the southeastern slope of Brushy Mountain, near Walker Creek

	Thickness Feet
Ottosee-Moccasin contact	
Ottosee formation:	
5. Massive, light-gray, coarsely crystalline limestone with ropy mud partings between layers 2-3½ feet thick, fossils include *Solenopora* and *Batostoma*	60
4. Massive, gray to pinkish, coarsely crystalline limestone in beds 2-2½ feet thick. Rock is composed of large calcite rhombs and granular rhodochrosite, *Lichenaria* corals and crinoid stems common	13
3. Thin-bedded, buff-gray crystalline limestones containing *Monticulipora, Echinosphaerites, Solenopora, Receptaculites, Mimella,* and *Plectorthis,* weathers to a mealy, nodular shale	28
2. Drab-gray, impure, thin-bedded limestones similar to the part of the Lenoir formation, brachiopods and trilobite pygidia	67
1. Black, cherty, impure limestone with *Bumastus* trilobites	3
Total Ottosee limestone	171

[27] Butts, Charles, Geologic map of the Appalachian Valley of Virginia with explanatory text: Virginia Geol. Survey Bull. 42, p. 17, 1933.

Section of the Ottosee limestone in Wassum Valley, northwest of Marion, Virginia

	Thickness Feet
Ottosee-Moccasin contact	
Ottosee formation:	
5e. Thick-bedded, dense, conglomeratic marble, matrix of blue-gray vaughanite with angular pebbles of blue, green, red, and greenish-gray vaughanite. Stylolites and slickensides, pebbles recrystallized to form white calcite blotches in places	12
5d. Massive, conglomeratic, gray variegated marble. Finely crystalline, greenish-gray groundmass with large pebbles of chertlike, flesh-colored *Solenopora* heads and small chips and pebbles of reddish and greenish limestone. Greenish-black serpentine developed in minute veins parallel to the bedding and along joint and fracture planes. En echelon calcite veins cut across the bedding	8
5c. Very dense, coarsely crystalline, apple-green marble with pink and white splotches of rhodochrosite and calcite. Recrystallization of calcite has obliterated fossils and stylolites, serpentine developed minute veins and in irregular blotches which give the surface a mottled appearance	9
5b. Thin beds of coarsely crystalline, pink marble which is almost identical in texture and color with the Tennessee (Holston) red marble, stylolites well developed. Pinkish granular masses of rhodochrosite, *Batostoma* and *Lichenaria* common	11
5a. Nearly white, dense marble beds with small erratic veins of serpentine. Individual beds welded together along the bedding planes by secondary calcite	5
Note: The above are subdivisions of Zone 5 in the Walker creek section. Zones 1, 2, 3, and 4 are not well exposed in Wassum Valley but appear to be very similar to corresponding zones in the Walker creek section.	
Zones 1, 2, 3, and 4	115
Total Ottosee limestone	160

Section of the Ottosee limestone along the wagon road south of the C. C. C. Camp, north of Marion, Virginia

	Thickness Feet
Moccasin-Ottosee contact	
Ottosee formation:	
Upper fossiliferous beds of limestone corresponding to Zones 3, 4, and 5 in the Walker creek section	137
2. Dense, massive, white, coarsely crystalline marble beds with pinkish streaks and blotches. Beds are intimately fractured. Ropy bands of graphitic material cut across the beds and occur along joint and shear planes	30
1. Dense, black graphitic beds with slaty cleavage and with oriented lentils of shale and limestone	9
Total Ottosee limestone	176

The above sections indicate that the Ottosee has undergone sufficient metamorphism to alter parts of the formation locally to marble.

The Ottosee lies conformably upon the Athens shale.

Economic prospects.—The marble developed in the Ottosee in Wassum Valley takes a high polish and is sufficiently compact and free of fractures to be suitable for decorative work. The apple-green marble is striking in color and would command a premium market price. However, commercial development of these marbles is inadvisable, because the rocks dip 60°-75°. Along the strike the marbles change into gray limestones which are of different color and texture. These conditions seriously limit the amount of stone which could be profitably quarried in this locality.

Paleontology and correlation.—The Ottosee is not very fossiliferous in the Marion area. The following forms were found in the Walker Creek and Wassum Valley sections:

Solenopora compacta Billings.
Receptaculites biconstrictus Ulrich.
Lichenaria carterensis (Safford).
Lichenaria sp. ind.
Echinosphaerites aurantium Gyllenhal.
Crinoid stems.
Monticulipora sp.
Batostoma sevieri Bassler.
Mimella melonica (Willard).
Illaenus sp.
Bumastus sp.

The Ottosee formation is characterized by *Echinosphaerites aurantium, Receptaculites biconstrictus,* and species of the coral *Lichnaria.* The Ottosee is strictly a southern Appalachian formation and has not been recognized north of Tazewell, Virginia. The Ottosee is upper Chazy in age.

BLACK RIVER GROUP

MOCCASIN FORMATION

Name.—The Moccasin formation was first described by Campbell[28] from Moccasin Ridge, Scott County, Virginia.

Description.—The Moccasin is composed of red, calcareous mudrock and thin-bedded, earthy limestones. In Wassum Valley, the Moccasin is approximately 150 feet thick. A rusty brown sandstone bed, 9 inches thick, occurs in the upper 25 feet of the formation and numerous other sandstone beds occur at intervals in the lower beds. About 70 feet from the base of the formation is a thin greenish zone of mudrock and green sandstone which is persistent throughout the Marion area. A bed of coarse-grained, red, conglomeratic limestone is found at the base of the formation on the southeastern slopes of Brushy Mountain, near Walker Creek, and this bed forms a variegated red marble in Wassum Valley. Mud-cracks occur on many of the bedding planes. Near the top of the formation there are two bentonite beds. The lower of these is approximately 2 inches thick and is separated from the upper bentonite by 2 feet of red mudrock. The upper bentonite is from 6 to 8 inches thick and contains irregular streaks of typical red Moccasin. These beds are clearly of Moccasin age, for overlying the upper bed is 4-7 feet of red limestone and mudrock. The bentonites do not occur in the eastern part of the Marion area and there is no evidence of an erosion interval at their horizon.

The Moccasin directly overlies the Ottosee with no evidence of an unconformity.

Paleontology and correlation.—The Moccasin contains few recognizable fossils in the Marion area. Fragments of the Ottosee form, *Solenopora compacta,* are found in the lower conglomeratic bed in Wassum Valley. This bed represents a part of a reworked bed of the Ottosee, the detritus from which was incorporated into the basal Moccasin layer.

Age and relations.—The Moccasin is definitely of Lowville age, but it does not represent a distinct formation, as was formerly supposed.[29]

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

[29] Bassler, R. S., The cement resources of Virginia west of the Blue Ridge: Virginia Geol. Survey Bull. 2A, p. 167, 1909.

It represents the shallow water facies of the Lowville limestone in southwestern Virginia. On the northwestern slopes of Clinch Mountain, the red Moccasin is interbedded with the dove-colored fine-grained Lowville limestone which carries the typical Lowville fossils, *Tetradium cellulosum* and *Beatricia gracilis*. The Moccasin, therefore, can not be regarded as a distinct stratigraphic unit, separable from the Lowville limestone. These formations are lower Black River in age.

UNCONFORMITY

The upper Black River beds overlying the Moccasin formation, or Lowville formation in other areas, are absent in the Marion area, and the Trenton member of the Martinsburg shale directly overlies the Moccasin. This hiatus is represented in the northern Appalachian region by the Chambersburg limestone, and in most sections of the southern Appalachians by the Eggleston formation.[30] At the close of sedimentation of the Moccasin formation, the shallow seas of Lowville time in this area withdrew and the Marion area was above the sea until the close of Black River time, after which the seas again encroached upon the Marion area and the Trenton and succeeding members of the Martinsburg shale were deposited.

TRENTON, EDEN, AND MAYSVILLE GROUPS

MARTINSBURG FORMATION

Name.—The name Martinsburg has long been used in the Appalachian area for a great thickness of shales of Trenton, Eden, and Maysville age. The subdivisions made of this formation are the three stratigraphic groups mentioned above. According to the rules of stratigraphic nomenclature, the term Martinsburg has no place in present stratigraphic literature. Obviously, group terms can not be made to designate subdivisions of a formation. Each of the three divisions of the Martinsburg recognized in this paper and in other reports must be given special formation names and then correlated with the Trenton, Eden, and Maysville. The renaming and the redefinition of the formation now known as the Martinsburg shale are deserving of special consideration in their own right and should be discussed in a separate paper. The writer, in this paper, conforms to present usage regarding the nomenclature of this formation.

Description.—The Martinsburg formation is predominantly a gray to light-brown, calcareous shale. Its thickness in this area is approximately 1,400 feet. The lower shales are brownish in color and are

[30] Mathews, A. A. L., Marble prospects in Giles County, Virginia: Virginia Geol. Survey Bull. 40, p. 7, 1934.

relatively free of sand, whereas the uppermost layers are thick-bedded, dark-green and red sandstones. The great thickness of intervening shale shows an even lithologic gradation between these two limits. Open jointing is characteristic of the upper, more competent sandstones, whereas the underlying shale is thoroughly fractured. The formation weathers into a fertile soil. The sandstones at the top, though hard, are not resistant to weathering and upon the solution of their calcareous cement, they disintegrate rapidly.

Paleontology.—The Martinsburg formation is very fossiliferous throughout and the species indicate that the beds are of Trenton, Eden, and Maysville age. The following forms have been identified by the writer:

Diplograptus amplexicaulis Hall.
Monticulipora sp.
Prasopora simulatrix Ulrich.
Mesotrypa angularis Ulrich and Bassler.
Hallopora ampla Ulrich.
Batostoma superbum Foord.
Rhinidictya sp.
Lingula modesta Ulrich.
Lingula nicklesi Bassler.
Pholidops subtruncata Hall.
Hebertella sinuata Hall and Clarke.
Hebertella borealis Billings.
Plectorthis plicatella Hall and Clarke.
Plectorthis fissicosta Hall.
Dalmanella multisecta Meek.
Dalmanella fertilis Bassler.
Pionodema cf. subaequata Billings.
Dinorthis pectinella Emmons.
Heterorthis clytie Hall.
Sowerbyella curdsvillensis (Foerste).
Sowerbyella rugosus (Meek).
Rafinesquina alternata Emmons.
Rafinesquina ulrichi James.
Orthorhynchula linneyi James.
Zygospira modesta Hall.
Zygospira recurvirostris Hall.
Orthodesma nasutum Conrad.
Orthodesma sp.
Sinuites cancellatus Ulrich.
Liospira progne Ulrich and Schofield.
Hormotoma trentonensis Ulrich and Schofield.

Orthoceras angusticameratum Hall.
Pterinea demissa Conrad.
Byssonychia radiata Hall.
Byssonychia praecursa Ulrich.
Modiolopsis modiolaris Conrad.
Modiolopsis milleri Ulrich.
Cryptolithus tessalatus Green.
Calymene sp.
Calyptaulax eboraceus (Clarke).
Bollia sp. ind.

Divisions.—On the basis of paleontology the Martinsburg is divided into three members, but at present in the southern Appalachian region, no one attempts to define the upper limits of the first and second of these members. The lower, middle and upper parts each carry fossil species characteristic of them in particular. However, there is no abrupt faunal or lithologic break between them. For example, the majority of the species in the Trenton member appear to carry over into the overlying Eden member and to persist even after the appearance of characteristic Eden forms.

Trenton member.—In all localities in the Marion area, the Trenton lies directly on the Moccasin formation. A part of the Trenton present on the northwest side of Clinch Mountain and in nearly all other areas in the Appalachian region is absent in the Marion area. Generally, the basal 20 feet of the Trenton carry at least 4, and in some places as high as 12 beds of bentonite, but there is no bentonite in the Trenton of the Marion area. These beds, therefore, probably never were deposited and the post-Moccasin hiatus includes a small part of the Trenton.

The Trenton is not exposed except in road cuts. It is a drab-yellow to brown shale with a very few thin layers of blue limestone at scattered horizons. (See Pl. 15, C.) The beds are all uniformly thin and porous. A blanket of soil is present on all but fresh outcrops and generally obscures the bedding. The Trenton is approximately 600 feet thick in this area.

The Trenton carries many fossils and the internal structures preserved in many facilitate identification. The Trenton is characterized by the presence of such common forms as: *Prasopora simulatrix, Diplograptus amplexicaulis, Mesotrypa angularis, Hallopora ampla, Zygospira recurvirostris,* and *Sowerbyella* sp. The less common *Orthoceras angusticameratum* and *Cryptolithus tessalatus* are excellent guide fossils. The Trenton of this area represents a near shore facies of the typical Trenton, a limestone, found in belts on the northwest side of

Clinch Mountain. The Trenton limestone differs faunally as well as lithologically from the Trenton member of the Martinsburg formation, although many species are common to both facies. The former, however, carries such index forms as *Hebertella frankfortensis* and *Rhynchotrema increbescens*, which distinguish it from the near shore facies. The Trenton is one of the most widespread formations in eastern North America and is Upper Mohawkian in age.

Eden member.—The Eden, like the Trenton, is made up of drab-yellow and brown calcareous shales. However, from the bottom upward, there is a gradual increase in the amount of sand and silt in the beds. The Eden in the Marion area is approximately 600 feet thick, except in the extreme eastern part where it and the Trenton together have a maximum thickness of 1,000 feet.

The Eden is likewise very fossiliferous. The forms, *Dalmanella multisecta, D. fertilis, Pholidops subtruncata, Rafinesquina alternata, R. ulrichi, Calyptaulax eboraceus,* and *Monticulipora* sp. are common in the Eden. Pygidia of a species of *Calymene* are likewise common. However, the trilobite species particularly characteristic of the Eden, *Cryptolithus bellulus,* is not known to occur in the Marion area. The Eden in this area is very similar to the Eden division of the Martinsburg in other areas in the Appalachians. It also corresponds to the Eden division of the Reedsville shale in the extreme southwestern part of Virginia and in eastern Tennessee. Faunally, it is very similar to the Eden of Ohio. The Eden is probably the equivalent of the lower Lorraine of New York, according to Butts.[31]

Maysville member.—The Maysville may be said to begin where the sandy shales of the Eden give way to the distinct siltstones and sandstones above. The thickness is approximately 250 feet. Drab-yellow siltstones and fine sandstones predominate in the lower 150 feet. Above these beds greenish sandstones occur, and the upper part of the formation includes reddish brown sandstones. The beds in the Maysville are thicker than in the underlying shales, and the red sandstones at the top are in very thick beds. The sandstones are very hard but are easily weathered and disintegrate rapidly upon solution of their calcareous cement. The upper part of the Maysville is very different from the rest of the formation.

The Maysville, although fossiliferous, carries fewer species than the two lower divisions and only a very few Eden forms carry over into its lower beds. The *Orthorhynchula linneyi* zone, one of the most widespread fossil horizons in the entire eastern United States, occurs in the red sandstones at the top of the formation. Also associated with the

[31] Butts, Charles, Geology of Alabama: The Paleozoic rocks: Alabama Geol. Survey Spec. Rept. No. 14, p. 127, 1926.

Maysville member are the forms *Hebertella sinuata, Lingula nicklesi, Byssonichia radiata, B. vera, Modiolopsis modiolaris, Zygospira modesta, Pterinea demissa, Plectorthis fissicosta,* and *Liospira* aff. *progne.* The Maysville is well known by its index fossil, *Orthorhynchula linneyi,* throughout the Ohio Valley, in the Michigan basin, as well as in the Appalachian region.

The uppermost beds of the Maysville are present in the Marion area and were not appreciably eroded during the long period of time indicated by the hiatus between the Maysville and the overlying Onondaga formation.

UNCONFORMITY

Definition.—There is a great stratigraphic break between the Maysville and the overlying Onondaga in this area. Except for an obvious faunal break there is little indication of a great hiatus. In adjacent areas in southwestern Virginia, there is no comparable unconformity at this horizon in the stratigraphic column.

Formations involved.—The Upper Ordovician Oswego sandstone which normally overlies the Maysville in the northern Appalachian region is absent in the Marion area, as in all areas south of Roanoke. The entire Silurian system is missing. The Juniata sandstone and Clinch sandstone are present at Lyons Gap in Walker Mountain, 4½ miles north of Chilhowie, Va. On Walker Mountain north of Marion, the Juniata, Clinch, and Clinton are present. The proximity of these areas to the Marion area makes the local absence of these formations of special interest. The Helderberg and Oriskany formations of the Devonian are also absent in this area, but abundantly fossiliferous patches of Oriskany are exposed on Walker Mountain. One of them is exposed along State Highway No. 88 over the mountain to Chatham Hill. Their general distribution south of Rocky Gap, Bland County, Virginia, is very erratic. Many areas north of Marion have no representatives of these beds.

Character.—The basal Onondaga does not bevel the beds of the upper Maysville and it can be assumed that any diastrophism in the post-Maysville—pre-Onondagan interim was uniform throughout the Marion area. The upper bed of the Maysville shows no evidence of erosion. However, the basal layer of the Onondaga formation is composed of glauconitic sandstone, containing both Onondaga and Maysville fossils. This bed represents the weathered detritus of the once uppermost layer of the Maysville which, at the beginning of Onondaga time, was reworked. A 6-inch bed of chert overlying this bed contains recognizable fragments of the Maysville fossil, *Orthorhynchula linneyi.* Weathered fossils representing a portion of the detritus later incorporated into the lowest Onondaga beds were present on the Maysville surface.

Conclusion regarding the hiatus.—Following deposition of the Maysville, the Marion area was uniformly uplifted above the sea to become low-lying land. This condition prevailed until the end of the Silurian period. During early Devonian time a gradual subsidence ensued, and by Oriskany time the Marion area was practically at sea level. The patchy distribution of the Oriskany on Walker Mountain north of Marion indicates locally, at least, a lagoonal environment during Oriskany time. Following this period, a further subsidence occurred and the Marion area was again covered by the Appalachian sea. The thin mantle of weathered residuum from the uppermost Maysville was reworked and incorporated in the basal layers of the Onondaga formation.

DEVONIAN SYSTEM

ONONDAGA FORMATION

Name.—The Onondaga formation was named by Hall from Onondaga County, New York. The present stratigraphic significance of the name is based upon a redefinition of the original Onondaga and Corniferous formations of that state in 1894.[32]

Description.—The Onondaga is composed primarily of dense, black chert and subordinate beds of brownish to greenish glauconitic sandstone. The section of the Onondaga along Walker Creek, at the foot of Brushy Mountain, measures 53 feet in thickness. The base of the formation is represented by a 3-inch layer of fossiliferous, glauconitic sandstone. This is overlain by 43 feet of massive, but irregular beds of rugged black chert. Several beds of green or brown fossiliferous sandstone are interbedded with the chert. The most conspicuous of these is approximately 6 inches thick. According to Butts,[33] the Onondaga is a cherty limestone on fresh exposures. However, in the Marion area there are no exposures which reveal a trace of limestone. The Onondaga is a resistant formation that weathers very slowly.

Paleontology and correlation.—The Onondaga is rather fossiliferous, but extraction of the fossils is difficult. The sandstone beds carry several species, the following of which were identified by the writer:

Pleurotomaria sp.
Dalmanella lenticularis (Vanuxem).
Schuchertella pandora (Billings).
Chonetes mucronatus Hall.

[32] Hall, James, Relation of the Helderberg limestones and associated formations in eastern New York State: *in* Thirteenth Ann. Rept. of State Geologist for 1893, p. 207, 1894.

[33] Butts, Charles, op. cit., pp. 30-31.

Chonetes buttski Kindle?
Spirifer duodenaria Hall.
Anoplotheca acutiplicata Conrad.
Amphigenia curta Hall.
Ambocoelia umbonata (Conrad).
Bellerophon pelops Hall.

The Onondaga is lower Middle Devonian. It is well-known throughout the Appalachian region and the Ohio Valley. The abundant coral fauna, so characteristic of the Onondaga elsewhere, has no representatives in this area so far as known.

"BLACK SHALE"

Name.—No geographic name has yet been published for this formation and Butts[34] has provisionally designated it as "black shale of Devonian age."

Description.—This formation is divisible into two units, the Marcellus member and the Naples member. The lower (Marcellus) member is composed of black, siliceous, paperlike shales with a total thickness of 150 feet. The upper (Naples) member is composed chiefly of gray to greenish lumpy shales with occasional thin horizons of black fissile shale and has a thickness of approximately 225 feet. The upper boundary of the formation is arbitrarily drawn where the shale changes into a siltstone. Above this horizon the Naples fauna does not occur. The black shale proper resembles bony coal on fresh outcrops, but long exposure brings out the fissile character of the rock. This shale is highly carbonaceous and fracture planes are lined with films of graphitic material. The formation contains a considerable quantity of iron, chiefly in the form of pyrite, and the rock weathers to a rusty brown due to the presence of this material. The upper shale member is distinguished from the lower member by its lack of fissility, its color, and its fossils. However, on the weathered outcrop, the two can scarcely be distinguished.

The "black shale" directly overlies the Onondaga with no evidence of an unconformity.

Paleontology and correlation.—The exact ages of the beds in this formation have been in some dispute. For this reason the writer made careful collections of fossils from both members. The following forms were identified:

Lingula cs. L. clarki Prosser and Kindle.	N
Schizobolus concentricus (Vanuxem).	M, G

[34] Butts, Charles, *op. cit.*, p. 32.

Orbiculoidea sp.	N
Leirorhynchus cf. L. limitare (Vanuxem).	M
Buchiola retrostriata (von Buch).	N
Nucula corbuliformis Hall.	N
Loxonema cf. L. pexata Hall.	G?
Orthoceras subulatum Hall.	M
Probeloceras sp.	N
Manticoceras sp.	N
Styliolina fissurella Hall.	O-N

The forms followed by "M" are clearly Marcellus species, those followed by "N" are Naples forms; those followed by M, G, are Marcellus and Genesee, and those followed by O-N range from Onondaga into Naples. The presence of Hamilton and Genesee forms is open to question, although *Loxonema* is generally considered to be indicative of Genesee age.

The "black shale" bears a definite relation to the Romney shale of West Virginia, northern Virginia, and Maryland. The Romney, however, contains beds of Hamilton and Genesee age as well as Onondaga, Marcellus, and Naples beds. The "black shale," according to Butts,[35] differs from the Romney in lacking beds of unquestionable Hamilton and Genesee age, and also in lacking beds of the Onondaga, which is separated as a mappable unit.

BRALLIER FORMATION

Name.—The Brallier shale was named by Butts[36] from Brallier, Bedford County, Pennsylvania.

Description.—The Brallier formation is composed chiefly of yellowish-clay shales and greenish siliceous shales, with smaller amounts of gray sandstone and greenish siltstones. The siliceous shale is micaceous and brittle and the clay shale soft and porous. The former weathers to a dark iridescent brown and the latter to a yellowish-brown. The sandstones are remarkably even bedded, the beds ranging in thickness from a fraction of an inch up to 15 inches. Some beds, particularly near the top of the formation, are 2 to 4 feet thick. The sandstones are very firm and form ledges on the outcrops. The shales are incompetent and wrinkle and crumple even where adjacent sandstone beds are scarcely bent. The shales, being hygroscopic, weather rapidly into little flat chips. The monotonous sequence of shale and sandstone, with no noticeable variation in lithology, is the most striking feature of this

[35] Butts, Charles. op. cit., pp. 32-33.
[36] Butts, Charles, Geologic section of Blair and Huntington counties, central Pennsylvania: Am. Jour. Sci., 4th ser., vol. 46, p. 52, 1918.

formation. The thickness of the Brallier is approximately 1,500 feet. The formation weathers to soil which is not suitable for agriculture.

The Brallier overlies the "black shale" conformably.

Paleontology and correlation.—The Brallier contains a scanty and diminutive fauna. Small pelecypods, such as *Buchiola,* compose all of the forms seen by the writer. The Brallier is known to be of later Portage age, and to correspond in lithology to the Hatch and Gardeau shales[37] of the Portage in New York State. It corresponds to the Woodmont member of the Jennings formation of Maryland, and probably forms the upper part of the Upper Devonian shales in the Big Stone Gap region.

CHEMUNG FORMATION

Name.—The Chemung formation was named by Hall from Chemung County, New York.

Description.—The Chemung formation is composed of thin-bedded, olive-drab shales and siltstones and brownish-red to purple sandstone. There are only two small patches of the Chemung preserved in the Marion area, one on the top of Mollies Knob in Hungry Mother State Park and the other on the crest of Brushy Mountain west of Marion. (See Pl. 14.) The Chemung has a maximum thickness of 275 feet on Brushy Mountain, northwest of Marion. The lower 50 feet is composed of greenish-gray siltstone. Overlying this siltstone is 150 feet of olive-drab shale in which are intercalated several beds of brownish to purplish sandstone. The shales are finely laminated but the rock is not fissile. The lower part of the formation weathers lumpy. The upper 75 feet of the formation is composed chiefly of light-brown to purplish sandstones, with a few thin horizons of brown shale. The sandstones are rather firm, but they weather rapidly to sand. On Brushy Mountain several beds of fossiliferous glauconitic sandstone occur in the upper 100 feet of the formation. The Chemung siltstones and shales are micaceous at the base of the formation, but gradually less so upward. The Chemung weathers a yellowish brown.

The Chemung is conformable with the underlying Brallier formation.

Paleontology and correlation.—Exposures are few and collecting of fossils is rather difficult. From the lower part of the formation on Brushy Mountain, the writer collected *Spirifer disjunctus, Productella lachrymosa?,* two species of *Chonetes, Camartoechia contracta,* and *Schuchertella chemungensis.* The upper part of the formation contains many fossils, most of which are species of *Productella, Leptodesma*

[37] Butts, Charles, Geologic map of the Appalachian Valley of Virginia with explanatory text: Virginia Geol. Survey Bull. 42, p. 34, 1933.

rogersi, and *L. elongatum.* A thin shale layer 20 feet below the top of the formation contains many species of pelecypods, the most common of which is *Grammysia* cf. *G. elliptica. Modiola* and *Leda* are common in the lower sandstones of the upper 75 feet of the formation.

The Chemung is Upper Devonian in age. It is significant that the Chemung on Brushy Mountain is the most southerly occurrence of this formation in the southeastern belts of the southern Appalachian region, that is in the belts southeast of Walker Mountain. The Chemung is known throughout the Appalachian Valley from southwestern Virginia to western New York.

POST-DEVONIAN DEPOSITS

There are no consolidated rocks of post-Chemung age in the Marion area. The Mississippian, Pennsylvanian, and Permian systems of the Paleozoic are all absent. Also there are no Mesozoic sediments known. Tertiary(?) and Recent gravels and sands are present in scattered patches on the flood plain of Hungry Mother Creek in the south-central part of the Marion area. The writer did not make a study of these deposits in detail, but he believes that the maximum thickness of this material is approximately 30 feet.

IGNEOUS ROCKS

On the Copenhaver farm, 1½ miles north of Marion, a deeply weathered pegmatite dike cuts through the upper part of the Nolichucky shale. There are no exposures of igneous rocks here, but the soil contains mica in flakes 3 to 4 inches in diameter. A petrographic examination of the soil reveals the presence of typical pegmatite minerals. The boundaries of this dike are not clearly indicated, for a thick mantle of soil completely covers the area. As far as the writer was able to observe, the bordering shales have not been metamorphosed, but a more complete examination of these beds would be necessary before a definite statement could be made. The age of this intrusion is not accurately known, but it cuts through the upper Nolichucky shale, and is at least post-Cambrian in age. The occurrence of dikes and plugs of melaphyre and basalt in the Appalachian region, particularly in the vicinity of Monterey, Va., has been noted by Darton,[38] and many types of small intrusions have been mentioned by Watson and Cline.[39] Most of them occur in central-western and northern Virginia.

[38] Darton N. H., U. S. Geol. Survey Geol. Atlas, Monterey folio (No. 61), 1899.
[39] Watson, T. L. and Cline, J. H., Petrology of a series of igneous dikes in central-western Virginia: Geol. Soc. America Bull., 24, pp. 301-334, 1913.

STRUCTURAL GEOLOGY

GENERAL FEATURES

The complex structures of the rocks in the Marion area were formed during the Appalachian Revolution which occurred about at the close of the Paleozoic era. The main component of lateral compression producing the structures came from the southeast, but direct evidence of additional compression from the east, south and southwest is apparent from the accompanying geologic map (Pl. 14). Names and locations of particular folds and faults are indicated on the geologic map.

The major structure of the region is an asymmetrical, overthrust dome. The presence of this structure would seem to account for much of the complex faulting in the region. The imbricate fault block pattern so characteristic of the southern Appalachian region is well exemplified in this area. The Marion region contains parts of two shingle-blocks, the Walker Mountain shingle-block and the Glade-Pond mountains shingle-block. These blocks are separated by the Seven Springs fault which swings irregularly across the area, dividing the typical Appalachian structures with regional trends from the more complicated structures peculiar to the Marion area.

MAJOR FOLDS

MARION DOME

The Marion dome is developed chiefly in the Ozarkian-Canadian systems of rock, and the core of the structure is indicated by the elliptical outcrop area of Conococheague dolomite located 1½ miles northwest of Marion. (See Pl. 17, Sections A-A′, D-D′, and E-E′.) The dome dies out to the southwest in Porter Valley. In Wassum Valley it ends in an overthrust of slight displacement. On the north it loses its surface expression in the mosaic pattern of thrust and normal faults which extend north, northeast, and east from the northern end of Wassum Valley. The dome is overturned on the side cut by the Wassum Valley overthrust, but on all other sides the dips are relatively low away from the apex of the dome. The two blunt salients in the Chepultepec outcrop belt indicate two anticlines, one plunging to the south and the other plunging to the west, which converge toward the dome. The forces producing the folding appear to have come from the east, southeast, south, and southwest, with the main compression coming from the southeast. The formation of the dome probably took place before any of the faulting in the area, but the latter directly followed doming.

MC MULLIN SYNCLINE

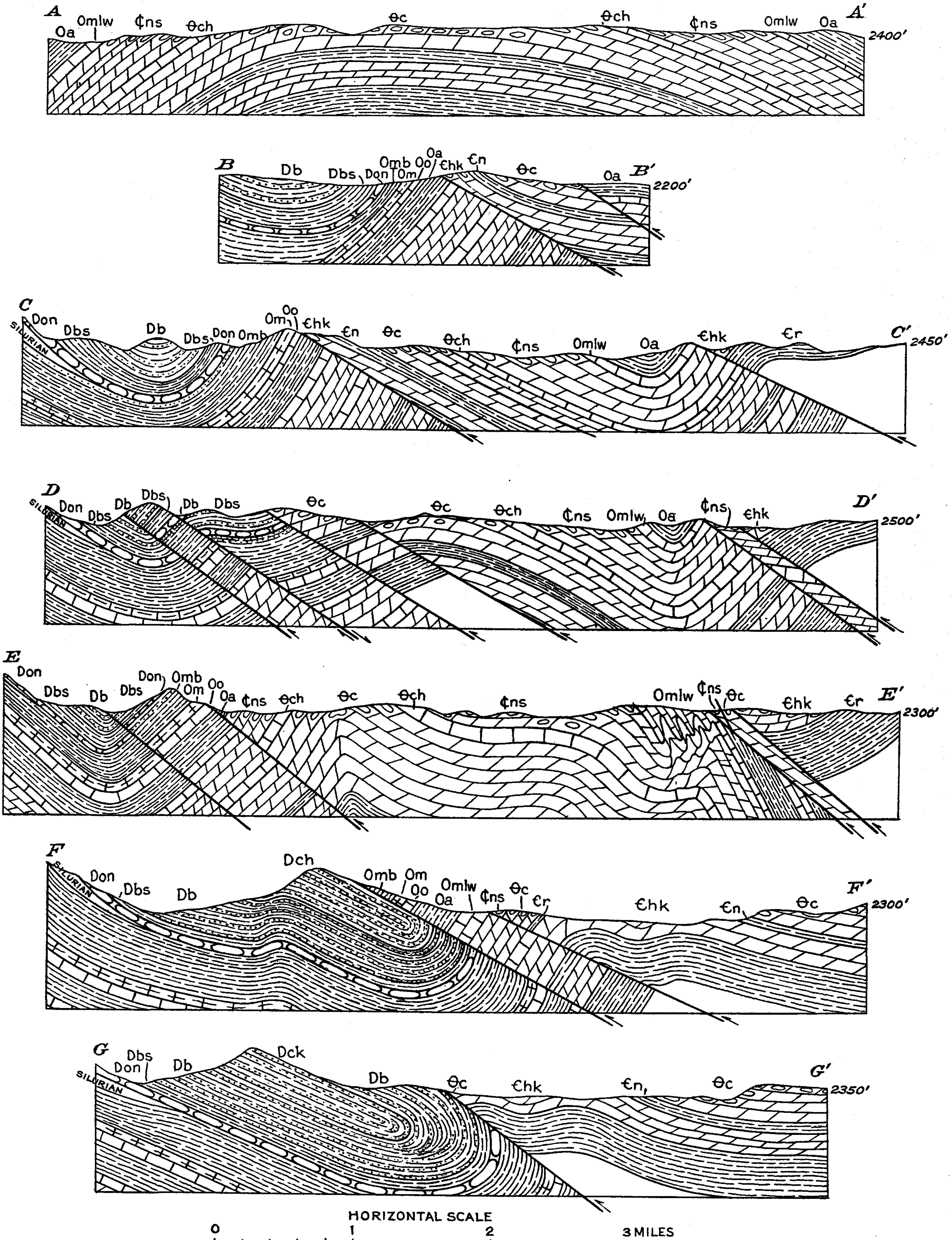
The McMullin syncline extends from McMullin northeast to and slightly beyond Marion, where the strike of the Mosheim-Athens beds swings almost due north. (See Pl. 17, Sections C-C′, D-D′, E-E′.) The syncline ends on the west in a structural basin, where a minor anticline in the Nittany plunges southward. The latter is another off-shoot of the Marion dome. The beds on either side of the syncline dip 40°-50° toward the axis. The beds involved in the structure range from the Mosheim to the Athens. The syncline is terminated on the southeast and south by the Seven Springs overthrust which brings the Honaker, Conococheague, and Nittany formations up against the Athens and Mosheim formations. The formation of this structure appears to be contemporaneous with that of the Seven Springs overthrust, which borders the southeast side of the syncline. Where, locally, displacement along this overthrust has not been great, adjacent parts of the McMullin syncline have been isoclinally folded. This would seem to indicate that both structures were yielding contemporaneously to the same compression, and in those localities where the syncline yielded to isoclinal folding a greater part of the compression was relieved. Hence, less displacement along the overthrust would be necessary adjacent to isoclinal folds.

HOLSTON RIVER SYNCLINE

The southwestern part of the area contains part of a large open syncline which has its northeastward beginning 1 mile southeast of McMullin. (See Pl. 17, Sections E-E′, F-F′, and G-G′.) The structure plunges in a southwest direction which carries it beyond the border of the map. The beds involved in the Marion portion of the syncline are the Honaker, Nolichucky, and Conococheague formations. A wide bulge on the north flank of the syncline between Chilhowie and Seven Mile Ford is of importance in determining the cause of the change of trend of the Seven Springs overthrust in the western part of the area. The Holston River syncline is a normal Appalachian structure except for this bulge, which is probably due to an added thrust from the southwest at the time when the Seven Springs overthrust was forming. This extra compression was sufficient to overthrust the rocks to the northeast instead of to the northwest along the Seven Springs fault northeast of Seven Mile Ford.

BRUSHY MOUNTAIN SYNCLINE

The Brushy Mountain syncline extends northeastward across the northern part of the area, parallel to Walker Mountain on the north. (See Pl. 17, Sections B-B′, C-C′, D-D′, E-E′, F-F′, and G-G′.)



Structure sections of the Marion area, Virginia. Єr, Rome formation; Єhk, Honaker dolomite; Єn, Nolichucky shale; Ꝋc, Conococheague dolomite; Ꝋch, Chepultepec limestone; ₵ns, Nittany and Stonehenge dolomites; Omlw, Mosheim, Lenoir, and Whitesburg limestones; Oa, Athens shale; Oo, Ottosee limestone; Om, Moccasin limestone; Omb, Martinsburg shale; Don, Onondaga chert; Dbs, black shale; Db, Brallier shale; Dch, Chemung shale.

The formations involved in the structure range from the Athens to the Chemung. In the western part of the area, on Brushy Mountain, the syncline is overturned and isoclinal. Here the Chemung is folded upon itself and appears to be twice as thick in its outcrop on the southeast slope of that mountain. The rocks dip 35°-45° SE. In its central part, the syncline is cut by a small overthrust which dies out to the east. This section of the syncline was compressed more than the portions to the northeast and southwest, due to the doming to the south of it. The beds of the Brallier on either side of the fault dip 30°-45° toward the overthrust. The eastern section of the syncline is an open structure and the beds dip gently toward its axis. Mollies Knob (Marleys Top) which rises above the trough of the structure is capped with nearly horizontal Chemung beds. (See Pl. 15, A.)

SEVEN MILE FORD ANTICLINE

The Seven Mile Ford anticline is situated to the north of the Holston River syncline and is bordered on the north and transversely cut off on the east by the Seven Springs fault. (See Pl. 17, Sections F-F′ and G-G′.) Minor warpings and folds on the crest of the anticline make for a wide outcrop area of the Honaker beds. The structure plunges to the southwest slightly and opens to the east. East of Seven Mile Ford the Seven Springs overthrust cuts across the structure and, eastward, only the south limb of the structure is revealed at the surface. The structure of the general anticline is further complicated by a series of small but sharp transverse folds all within the Honaker. These beds have a trend of N. 30° W. The Honaker is cut by an oblique thrust fault in the western part of the area, but the vertical displacement is not sufficient to make a break in its outcrop area.

MINOR FOLDS

The isolated outcrop of Rome shale in the western part of the area is due to a minor anticline with a northeast-southwest axis, which has brought the upper Rome to the surface. The anticline is faulted down its crest by an overthrust of small displacement. The orientation of this fold is in sharp contrast to the folds in the Honaker just described.

In Porter Valley the wide expanse of Athens shale is due to local crumplings which reverse the dip of the beds. In general, however, two folds are evident. The northern part of the belt lies in an anticline pitching to the southwest and opening to the east into the Marion dome. South of this structure is a broad open syncline which plunges to the southwest also, but it is cut off in that direction by the Seven Springs fault.

The wide expanse of the Mosheim-Whitesburg series in the McMullin syncline is due to the development of a number of isoclinal folds within that group of beds. The bottom of the McMullin syncline has been bowed up and strongly compressed locally. (See Pl. 17, Section E-E′.) These structures have relieved much of the compression which also produced the Seven Springs overthrust, and consequently the latter structure has less displacement to the south of these folds than it has to the east and northwest. The presence of these isoclinal folds has transformed the extreme western part of the McMullin syncline into a structural basin. The structures die out rapidly to the east and west.

The drag folds and normally faulted folds on the northern flank of the McMullin syncline east of McMullin represent the eastward extensions of the folds just described. The similar structures just north of Marion were produced at the time when a force from the east was acting to form the Marion dome. The sudden and abrupt change in the strike of the beds in this locality was partly relieved by this minor faulting.

North of Marion along Hungry Mother Creek road, there are two transverse folds indicated by the gentle salient and reentrant in the Moccasin-Ottosee belt of outcrop running northeast of the creek road. The western structure, a syncline, opens to the Brushy Mountain syncline on the north and the anticline to the east plunges to the southeast, and it is cut off abruptly on the southeast by a fault. Although the beds are cut off by this overthrust, the older beds on the upthrown side of the fault and the fault plane itself are also slightly folded in the same structures, indicating that they were formed after the overthrust.

Numerous other folds and crumplings of the beds are present in the rocks of this area but do not contribute to the areal expression of the rock formations. The Rome, Martinsburg, Athens, and Brallier shales are all very incompetent and, by the formation of innumerable folds and minor faults, these rocks have alleviated much of the horizontal stresses to which all of the formations have been subjected.

MAJOR FAULTS

SEVEN SPRINGS OVERTHRUST

The Seven Springs overthrust separates the Marion area into parts of two shingle-blocks. (See Pl. 17, Sections C-C′, D-D′, E-E′, F-F′, and G-G′.) Unequal displacement along the fault and sharp variations in the trend of the overthrust bring several different formations in contact with one another. At the western border of the map, the Honaker is in contact with the Brallier and the vertical displacement along the fault plane is approximately 8,700 feet. To the east the Conococheague is slightly overthrust upon the Nittany dolomite, with a displacement of approximately 1,500 feet. Further eastward where the fault trend swings southeastward the Honaker is thrust upon the Athens with a vertical displacement of approximately 6,500 feet. The line of the fault is clearly indicated in this locality by a well-developed shear zone in the Athens shale on the downthrown side. One mile east of Seven Mile Ford the fault again swings eastward. At this point the fault splits into three branches, each of which is of relatively small displacement. The north branch lies between the Mosheim and the Nittany. Both formations dip sharply to the southeast. The upper part of the Nittany or *Lecanospira* zone has been cut out by the fault. The total displacement along this branch has not been in excess of 600 feet. Farther to the east the Nittany is thrust upon the Athens and the displacement is about 900 feet. The middle branch lies between the Conococheague and the Nittany and the displacement has been sufficient to cut out the upper Conococheague, the Chepultepec, and the lower part of the Nittany. The displacement appears to be about 900 feet. The south branch lies between the Honaker and the Conococheague and only about 500 feet of beds are missing. The middle and south branches join to the east and the Honaker is brought in contact with the Nittany. Further to the east the upper branch joins the lower. In the vicinity of Marion, the Honaker is thrust upon the Athens and Mosheim with a vertical displacement of about 6,500 feet.

East of McMullin the direction from which the compressional force was applied was southeast, but west of McMullin the major compression came from the southwest. The small southward component of the force is shown in the small displacement along the fault, north of Seven Mile Ford, and the major southwest component is shown by the great displacements of 6,500-8,700 feet to northwest and east of this point. The small net throw of the split fault south of McMullin is in part due to the fact that there was less compression applied at this point normal to the trend of the fault, that is, from a southerly direction. Greater compression was applied from the southwest to the areas west of McMullin, and from the southeast to the areas east of McMullin. Also the close isoclinal folds to the north of the fault have taken up much of the pressure which otherwise could have been relieved only by increased displacement along the overthrust. It seems probable that the Seven Springs overthrust was formed during the later stages in the development of the Marion dome. Compression from the southwest was necessary to form the dome, and it seems likely that compression from this direction also produced the abrupt change in the strike west of McMullin. This change in trend is obviously not one produced by erosion because the fault plane as well as its trace changes trend. From the geologic map alone it might be inferred that the Seven Springs fault changes trend because of erosion alone. The fault is unlike certain other overthrusts, such as the Pulaski fault, in that it is notably a high-angle thrust.

BRUSHY MOUNTAIN OVERTHRUST

This overthrust cuts across the Seven Springs overthrust 2 miles northeast of Chilhowie and trends northeast, dying out in the middle portion of the Brushy Mountain syncline. (See Pls. 16 and 17, D-D′.) It truncates the line of outcrop of the Athens-Romney group of beds along the southeast slope of Brushy Mountain. Only in this region is the fault of great displacement. The formation of the overturned isoclinal syncline to the northwest failed to relieve the great compression producing it, and overthrusting along this fault plane followed. This fault is clearly later than the Seven Springs overthrust, which is offset by the Brushy Mountain overthrust. The formation of the small anticline in the Rome shale which is abruptly terminated on the northwest by that structure was developed at the same time as the fault.

GREENWOOD OVERTHRUST

The Greenwood overthrust is well within the northern boundary of the Marion dome. (See Pl. 17, Sections B-B′, C-C′, and D-D′.) From the geologic map it is evident that the rocks of the upthrown side of the fault are greatly offset by erosion from those of the downthrown side. The vertical displacement along the fault is less than 800 feet, but the horizontal separation of the beds is much greater. The magnitude of the horizontal displacement of the upthrown side was great enough to overturn the Marion dome on the northwest side in Wassum Valley and to produce the slight overthrust which cuts the dome in that valley. The Greenwood overthrust directly followed the formation of the Marion dome.

WASSUM VALLEY OVERTHRUST

This overthrust cuts the Athens formation and the vertical separation of the beds has not been sufficient to cut out entirely the outcrop of the Athens. (See Pl. 17, Section E-E′.) The causes producing the overthrust have been noted above, and to the southwest the fault dies out where the thrust of the Greenwood fault failed to deform the beds further. Both of these related faults appear to converge and then to die out suddenly in Wassum Valley. The thrust of the Greenwood fault would have overturned the Brushy Mountain syncline to the northwest, had it not been that the Athens shale gave away as it did. The Wassum Valley fault clearly follows the faulting of the Marion dome.

HUNGRY MOTHER OVERTHRUST

The Hungry Mother overthrust parallels the Greenwood overthrust and was apparently formed at the same time as that structure. (See Pl. 17, Section C-C′.) The displacement along this fault is chiefly vertical, while that of the overthrust on the south was chiefly horizontal. The fault passes into the normal fault bordering the east side of the "black shale" faulted wedge. The writer was unable to ascertain the relations between these two faults in the field. The vertical displacement along the Hungry Mother Creek fault is about 6,500 feet. The fault antedates the formation of the "black shale" fault wedge which cuts it. It appears to the writer that this fault represents the southern extension and terminus of the great Pulaski overthrust.

"BLACK SHALE" FAULT WEDGE

This complex wedge is bordered by two converging normal faults. (See Pl. 17, Section D-D′.) The wide expanse of "black shale" is due to its low dip. The formation outcrops over an area within which there is a relief of more than 400 feet, which is greater than the thickness of the formation. Slight upward undulations in the formation make this unusual topographic expression of the formation possible. The Martinsburg, Onondaga and "black shale" outcrops within the wedge fail to show any conformity of dip and strike with the belts on any side of it. The wedge appears to have been formed from a segment of the southeast flank of the Brushy Mountain syncline. This segment was rotated about 60° counterclockwise and at the same time differentially tilted and normally down faulted to the southeast. This tilting and rotation reduced the dip of the beds to a minimum, save for the slight upbowings produced by the up-tilting. The normal faults bordering the wedge are clearly younger than the overthrusts to the south. On the other hand, the formation of the structure seems to indicate that it was an outgrowth of the formation of the Marion dome.

MINOR FAULTS

Associated with the shaly formations are many small thrust and normal faults, most of which fail to reveal themselves in succeeding formations. Such structures are common to incompetent formations throughout the Appalachian region. Most of them are of such small magnitude that they do not change the areal distribution of the formations on the geologic map, and for this reason they are not treated in this report. Conspicuous minor faults cut the Nittany, Mosheim, Lenoir, Whitesburg, and Athens on the north side of the McMullin syncline. They appear to have been derived from drag folds which were formed by severe compression of the original synclinal structure. Evidence of this great compression is shown by the isoclinal structures near McMullin.

OTHER STRUCTURES

Joints, fractures, and irregular fissures occur in all of the rocks of the Marion area. The orientation of different sets of these structures to one another and to the general structures of the region is a distinct and complex problem, not discussed in this paper.

RELATION OF IGNEOUS INTRUSION TO STRUCTURE

The pegmatite dike in the Marion area would seem to indicate that possibly the dome structure resulted from igneous intrusion. Such an hypothesis is not easily substantiated by a close examination of the field evidence. The age of the dike is not known, except that it is younger than the Honaker formation. Also, there is no indication that the dike is an offshoot of a larger igneous mass beyond the local area of the dike. On the other hand, the Ottosee limestone north of the dike has been altered to true marble. Thin sections of the rock show the presence of garnet, epidote and possibly wollastonite, all of which are common contact metamorphic minerals associated with marbles. This study does not indicate the age of the intrusion and this must be determined before the igneous body can be said to be directly responsible for the formation of the Marion dome. If the dome were the result of igneous intrusion, then the faults associated with the dome should be normal faults instead of overthrusts. As this is not true, igneous activity can not be said to have played a part in the formation of the structures of the Marion area.

PERIODS OF DEFORMATION

In recent years attention has been called to the possibility of two periods of deformation in the southern Appalachian region. Mathews[40] has worked out a grid pattern for transverse structures which cut the structures of normal trend in Giles County, Virginia. The numerous transverse structures are of no regular or uniform orientation. The two minor transverse anticlines along the Hungry Mother Creek road, north of Marion, appear to be later than the fault on the south, for the rocks on either side of the fault are deformed in the folds. These are the only structures which are clearly later than adjacent overthrusts. There is no grid pattern formed by the intersection of the transverse structures with the northeast-southwest structures. All of the transverse structures, with the possible exception of the two structures mentioned above, can be explained on the basis of one period of deformation.

[40] Mathews, A. A. L., New lights on Giles County structure (abstract): Virginia Acad. Sci. Proc. for 1931-1932, p. 61, 1932.

THE BIG A MOUNTAIN AREA, VIRGINIA

BY

Robert L. Bates

State Commission on Conservation and Development

VIRGINIA GEOLOGICAL SURVEY

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The Big A Mountain Area, Virginia[1]

By Robert L. Bates[2]

INTRODUCTION

LOCATION OF THE AREA

The Big A Mountain area lies in southwestern Virginia, mostly in Russell County northwest of Honaker. (See Fig. 10.) A small part of the area is in Buchanan County, the summit of Big A Mountain forming the county boundary. The area is bounded on the west by the 82° 5′ meridian, on the south by the 37° parallel, on the east by a north-south line through Putnam, a mile east of Honaker, and on the north by an east-west line crossing Sandy Ridge about 1½ miles north of the summit of Big A Mountain. About three-fifths of the area lies in the southeast rectangle of the Bucu quadrangle, and the remainder in the southwest part of the Richlands quadrangle. The topography is shown on Plate 19.

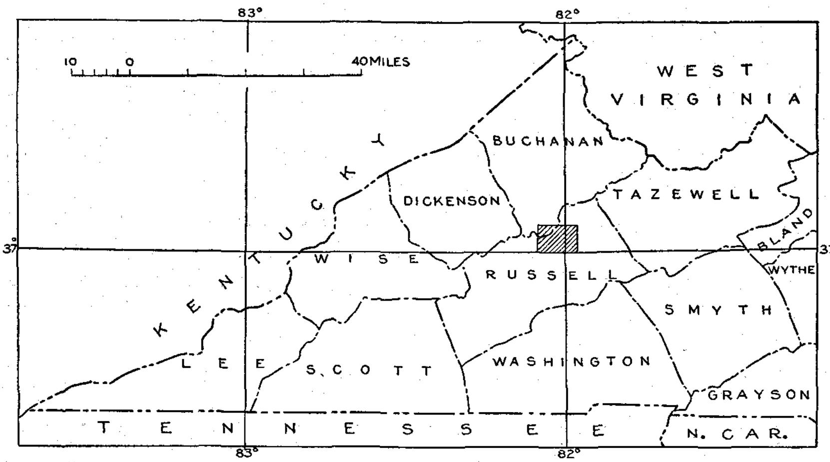

Figure 10.—Index map of the Big A Mountain area, Virginia.

The only important town is Honaker, near the southeast corner of the mapped area. A paved road connects Honaker with the main valley road, U. S. Highway 19, at Old Rosedale, 6 miles to the southeast. There is one paved road in the mapped area,

[1] A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in the Department of Geology, State University of Iowa, February, 1936.
[2] Temporary assistant, Virginia Geological Survey.

north and west from Honaker which leaves the map near the Russell-Buchanan county line on Sandy Ridge north of the summit of the mountain. The other roads are secondary. The Clinch Valley division of the Norfolk and Western Railway crosses the southeast corner of the area, through a tunnel in a small divide just west of Honaker and then utilizes the valley of Thompson Creek. The drainage is by small streams; that part of the area southeast of Sandy Ridge is drained by tributaries of Clinch River, and the remainder by Russell Fork and its branches.

SCOPE OF THE REPORT

This report comprises a more detailed geologic map of the area than has heretofore been made, and a detailed discussion of the stratigraphy. The making of this map was the immediate object of the field work. The writer has dealt with fossils only secondarily, as a help in determining stratigraphic facts, as detailed work on the paleontology is not a purpose of the report. The structure of the rocks is discussed and structure sections are included.

ACKNOWLEDGMENTS

The writer wishes to express his gratitude to Dr. Arthur Bevan, State Geologist, and to the Virginia Geological Survey for making this project possible. In the field the writer had the valuable assistance of Dr. Herbert P. Woodward, to whom he extends thanks. He is also indebted to Dr. Charles Butts for constructive criticism of the mapping. Grateful acknowledgment is made to Drs. A. C. Trowbridge and A. K. Miller, of the Geology Department of the State University of Iowa, for helpful suggestions during the writing of the report. Finally the writer wishes to record the hospitality and interest of the residents of Honaker and vicinity.

PREVIOUS WORK

In 1894, Campbell[3] surveyed the Tazewell quadrangle for the United States Geological Survey. His geologic map includes that part of the Big A Mountain area east of the Bucu quadrangle boundary, which is about 1¼ miles west of Honaker. The southwestern part of the Tazewell quadrangle has been remapped topographically as the Richlands sheet. It bounds the Bucu quadrangle on the east.[4] Because of the small scale of the Tazewell map,

[3] Campbell, M. R., U. S. Geol. Survey Geol. Atlas, Tazewell folio (No. 44), 1897.
[4] Only that part of the Richlands quadrangle north of the Clinch Valley division of the Norfolk and Western Railway was mapped topographically.

and also because rocks then mapped as formations have since been subdivided, that geologic map shows only an outline of the geology.

Campbell[5] mapped also the Bristol quadrangle which lies immediately south of the area mapped by the writer. That map is on the same scale as the Tazewell sheet and thus shows only the regional geology.

Hinds[6] included a geologic map of the Bucu quadrangle in his report on the coal of that area, but the folded Paleozoic rocks in the Big A Mountain area were undifferentiated. In a report two years later on Buchanan County, he[7] includes on the geologic map that part of the Big A Mountain area in the county—a relatively small portion northwest of Sandy Ridge. Wentworth[8] gives only a very small portion of the Big A Mountain area on his map of the coal-bearing part of Russell County.

The only geologic map of the Big A Mountain area was made by Butts[9] in 1928.

STRATIGRAPHY

GENERAL STATEMENT

The rocks of the area are all sedimentary and range in age from Lower Cambrian to basal Pennsylvanian. (See Pl. 18.) They comprise 22 formations with an aggregate thickness of more than 13,000 feet. Slight local metamorphism has taken place along major faults, and as a result shales are glazed on bedding planes and limestones that are typically thin bedded have in places become massive and more indurated.

The coal-bearing, relatively flat-lying Pennsylvanian rocks in the northern part of the area were not included because they have been discussed in numerous publications of the Virginia Geological Survey. The youngest formation studied was the Lee conglomerate, of Pottsville age.

The Cambrian rocks are shales and dolomites, the Ozarkian and Canadian comprise sandy and cherty dolomites, and the Ordovician consists chiefly of limestones. The Silurian consists of red and white sandstones and conglomerates and the Devonian of shales with some limestone. Mississippian rocks are sandstones, shales, and limestones; the Pennsylvanian formations are coarse clastic rocks.

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[5] Campbell, M. R., U. S. Geol. Survey Geol. Atlas, Bristol folio (No. 59), 1899.

[6] Hinds, Henry, The coal resources of the Clintwood and Bucu quadrangles, Virginia: Virginia Geol. Survey Bull. 12, Pl. 9, 1916.

[7] Hinds, Henry, Geology and coal resources of Buchanan County, Virginia: Virginia Geol. Survey Bull. 18, Pl. 2, 1918.

[8] Wentworth, C. K., The geology and coal resources of Russell County, Virginia: Virginia Geol. Survey Bull. 22, Pl. 28, 1922.

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

There are several unconformities, but only one is of major importance.

Following the present usage of the Virginia Geological Survey, the stratigraphic classification of Ulrich is used in this report. The terms Ozarkian and Canadian reserve the names Cambrian and Ordovician for use in their restricted senses. The division of the lower and middle Ordovician limestones into the Stones River, Blount, and Black River groups is followed.

CAMBRIAN SYSTEM

ROME FORMATION

Name.—The rocks now termed the Rome formation are widespread, extending from the Cumberland Valley in Pennsylvania to Alabama. Each of the early workers in Appalachian geology coined his own term for the formation; thus several names have been applied to it. All these names except Rome, Waynesboro, and Watauga have been discarded. The name Rome was first applied to the formation by Hayes,[10] from the city of Rome, in Floyd County, Georgia. The name Watauga was proposed by Keith[11] some years later, from Watauga River in northeastern Tennessee. As the name Rome has priority[12] and is equally applicable, it should be universally used.

Description.—In the Big A Mountain area, as elsewhere, the Rome is a heterogeneous assemblage of shale and sandstone with some limestone and dolomite. The red shales of the Rome are typical and comprise, perhaps, a quarter of the mass. They occur in thicknesses up to 100 feet and are easily recognizable. There are also green and buff shales less prominent than the red ones. Some thin lenses of sandy gray-brown shale occur, not unlike that in the Nolichucky shale.

Impure thin-bedded fine-grained sandstone is found throughout the formation. Some of it approaches shale and much of it is calcareous. The calcareous beds weather to a yellow ochre. Thick beds of dolomite occur also, especially toward the top of the formation, where there are several zones, 3 to 4 feet thick, of gray-black dolomite similar to that in the Honaker formation. A few thin beds of pure limestone are found.

Much of the shale and sandstone of the formation carries ripple marks, rill marks, and other indications of shallow-water

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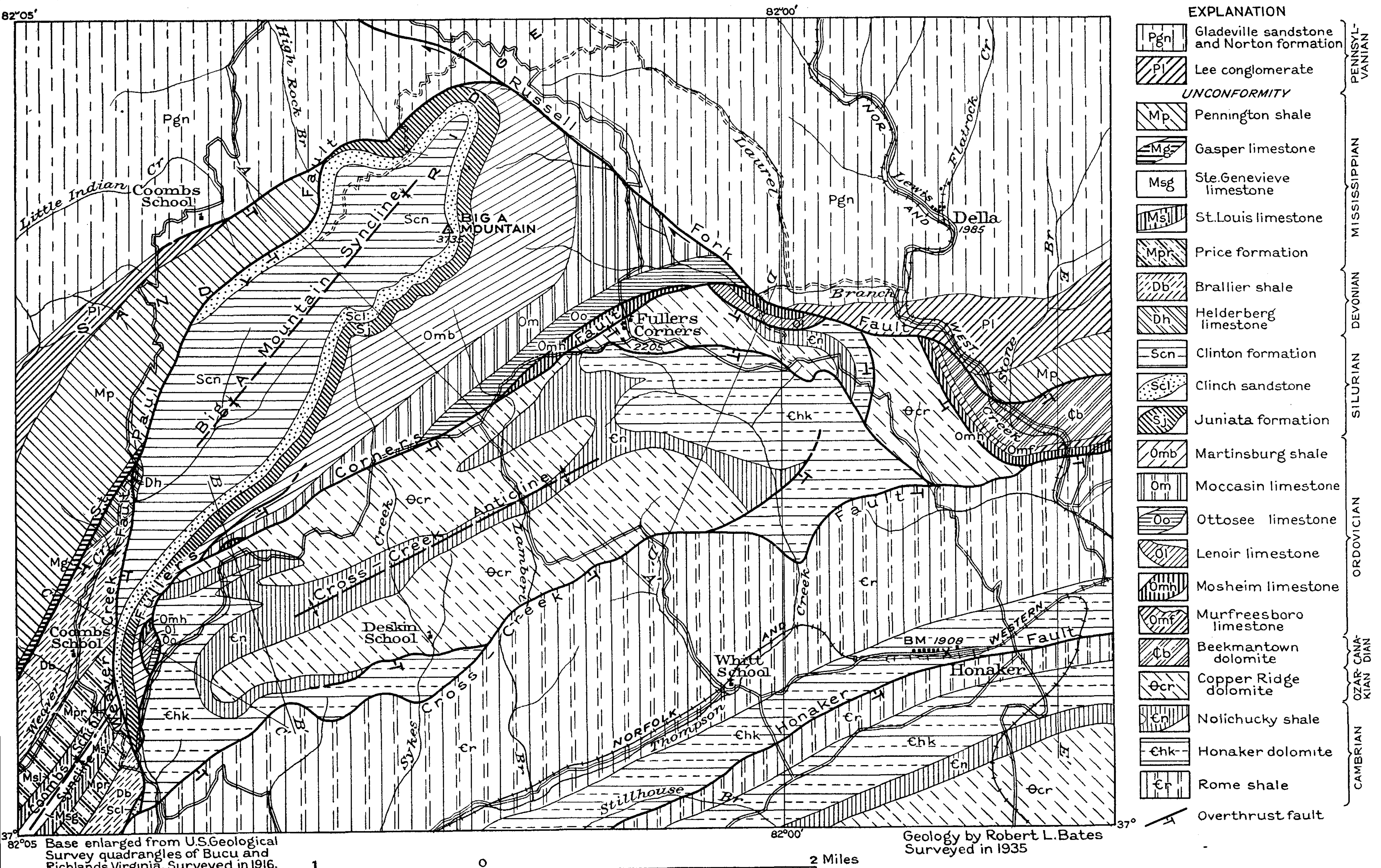
[10] Hayes, C. W., The overthrust faults of the southern Appalachians: Geol. Soc. America Bull., vol. 2, p. 143, 1891.

[11] Keith, Arthur, U. S. Geol. Survey Geol. Atlas, Cranberry folio (No. 90), p. 3, 1903.

[12] Woodward, H. P., Age and nomenclature of the Rome ("Watauga") formation of the Appalachian Valley: Jour. Geology, vol. 37, pp. 594-595, 1929.



GEOLOGIC MAP OF THE BIG A MOUNTAIN AREA, VIRGINIA.

The formation labeled the Copper Ridge dolomite is the Conococheague formation and is so discussed in the text.

deposition. The intercalated beds of shale and limestone indicate that conditions of deposition must have been unstable.

As in other Appalachian areas where folding and faulting have affected the lower Paleozoic rocks, the Rome in the Big A Mountain area has been considerably compressed and sheared. There are sudden changes in strike and dip, small slips on bedding planes, and other similar indications of deformation. Considerable fracturing has occurred.

Topographic expression.—The Rome produces a series of steep conical hills, generally more than 100 feet in height. (See Pl. 20, A.) These knobby hills strongly resemble those made in the Nolichucky shale. The Rome soil is poor and thin. It supports a good stand of trees, but where cleared gives hilly, nearly barren pasture land.

Thickness.—Due to deformation, the thickness of the Rome formation is difficult to obtain in the Big A Mountain area. Campbell reports its thickness as more than 600 feet in the Tazewell area, immediately to the east, and 1,000 feet in the Bristol area. A close approximation of the thickness in the Big A Mountain Area is probably about 1,000 feet.

Paleontology and correlation.—Fossils are not plentiful in the Rome, and no recognizable forms were collected. The fossils occur either in a gray-black, coarse-grained limestone, in which they are highly macerated and scattered, or in a light-gray, calcareous sandy shale. Specimens collected from the limestone contain probable remnants of the trilobite *Olenellus*. This is the diagnostic Rome fossil which places the formation in the Lower Cambrian.

On the basis of paleontology and lithology, the Rome of southwestern Virginia has been correlated by others[13] with the Rome shale in Georgia, the Montevallo shale in Central Alabama, the Watauga shale in western North Carolina, and the Waynesboro shale in northern Virginia, Maryland, and Pennsylvania.

HONAKER FORMATION

Name.—The type locality of the Honaker formation is in the Big A Mountain area. In 1897, Campbell[14] named the formation from the numerous well-exposed sections in and around the town of Honaker.

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[13] See Cooper, B. N., Stratigraphy and structure of the Marion area, Virginia: Thesis, State Univ. of Iowa, 1935. Published in this Bulletin.

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

Description.—In its most characteristic occurrence, the Honaker is a thick-bedded, very dark, fairly pure dolomite. It contains a few thin layers of limestone, which are locally interlaminated with the dolomite. There are also crenulate bands of dolomite of different degrees of dark color. Some of the rock has very small black specks through it. The texture is neither very dense nor very coarse. The dolomite is rough on weathered surfaces.

The Honaker weathers characteristically. It is not shaly or platy. Weathered fragments grade down from angular blocks as much as 1 foot in diameter to grains about equivalent to sawdust particles. This has been referred to as a "mealy" soil. Another distinguishing characteristic of the weathering product of the dolomite is its rich, red-brown, ochreous color. Sandstone and chert are lacking in weathered residues.

Topographic expression.—Numerous sink-holes occur in outcrops of the Honaker formation, indicating a high solubility. Many water-worn ledges cropping out through a thin reddish-brown soil are other characteristic features. Though the soil is not very thick as a rule, it is fertile enough to support a stand of bluegrass and is generally cleared for pasture land.

Thickness.—The Honaker dolomite is from 1,000 to 1,200 feet thick in the Big A Mountain area.

Paleontology and correlation.—It is thought that the Honaker has conformable relations with the beds above and below it. There are some thick dark-colored beds of dolomite in the uppermost Rome, which resemble the Honaker, and similar dolomite occurs at intervals in the Nolichucky.

Fossils are very scarce in the Honaker dolomite. None was collected in the Big A Mountain area, but the writer found specimens of chertified *Cryptozoon* in the formation a few miles to the south.

The band of Honaker in the type locality grades laterally into the Rutledge limestone, Rogersville shale, and Maryville limestone to the southwest. They are thought to be Middle Cambrian in age.[15] In central and northern Virginia, the Honaker is included in the Elbrook formation.

NOLICHUCKY FORMATION

Name.—The type locality of the Nolichucky formation is along Nolichucky River in Greene County, Tennessee. The name was first published by Campbell.[16]

[15] Butts, Charles, Geologic map of the Appalachian Valley of Virginia with explanatory text: Virginia Geol. Survey Bull. 42, p. 7, 1933.

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

Description.—The Nolichucky consists of drab-colored sandy shale, which weathers fissile, and thin-bedded flaggy calcareous sandstone. There are a few limestone layers and several thick beds of dolomite. Rill and ripple marks and fucoidal imprints are common. These are indications of shallow-water or strand-line conditions of deposition during at least a part of Nolichucky time. The sandstone beds vary in thickness from less than 1 inch to 8 inches or more. They are hard and gray when fresh but weather to soft brown blocks. Fossils occur in the sandstone and the shale.

Topographic expression.—The Nolichucky formation gives rise to a type of topography which is similar to that of the Rome formation. The steep conical hills vary in height from 100 to 300 feet or more. As they are generally cleared, they are very striking.

The Nolichucky soil is thin and poor, being composed of tiny chips and flakes of shale. A slight covering of vegetation grows on the Nolichucky hills, and consequently the soil is commonly exposed where the steep slopes have been eroded. The color of the soil, as of the shale beneath, is gray-brown.

Thickness.—The Nolichucky formation is about 400 feet thick in this area.

Paleontology and correlation.—Butts[17] reports a fossiliferous limestone just above the contact of the Nolichucky and the underlying Honaker, but if present in the Big A Mountain area it is inconspicuous.

The Nolichucky is sparingly fossiliferous in this area. Highly macerated organic remains occur in a few thin beds of dark oölitic limestone, very similar to material found in the Rome formation. Better preservation is characteristic of some of the thin sandstone layers, from one of which the following forms were collected and identified:

Crepicephalus sp.
Acrotreta kutorgai Walcott.
Lingulella sp.

The trilobite, *Crepicephalus,* proves the early Upper Cambrian age of the formation.

The Nolichucky is a distinct formation south of Giles County, Virginia; to the north it is combined with the Honaker dolomite and forms the upper part of the Elbrook formation. To the south, the Nolichucky is equivalent to the upper part of the Conasauga

[17] Butts, Charles, Geologic map of the Appalachian Valley of Virginia with explanatory text: Virginia Geol. Survey Bull. 42, p. 8, 1933.

formation of Alabama. The Nolichucky is the highest formation of the Cambrian system in this area. An unconformity between the Nolichucky and the Copper Ridge dolomite is indicated by the absence of the Brierfield, Ketona, and Bibb dolomites of Lower Ozarkian age. These formations aggregate 2,500 feet in thickness and crop out in Alabama and southern Tennessee.

OZARKIAN SYSTEM

COPPER RIDGE FORMATION

Name.—The term Copper Ridge was first applied by Ulrich[18] from a prominent ridge of the same name made by the formation in southwestern Virginia and eastern Tennessee.

Description.—The Copper Ridge in the Big A Mountain area is a thick-bedded, light-gray and medium to coarsely crystalline dolomite. The formation carries an abundance of light-colored chert, and chertified oölites are common. The chert is not of the nodular type, but occurs in angular blocks and is seen in most places only on weathered surfaces.

Layers of pure quartz sandstone occur throughout the Copper Ridge formation. They are variable in both vertical and horizontal occurrence. When fresh, the sandstones are hard and either white or grayish; when weathered they become buff-colored, soft and friable.

The formation generally weathers to large slabs or flattish blocks. Weathered surfaces of the dolomite are rough and gritty, due to the presence of partly weathered grains of dolomite. The soil of the Copper Ridge is thick, contains considerable chert, and is fairly fertile. It is in contrast to the non-cherty, non-sandy thinner soil of the Honaker dolomite.

At several places in the Big A Mountain area, as also to the south of it in Russell and Scott counties, a characteristic lithologic bed occurs at the top of the Nolichucky shale. This is a limestone about 25 feet thick, which on weathering shows a noticeable banding, due probably to laminations of clay within the limestone. These beds are easily distinguished and indicate the uppermost Nolichucky. Fossils of Nolichucky age have been found in the limestone in Lee County.

Paleontology and correlation.—The Copper Ridge contains no diagnostic fossils, though chertified heads of *Cryptozoon* have been found. The age of the formation, however, is determined from the fact that it grades laterally into the Conococheague limestone northwest of Tinker Mountain near Roanoke, and the Conococheague carries a trilobite, *Tellerina,* indicating its age as Early Ozarkian.[19]

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

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

Thickness.—The Copper Ridge dolomite is from 1,100 to 1,200 feet thick in the Big A Mountain area.

Stratigraphic relations.—The Chepultepec limestone, which normally lies between the Copper Ridge dolomite and the overlying beds of Beekmantown age, is missing at exposures in the Big A Mountain area. At no place in the area, however, is the contact between the Copper Ridge and the Beekmantown exposed.

CANADIAN SYSTEM

Near the east edge of the Big A Mountain area, along Lewis Creek, there are beds of dolomite below the Murfreesboro formation which are referred to the Beekmantown group, or its equivalent in Virginia. As it seems inadvisable in this study to attempt subdivision of these beds into named formations, they are here designated simply as "Formations of Beekmantown Age."

FORMATIONS OF BEEKMANTOWN AGE

Name.—The name Beekmantown was first used by Clarke and Schuchert,[20] the type locality being the town of Beekmantown, Clinton County, New York.

Description.—The beds of Beekmantown age in this area as in adjacent regions consist of thick-bedded argillaceous cherty dolomite. The rock varies in texture from dense and tough to moderately granular. The color is uniformly light, tints of gray, cream, and pink being common. The dolomite weathers to a soiled gray-brown. The soil is thin and cherty.

Thickness.—Although cut off on the north by a fault, there are 650 feet of the beds present on the Lewis Creek road.

Paleontology and correlation.—Fossils occur but generally are found only in the residual chert, and were not collected in this area. The stratigraphic position of the beds below the Murfreesboro and their lithology show them to be Beekmantown. The equivalents of these formations are known from Pennsylvania to Alabama, and the upper Beekmantown, which is probably at least partly represented here, is correlated with the Cotter and Powell formations of Missouri, and with the Shakopee in the upper Mississippi Valley. The lower part carrying the gastropod *Lecanospira* is correlated with the Roubidoux of Missouri, the Longview of Alabama, and the Nittany of Pennsylvania.

[20] Clarke, J. M., and Schuchert, Charles, The nomenclature of the New York series of geological formations: Am. Geologist, vol. 25, p. 117, 1900.

ORDOVICIAN SYSTEM

STONES RIVER GROUP

MURFREESBORO FORMATION

Name.—The term Murfreesboro was first used by Safford and Killebrew,[21] from the town of Murfreesboro, Tennessee.

Description.—The Murfreesboro consists of red and gray dolomite, and red and green shale. The following measured section shows its composition:

Section of the Murfreesboro formation on the Lewis Creek road, northeast of Honaker, Virginia

Mosheim formation

Murfreesboro formation:	Thickness Ft.	In.
7. Gray-green dolomite with shale; weathers checky; some appears vaughanitic	40	
6. Gray, sandy, massive dolomite with shale partings; weathers checky; occurs in beds about 1 foot thick	25	
5. Green, red, and gray dolomite, checky and crumbly; some shale	10	
4. Green shale		6
3. Massive red dolomite	5	
2. Red shale		6
1. Massive gray-green dolomite	8	
	89	

Beekmantown beds.

Correlation.—Butts[22] places the Murfreesboro in the Stones River group, making it basal Ordovician in age. The Murfreesboro extends into middle Tennessee, where it underlies the Ridley formation.

MOSHEIM FORMATION

Name.—The Mosheim was first named by Ulrich[23] from Mosheim, Greene County, Tennessee.

Description.—In the Big A Mountain area, as elsewhere in the southern Appalachian region, the Mosheim is a light-gray pure compact

[21] Safford, J. M., and Killebrew, J. B., The elements of the geology of Tennessee, Nashville, Tenn., 1900.

[22] Butts, Charles, Geologic map of the Appalachian Valley of Virginia with explanatory text: Virginia Geol. Survey Bull. 42, p. 14, 1933.

[23] Ulrich, E. O., Revision of the Paleozoic systems: Geol. Soc. America Bull., vol. 22, pp. 413-414, 1911.

limestone (vaughanite). There are some medium-gray layers. The formation is irregularly bedded. The characteristic conchoidal to splintery fracture is present. As every outcrop of the Mosheim in this area occurs along one or more faults, considerable fracturing is the rule. When the formation weathers, rounded light-gray to light-blue masses are formed, which have a distinctive outcrop surface. The high degree of purity of the limestone makes it an excellent source of agricultural lime, for which it has been used at places in the area.

Thickness.—The Mosheim appears to be not more than 100 feet thick and it is generally less. In the Big A Mountain area it is 50 feet thick, but this may be too low as each outcrop is cut off by a fault.

Paleontology and correlation.—The Mosheim is noted for its many gastropods, generally preserved only as etched outlines on the weathered surface. Bryozoa are also common. Near Fullers Corners the writer collected the characteristic fossils *Tetradium syringoporoides* Ulrich and *Lophospira* sp.

The Mosheim crops out from Virginia to Alabama. Where the Murfreesboro formation is absent, the Mosheim rests directly on the Beekmantown and is basal Chazyan in age.[24]

LENOIR FORMATION

Name.—The name Lenoir was first used by Safford and Killebrew,[25] from Lenoir City, Loudon County, Tennessee.

Description.—In the Big A Mountain area the Lenoir is a dark-colored granular cherty limestone not differing markedly from the Lenoir in other areas. It is impure and argillaceous and weathers into irregular slabs. The knobby and rubbly appearance characteristic of outcrops of the formation elsewhere is also present. Like the Mosheim in this area, the Lenoir occurs only in restricted localities along faults. As a result it is highly fractured and veined and the bedding is indefinite. The thickness is about 115 feet.

Paleontology and correlation.—Because of the great amount of fracturing in the exposures of the Lenoir in the Big A Mountain area, it was impossible to obtain good fossils. The formation is, however, of late Stones River age, and the presence of the gastropod *Maclurea magna* shows its age to be the same as the Crown Point member of the Chazy limestone of New York state. The Lenoir is known in the Appalachian region from Pennsylvania, where it is equivalent to the Lemont member of the Carlim formation, to Alabama, where it succeeds the Mosheim limestone.

[24] Woodward, H. P., Geology and mineral resources of the Roanoke area, Virginia: Virginia Geol. Survey Bull. 34, p. 44, 1932.

[25] Safford, J. M.. and Killebrew, J. B., The elementary geology of Tennessee, pp. 108, 130-131, 1876.

Stratigraphic relations.—The presence of an unconformity between the Lenoir and the overlying Ottosee is indicated by the absence of the three lower members of the Blount group, the Holston, Whitesburg, and Athens formations. The only representative of the Blount group in the area is the Ottosee limestone. The unconformity is evident in the small infaulted area in the southwestern part of the mapped area, where the Ottosee lies directly on the Lenoir.

The thickness of the Holston is 200 to 300 feet in adjoining areas; that of the Whitesburg, 50 feet; and the Athens shale reaches a maximum thickness of 5,000 feet. Thus it is evident that the hiatus here is of considerable magnitude when measured in terms of the thickness of beds not deposited.

It would appear that during Holston, Whitesburg, and Athens time, the Big A Mountain area stood above the sea. A high elevation is not suggested, because there does not seem to have been a rough erosion surface developed on the Lenoir. Furthermore, Holston limestone is well developed at Blackford, 6 miles southeast of the Big A Mountain area. Both Whitesburg and Athens, however, are not found in such close proximity, and the sea which deposited the Lenoir sediments may have retreated slowly, depositing Holston sediments not far distant, and the later formations still farther away.

BLOUNT GROUP

OTTOSEE FORMATION

Name.—The name Ottosee was applied by Ulrich to the basal part of the Sevier shale which occurs southeast of Knoxville, Tennessee. The type locality is the Ottosee Lake, in Chilhowie Park, Knoxville, Tenn.

Description.—The Ottosee formation in the Big A Mountain area is an assemblage of shales and thin-bedded limestones. The shales are generally calcareous and some are sandy. The limestones are hard and dark blue when fresh but weather to buff-colored soft rubble. Fossils are abundant throughout the formation, occurring in the shale and in the fresh limestone or on weathered surfaces.

The thin-bedded character of the Ottosee, and the alternation between shale and limestone, produce a rubbly appearance on exposures. In addition, the limestones weather by solution and thus make very irregular exposures.

The Ottosee is 400 feet thick in central Russell County, and approximately that in the Big A Mountain area.

Paleontology and correlation.—The following fossils were collected and identified from the Ottosee formation:

Receptaculites biconstrictus Ulrich.
Echinosphaerites aurantium (Gyllenhal)?
Batostoma sevieri Bassler.
Mimella melonica (Willard)?
Monticulipora sp.
Valcourea magna Schuchert and Cooper?
Ramose bryozoa.
Crinoid stems.

Typical fossils are *Receptaculites biconstrictus* Ulrich and *Echinosphaerites aurantium* (Gyllenhal)?

At its type locality, the Ottosee overlies the Tellico sandstone, which has not been recognized in Virginia. The Ottosee is known only in southwestern Virginia and eastern Tennessee. It is upper Chazy in age.

BLACK RIVER GROUP

MOCCASIN FORMATION

Name.—Campbell[26] first applied the name Moccasin to a formation, from Moccasin Ridge, Scott County, Virginia.

Description.—In the Big A Mountain area the Moccasin is a crumbly mudrock. It seems to have less of the typical red color than elsewhere in Russell County, being prevailingly brown-gray to drab. Much of the mudrock weathers green-gray. Beds of fine-grained sub-crystalline limestone, resembling a brownish vaughanite, occur at the base of the formation.

The Moccasin is about 600 feet thick in the Big A Mountain area.

Paleontology and correlation.—In this area the Moccasin is practically without fossils. The typical Lowville forms, *Tetradium cellulosum* and *Beatricea gracilis,* are known to occur sparingly in the Moccasin, however, and since also in places the two units interfinger, they are thought to be facies of the same formation. The Moccasin is the shallow-water facies. The Lowville and the Moccasin are Lower Black River in age.

Stratigraphic relations.—The Chambersburg limestone, which normally occurs between the Moccasin (Lowville) and Martinsburg formations, is missing in the Big A Mountain area. It consists of several hundred feet of limestone in northern and central Virginia. The Eggleston[27] formation occupies the same horizon in many southern sections. It is evident that after deposition of Moccasin sediment, the shallow sea

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

[27] Mathews, A. A. L., Marble prospects in Giles County, Virginia: Virginia Geol. Survey Bull. 40, p. 7, 1934.

withdrew from this area and did not return until early Martinsburg, or Trenton, time. The Moccasin is thus the only representative of the Black River group in this area.

MARTINSBURG FORMATION

Name.—The name Martinsburg was first applied by Darton[28] from Martinsburg, West Virginia. At one time the term Sevier shale was applied to the Martinsburg in southwestern Virginia, but the younger age of the Martinsburg has been shown. The Martinsburg includes beds of Trenton, Eden, and Maysville age.

Description.—As it occurs in the Big A Mountain area, the Martinsburg consists chiefly of thin beds of highly fossiliferous limestone alternating with thinner beds of calcareous shale. (See Pl. 22, A.) The limestone beds average 4 to 6 inches in thickness, and the layers of shale 1 inch or less. The limestone is subvaughanitic to medium crystalline and is generally dark blue. Within the Martinsburg, near the base, there are layers of thick fine-grained brown mudrock. Though most of the thin layers of limestone are pure, a few are argillaceous.

The formation weathers rubbly. (See Pl. 20, B.) It has thus a superficial resemblance to the Ottosee. On an exposure, the limestone layers stand out distinctly; in fields they appear as thin ledges. The soil is of fair fertility, though locally shaly. None of the bentonite of early Trenton age was observed in this area.[29]

In addition to the limestones and shales just described, the Martinsburg in the Big A Mountain area contains, near the top, a buff sandy shale which weathers friable and where seen contains no fossils. This is thought to be the Maysville facies of the Martinsburg, whereas the limestone first described is undoubtedly the Trenton. The Eden is probably concealed in this area.

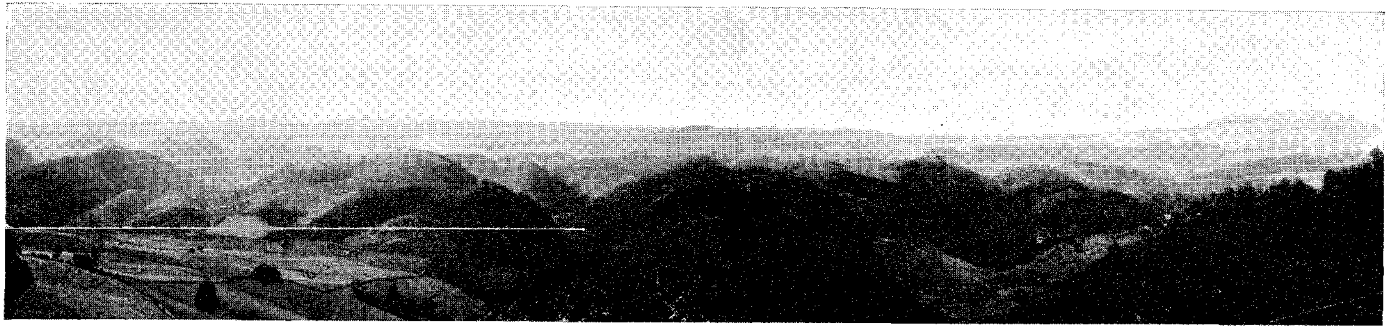
The Martinsburg is approximately 1,600 feet thick in this area.

Paleontology.—From cuts along the new road (not shown on the map), on the southeast slope of Big A Mountain, the following forms were collected and identified:

Prasopora simulatrix Ulrich.
Hallopora ampla Ulrich.
Rhinidctya sp.
Dalmanella multisecta Meek.
Sowerbyella curdsvillensis (Foerste)?
Sowerbyella sericeus (Sowerby).

[28] Darton, N. H., Notes on the stratigraphy of a portion of central Appalachian Virginia: Am. Geologist, vol. 10, p. 13, 1892.

[29] Rosenkrans, R. R., Stratigraphy of Ordovician bentonite beds in southwestern Virginia: This Bulletin, Part I.



A. Panorama of the area southwest of Big A Mountain, Russell County, Virginia. Looking north from road across Copper Ridge about 7 miles southwest of Big A Mountain. Big A Mountain in right background; Cumberland Plateau in middle and left background. The Big A Mountain salient projects onto the flat-lying Pennsylvanian rocks of the plateau. Photograph by H. P. Woodward.

B. Panorama across the Coombs School syncline. Looking east from the road on the Price formation. Clinch sandstone (white) in foreground; Honaker dolomite in wooded hill at right. The Weaver Creek fault is between observer and the first hill; the Fullers Corners fault is between the first and second hill. Photograph by H. P. Woodward.

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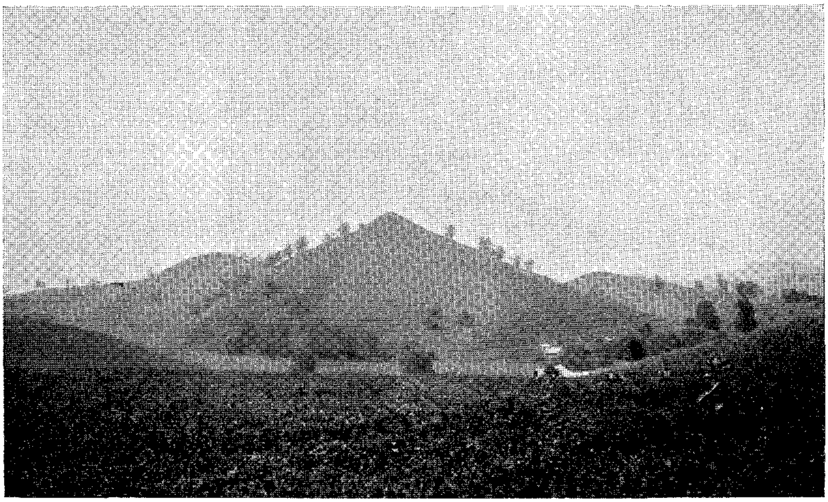
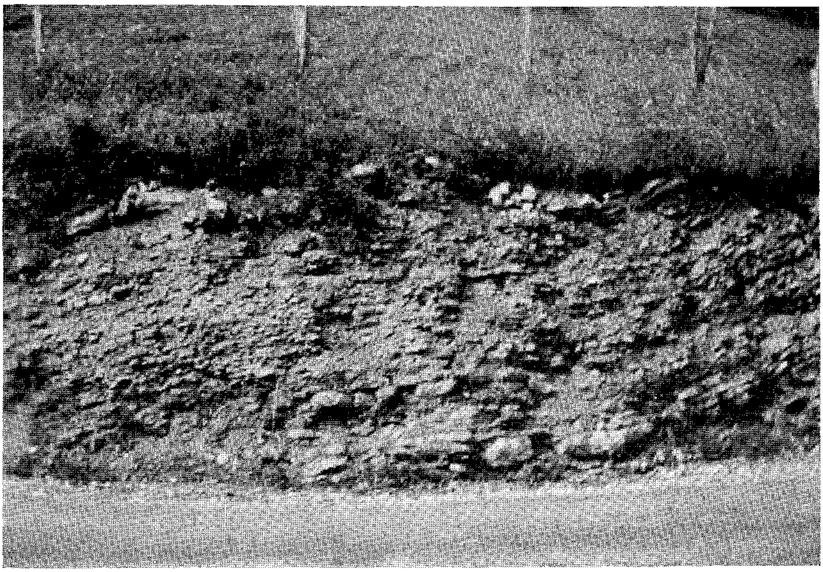
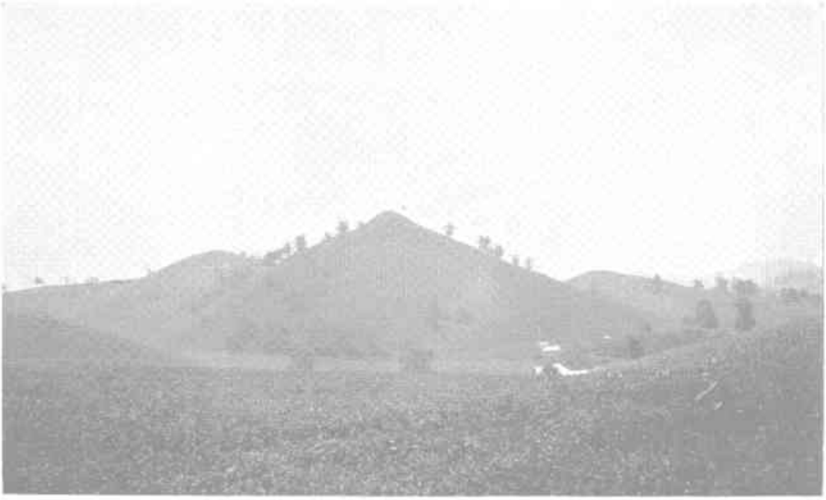


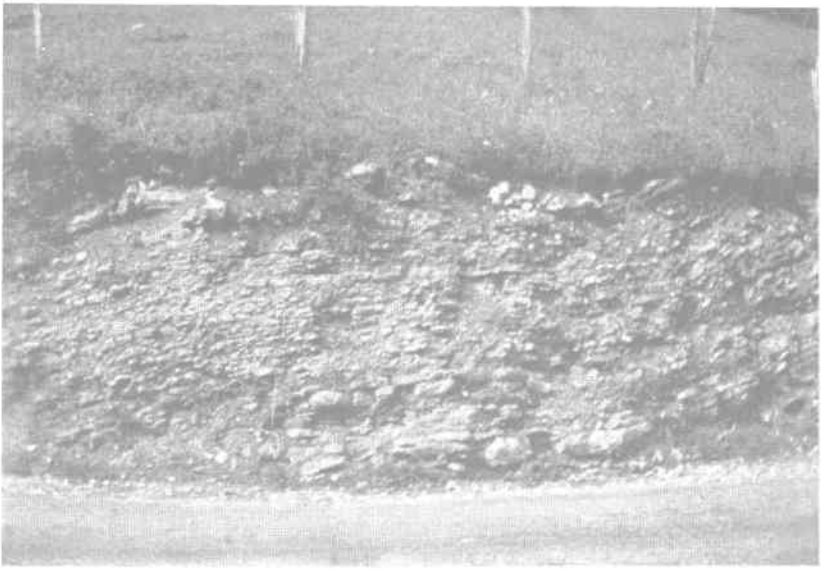
A. Typical conical hills in the Rome formation northeast of Honaker, Virginia. Photograph by H. P. Woodward.



B. Rubbly thin-bedded limestone in the Trenton part of the Martinsburg formation on the southeastern flank of Big A Mountain.



A. Typical conical hills in the Rome formation northeast of Honaker, Virginia. Photograph by H. P. Woodward.



B. Rubbly thin-bedded limestone in the Trenton part of the Martinsburg formation on the southeastern flank of Big A Mountain.

Rafinesquina alternata Emmons.
Strophomena incurvata (Shepard)?
Zygospira modesta Hall.
Crania scabiosa Hall?
Sinuites cancellatus Ulrich?
Liospira progne Ulrich and Scofield.
Orthoceras sp.
Crinoid columnals.
Ramose bryozoa.

Divisions and correlation.—The Martinsburg is divided on the basis of paleontology, and to some extent also on lithology, into three parts, the Trenton, Eden, and Maysville. Only where there is a good exposure of the entire formation is this subdivision possible, and it is not feasible in the Big A Mountain area. The Martinsburg characteristically occurs on mountain slopes in this area and consequently is nearly all covered with soil. Detailed subdivision here is not justified.

The Trenton member of the Martinsburg is Upper Mohawkian in age, and the remainder of the formation is Cincinnatian. In some regions the Trenton is removed from the Martinsburg and is given the status of a formation; as such, it is known from Pennsylvania to Alabama. With the Trenton removed, the remaining shales are known as the Reedsville formation which extends from Pennsylvania to Tennessee. The Reedsville where differentiated corresponds approximately to the Eden and Maysville of the Cincinnati region.

Stratigraphic relations.—A hiatus between the Martinsburg and the overlying Juniata formation is indicated by the absence of the Oswego sandstone elsewhere 200 to 500 feet thick. According to Butts, the Oswego is known in Virginia only as far south as Rockingham County, indicating that the southwestern part of the State was not receiving sediments at that time.

SILURIAN SYSTEM

JUNIATA FORMATION

Name.—The Juniata formation was first named by Darton,[30] from the Juniata River in Pennsylvania.

Description.—The Juniata in the Big A Mountain area consists of crumbly red sandstone, some sandy red shale, and a few beds, 2 to 3 feet thick, of hard red sandstone. The first red sandstone contains patches of green-gray sandstone, in sharp contrast to the prevailing red color, which seem to be the result of weathering. The formation is

[30] Darton, N. H., U. S. Geol. Survey Geol. Atlas, Franklin folio (No. 32), p. 2, 1896.

lighter red and less purplish than the Clinton, which it superficially resembles. Shallow-water deposition is strongly indicated. The soil is red and sandy.

The thickness of the Juniata is 200 feet in the Big A Mountain area.

Paleontology and correlation.—The Juniata formation is correlated with the Queenston shale of the Niagara gorge on the bases of lithology and stratigraphic position. *Drepanella richardsoni* occurs in the Queenston and in the Sequatchie formation, which appear to be a marine facies of the Juniata. Although no fossils were found, it was noted that the lithology of the Juniata strongly resembles that of the Queenston, especially the patches of green-gray sandstone within the red. The Juniata, like the Queenston, is Richmond in age.

CLINCH FORMATION

Name.—Safford[31] originally gave the name Clinch Mountain sandstone to both the Juniata and Clinch formations. The term Clinch was given its present definition by Keith.[32]

Description.—As elsewhere in the southern Appalachian region, the Clinch in the Big A Mountain area is a pure, massive, quartzitic sandstone. It consists of grains of quartz sand, of varying degrees of coarseness, cemented by silica. Some of it is brown, due to iron-oxide stain, but the prevailing color is white. Cross-bedding is noticeable, as is differential weathering of alternating layers. As a whole the formation is highly resistant to erosion. It forms the top of Big A Mountain. On the ridge extending to the southwest, the Clinch makes a cliff about 40 feet high, and serves to support the Clinton, which is found at the very top of the ridge.

Paleontology and correlation.—The Clinch is nowhere very fossiliferous; its chief fossil, *Arthrophycus alleghaniensis* (Hall), is present and was collected on Big A Mountain.

The Clinch is of Alexandrian age. It corresponds to the Tuscarora quartzite of northern Virginia and Pennsylvania, and is the chief ridgemaker of the Appalachian Valley and Ridge province from Pennsylvania to Alabama.

CLINTON FORMATION

Name.—The name Clinton was first applied by Vanuxem,[33] from the town of Clinton, Oneida County, New York.

[31] Safford, J. M., A geological reconnaissance of the State of Tennessee . . . ., p. 15, Nashville, 1856.
[32] Keith, Arthur, U. S. Geol. Survey Geol. Atlas, Loudoun folio (No. 25), p. 4, 1896.
[33] Vanuxem, Lardner, Geology of New York, Part III. . . ., Albany, 1842.

Description.—The Clinton of the Big A Mountain area is predominantly red hematitic sandstone and conglomerate. The sandstone is moderately fine grained and most of it is stained a dark red. The conglomerate is thick bedded and consists of small rounded pebbles of dark-red sandstone set in a matrix of the same material. There are all gradations in texture between the fine-grained sandstone and the conglomerate. The Clinton horizon here is the same one which contains the Clinton iron ore, but in the Big A Mountain area the content of iron is low and of no value commercially.

A highly fossiliferous buff sandstone occurs on the ridge extending southwest from the summit of the mountain. It is 2 feet thick and is separated from the Clinch below by a few feet of sandstone. The fossils in the buff sandstone are profuse but not identifiable, largely because they are much macerated. Little shale was observed. The sandstone and conglomerate described above are of the Cacapon type.

The Clinton is 300 feet thick in this area.

Paleontology and correlation.—The Clinton is poorly fossiliferous, and no fossils were collected in this area. A number of dubious vertical markings (*Scolithus?*) were seen in the sandstone, one bedding surface being thickly studded with their cross-sections. In adjacent regions, the Clinton locally is highly fossiliferous, beds closely packed with *Coelospira hemispherica* (Sowerby) occurring in Scott County.

The Clinton of the Big A Mountain area apparently corresponds to the Cacapon sandstone, this being equivalent to the lower Clinton horizon of New York. It is Niagaran in age.

Stratigraphic relations.—Above the Cacapon member of the Clinton formation, as represented in the Big A Mountain area, there are normally 100 to 200 feet of shale and sandstone. This is the Keefer member of the Clinton, which is absent in this area. It is equivalent to the upper Niagaran.

Between the topmost Clinton beds and the Helderberg, or basal Devonian, there are normally some 300 feet of shale and limestone. These comprise the "Formations of Cayuga age" of Butts and consist of the McKenzie, Bloomsburg, Wills Creek, and Tonoloway formations. As the base of the Helderberg in this area is not exposed because it is concealed by faults, it is not possible to say definitely whether any beds of Cayugan or early Helderberg age are present. On Stone Mountain, about 10 miles due east of Big A Mountain, the uppermost Helderberg, the Becraft limestone, with its guide fossil *Aspidocrinus scutelliformis* ? immediately overlies the Clinton.

DEVONIAN SYSTEM

HELDERBERG FORMATION

Name.—The name Helderberg was originally applied by Mather,[34] the type locality being the Helderberg escarpment west of Albany, N. Y.

Description.—The Helderberg is present in the Big A Mountain area in only a small outcrop on Weaver Creek. It seems to have two facies. The first is an argillaceous, sparingly fossiliferous, thin-bedded slabby limestone. Its weathered surface has a superficial resemblance to dolomite. The second facies is a coarse-grained, more irregular limestone which is purer than the other type.

The true thickness can not be obtained, but it is at least 75 feet.

Paleontology and correlation.—The Helderberg in this area is moderately fossiliferous. The following list of fossils is supplied by Butts:

Stromatopora sp.?
Favosites helderbergiae.
Aspidocrinus scutelliformis?
Leptaena rhomboidalis.
Nucleospira ventricosa?
Meristella arcuata.
Renssaeleria mutabalis?
Spirifer concinnus.
Stenochisma formosa.
Leperditia sp.?

The presence of *Aspidocrinus scutelliformis* ? and *Spirifier concinnus* proves the Becraft age of the formation. There is certainly a considerable hiatus both above and below the Becraft here.

Stratigraphic relations.—Between the Helderberg and the overlying Brallier there is a hiatus which represents the Oriskany, Onondaga, Marcellus, Hamilton, and perhaps Genesee and early Portage (Naples) formations, the thickness of which is estimated as 1,500 feet.

BRALLIER FORMATION

Name.—Brallier, Bedford County, Pennsylvania, is the type section, from which Butts[35] named the formation in 1918.

Description.—The Brallier is an assemblage of shales and thin-bedded sandstones. The shale is light brown and sandy, with some

[34] Mather, W. W., Fourth annual report of the first geological district of the State of New York: New York Geol. Survey Ann. Rept. 4, pp. 236-246, 1840.
[35] Butts, Charles, Geologic section of Blair and Huntingdon counties, central Pennsylvania: Am. Jour. Sci., 4th ser., vol. 46, p. 52, 1918.

mica. It is laminated and argillaceous, rather soft, and weathers buff. The sandstone is light colored and fine grained. At the road intersection near the southwest corner of the area, proximity to faults has made the shale very crumbly. At the top of the formation there are 20 to 30 feet of beds in which occur sandstone beds, some of which are 2 to 3 feet thick. The main part of the formation consists of at least two-thirds shale, with the beds of sandstone only a few inches thick. Thin beds of dark-gray to black shale occur rarely throughout the formation.

The thickness of the Brallier in this area is about 1,000 feet.

Paleontology and correlation.—Fossils are very scarce in the Brallier. The only ones collected from this area are unidentifiable plant remains which occur as carbonaceous films in the shale. The lithology and stratigraphic position, however, show that the formation is Brallier. It corresponds to the Hatch and Gardeau formations of the Portage group in western New York.

Stratigraphic relations.—The Brallier is overlain by the Big Stone Gap shale, which indicates that typical Chemung strata are absent between them. It is thought that the 20 to 30 feet of thick-bedded sandstone at the top of the Brallier, noted above, may represent the Chemung horizon, although the characteristic fossils were not found.

BIG STONE GAP SHALE

Name.—The Big Stone Gap shale was so named by Stose[36] from Big Stone Gap, Wise County, Virginia.

Description.—At the road junction just south of Coombs School, in the southwest portion of the area, there are 20 to 25 feet of black very fissile splintery shale. Iron stain is not uncommon, some of the fossils showing it. Tiny crystals of selenite were found between chips of the shale.

Paleontology and correlation.—The shale carries *Orbiculoidea* and *Lingula*. It has the lithologic appearance and stratigraphic position as well as the fossils of the Big Stone Gap shale. Butts[37] states that the beds here discussed lie "between the Brallier shale and the Price and probably fall into the zone of the Big Stone Gap shale." If this be the case, the question arises as to its age, whether Devonian or Mississippian. At present this is a controverted question. Some geologists regard it as Devonian, others as Mississippian, and still others as partly one and partly the other. In the Big A Mountain area the sequence is from

[36] Stose, G. W., The 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.
[37] Butts, Charles, Personal communication, Nov. 29, 1935.

the Brallier shale of Late Devonian age through the Big Stone Gap shale to the Price sandstone of Early Mississippian age.

MISSISSIPPIAN SYSTEM

PRICE FORMATION

Name.—This formation was first named Price by Campbell[38] from Price Mountain, Montgomery County, Virginia.

Description.—The Price in the Big A Mountain area is composed of about one-third shale and two-thirds sandstone. The shale is thin-bedded, micaceous, and crumbly, similar to that in the Brallier formation. The sandstone is fine grained and gray to reddish. It breaks blocky and slabby and is crumbly when weathered. In places the shale predominates, especially in the lower 150 feet of the formation; at higher horizons, beds of sandstone 3 feet thick take the place of the shale.

Large concretions of the type called "pillow structures" are present. They consist of concentric shells of sandstone which are apparently more firmly cemented than the surrounding rock.

The thickness of the Price, as measured on the southeast side of the Coombs School syncline, is 350 feet.

Paleontology and correlation.—Fossils were not found in the Price of this area. Eight miles east of Gate City, Scott County, the writer collected numerous well-preserved specimens of *Chonetes* sp. from the Price.

The Price is basal Mississippian in age. According to Butts, in the southwestern counties of Virginia and as far north as Alleghany County, the Price carries a rather abundant New Providence or Cuyahoga fauna. He has made a large collection at Richlands and the same fauna may occur at places in this area.

Stratigraphic relations.—In Pulaski County there are 500 feet of Maccrady red shale overlying the Price, and northeast of Richlands, Tazewell County, about 100 feet of limestone, is tentatively referred by Butts to the Warsaw. These formations are absent in the Big A Mountain area. No evidence of an erosional unconformity was observed, and it seems probable that the Maccrady and the Warsaw were not deposited in this area. Both the formations vary considerably in thickness laterally, and it is not surprising to find them missing.

[38] Campbell, M. R., U. S. Geol. Survey Geol. Atlas, Pocahontas folio (No. 26), p. 3, 1896.

ST. LOUIS FORMATION

Name.—The name St. Louis was first used by Engelmann[39] from St. Louis, Missouri.

Description.—The St. Louis is a highly fossiliferous fine-grained argillaceous limestone. It is very cherty at the bottom, becoming less so in the higher portions. It is vaughanitic in places. The color of most of the formation is medium gray to bluish, but some of the argillaceous material is light gray. Near Coombs School on the southeast flank of a syncline, a bed of red mudrock about a foot thick was observed about 30 feet from the base of the formation. It was not seen on the northwest side of the syncline where there is calcareous shale near the base of the formation.

The thickness of the St. Louis formation is approximately 200 feet.

Paleontology and correlation.—The type St. Louis fossil, *Lithostrotion canadense,* was not found in this area, but excellent specimens were collected from the formation on the same outcrop, 1½ miles northwest of Cleveland, Russell County. There the fossils are preserved in chert. From the Big A Mountain area, the following fossils were collected and identified by the writer:

Productus ovatus Hall.
Productus cf. P. altonensis Norwood and Pratten.
Spirifier littoni Swallow?
Leptaena sp.
Orbiculoidea sp.
Fenestella sp.
Crinoid columnals.
Ramose bryozoa.

The St. Louis limestone of southwestern Virginia carries the same fossils and has to some extent the same lithology as the St. Louis of the Mississippi Valley, which is of Middle Mississippian age.

STE. GENEVIEVE FORMATION

Name.—The term Ste. Genevieve was first used by Buckley[40] for this formation in Ste. Genevieve County, Missouri.

Description.—The Ste. Genevieve is a medium crystalline, partly oölitic, crinoidal limestone. Its oölites distinguish it from the St. Louis, which it otherwise resembles. The oölites fill some layers. They are

[39] Engelmann, George, Remarks on the St. Louis limestone: Am. Jour. Sci., 2d ser. vol. 3, pp. 119-120, 1847.
[40] Buckley, E. R., Geology of the disseminated lead deposits of St. Francois and Washington counties, Missouri: Missouri Bur. Geol. and Mines, vol. 9, Pt. 1, 1909.

very abundant in beds in the saddle of the gap south of Coombs School. When weathered, the oölitic beds have a rough surface, with small pits produced by solution of the oölites. The crinoidal layers are also rough, with small fragments of crinoid stems and plates adhering to the surface in great profusion. The color of the fresh rock varies from light to dark gray. It weathers buff. A small amount of chert is present. The St. Louis and the Ste. Genevieve are both highly soluble, as is evidenced by the numerous sink holes to be found along their outcrops.

The thickness of the Ste. Genevieve in the Big A Mountain area can not be determined, as it occurs in the center of a syncline with no beds above it, but it is at least 200 feet.

Paleontology and correlation.—The type fossil, *Platycrinus penicillus* (*huntsvillae*), was observed in the form of plates on the weathered surfaces of the limestone. There are not many other fossils.

The Ste. Genevieve is late Valmeyer or early Chester in age and corresponds to the Fredonia limestone of central Kentucky.

Stratigraphic relations.—In the normal sequence of formations, the Ste. Genevieve limestone is overlain conformably by the Gasper limestone. Because of structural conditions in this area, the two formations, though present, are not in contact. It is logical to assume that, since the Gasper occurs within a mile of the Ste. Genevieve, it also occurred above the latter in the center of the syncline in the southwest portion of the area, from which erosion has since removed it.

GASPER FORMATION

Name.—The Gasper was named by Butts[41] from Gasper River west of Bowling Green, Kentucky.

Description.—The Gasper formation in the Big A Mountain area is a fine-grained light- to medium-gray limestone. It is rather massive and contains some chert. It is highly crinoidal and very soluble. It weathers to rounded masses or to fluted surfaces with many solution channels. The thickness here is about 30 feet, but some of the formation is doubtless cut out by faulting.

Paleontology and correlation.—Several species of *Pentremites* and *Talarocrinus* occur in the Gasper, some of which were observed in the Big A Mountain area on weathered surfaces of the limestone. The formation is of Middle Mississippian age and is known from the Mississippi Valley to Virginia.

[41] Butts, Charles, Descriptions and correlation of the Mississippian formations of western Kentucky: Kentucky Geol. Survey, Mississippian formations of western Kentucky, 1917.

Stratigraphic relations.—Due to a fault, the Gasper is not in contact with the Ste. Genevieve. The Gasper is overlain by the Pennington formation, in the base of which there are beds which may correspond to the Bluefield shale, which normally succeeds the Gasper.

PENNINGTON FORMATION

Name.—The Pennington formation was named by Campbell[42] from Pennington Gap, Lee County, Virginia.

Description.—With the possible exception of the Rome formation, the Pennington is the most heterogeneous formation in the Big A Mountain area. It contains shale, limestone, and sandstone.

More than half of the Pennington is shale. It is variegated, some being red, some green, and some brown to buff. The green shales are the least prominent. The red shales are not unlike those of the Rome. The brown shales weather so as to give a clayey material. Chips and flakes, such as the Devonian and Cambrian shales produce, are generally absent and the shale produces a softer weathering product which in many places still shows the bedding planes of the shale. The shales are sparingly fossiliferous.

In the lower third of the formation occurs a 20-foot bed of fairly uniform blue massive argillaceous limestone. It is a distinctive rock type, being softer and less brittle than the other limestones of the area, yet tough to break. Although the fresh rock is massive and dark-colored, it weathers to a light greenish, thin-bedded shale. Many bryozoa occur, indistinct in the fresh rock but very noticeable in zones of weathering at the surface. A clayey weathered zone as much as 2 inches thick is packed with fenestelloids, which weather white and are thus very distinct.

The sandstone of the Pennington formation is composed of fairly clean quartz. Some beds strongly resemble the Clinch sandstone. Other layers have a greenish tint. The sandstone in general is purer and finer grained than other local Carboniferous sands. It is highly resistant to erosion, and one bed of it forms the northwestern of the two ridges extending southwest from the end of Big A Mountain. In places the sandstone contains considerable macerated carbonaceous matter, probably plant remains. Other layers carry recognizable plant fibers, running both parallel to and at right angles to the bedding. Fucoidal imprints are present, indicating shallow-water deposition.

The sandstone weathers similar to the Clinch, forming lichen-covered, light-gray surfaces in place and breaking up into rough

[42] Campbell, M. R.. Geology of the Big Stone Gap coal field of Virginia and Kentucky: U. S. Geol. Survey Bull. 111, p. 37, 1893.

blocks. Float from this sandstone is widespread. The rock has a tendency to weather so that the outside of a block is more tightly cemented than the material within by concentration of silica at the surface. This has been termed "case-hardening."

The thickness of the Pennington in the Big A Mountain area is 2,000 feet. At the type section, Pennington Gap, it is only about 1,200 feet, but it is believed that the upper beds were eroded away there before deposition of the overlying basal Pennsylvania rocks.

Paleontology and correlation.—The Pennington is sparingly fossiliferous in this area. Specimens of *Archimedes* in the blue limestone are the only fossils collected which are susceptible of even generic identification. In other areas the occurrence of *Sulcatopinna missouriensis* indicates the age of the formation as late Chester of the Mississippi Valley.

Stratigraphic relations.—The Hinton formation occurs in close association with the Pennington in the southern Appalachian region. Butts[43] considers the Hinton to be identical with the Pennington, but others believe the Pennington includes the Hinton, the Princeton sandstone, and the Bluestone formation. The present status of knowledge concerning these formations is insufficient for final conclusions about their relations. It is probable that beds representing the Bluefield formation are present in the basal Pennington in this area, although the writer was unable to separate them.

The occurrence of an erosional unconformity is generally conceded between the uppermost Mississippian formation, the Pennington, and the basal Pottsville formation, the Lee conglomerate. That the Pennington surface was eroded before deposition of the Lee is shown by the fact that both formations vary in thickness, the Lee ranging from 110 to 950 feet in eastern Pike County, Kentucky.[44] Further, the different character of the basal Pennsylvanian rocks from those underlying them show that there must have been changes in sources of material and agents of transportation and deposition.

It is supposed that after the deposition of the Pennington formation the seas retreated, the land was exposed to considerable erosion, and from a source of abundant quartz, possibly quartz veins in the highlands of Appalachia, swift streams carried much quartzose gravel and coarse sand onto the eroded land surface and there deposited it in layers of variable thicknesses. The wide-

[43] Butts, Charles, Geologic map of the Appalachian Valley of Virginia with explanatory text: Virginia Geol. Survey Bull. 42, p. 46, 1933.

[44] Hinds, Henry, The geology and coal resources of Buchanan County, Virginia: Virginia Geol. Survey Bull. 18, p. 13, 1918.

spread occurrence of basal Pottsville conglomerate indicates that this occurred over large areas.

PENNSYLVANIAN SYSTEM

LEE FORMATION

Name.—The Lee formation was named by Campbell[45] from Lee County, Virginia.

Description.—The Lee formation in the Big A Mountain area consists of coarse conglomerate, arkosic sandstone, and some shale. The conglomerate has large pebbles of quartz, smoothly rounded, in a matrix of rather pure quartz sand. The pebbles vary from a fraction of an inch to more than 1 inch in diameter. The cementation is so firm that in some instances pebbles break through when the conglomerate is broken. The conglomerate is thus very resistant to erosion.

The sandstone is highly micaceous, arkosic, and easily crumbled. It is impure and has a deep brown color. The shale of the formation, though extensive in other areas, is not prominent in the Big A Mountain area.

The thickness of the formation varies. It appears to thin northward, both from an actual thinning of the beds and from a varying relief on which these beds were deposited. In the Big A Mountain area the thickness is about 1,700 feet. Along Pine Mountain to the northwest it is only 800 feet.

The Lee formation carries several coal seams, among them the Pocahontas of eastern Tazewell County, Virginia. There is no commercial coal in this formation in this area.

Correlation.—Fossils are apparently absent from the Lee except for scattered plant remains in the beds of coal, which were not examined. The formation is correlated with lower Pottsville formations in the anthracite coal fields of Pennsylvania and in the Birmingham, Alabama district.

NORTON AND GLADEVILLE FORMATIONS

The Norton and Gladeville formations are not closely involved in the structure of the Big A Mountain area, and are undifferentiated on the map. They consist of nearly horizontal sandstones and shales, with considerable bituminous coal. These formations, with their coal reserves, have been discussed in detail in numerous

[45] Campbell, M. R., op. cit.

publications of the Virginia Geological Survey.[46] The lower half or so of the Norton formation is of Middle Pottsville age.

UNCONSOLIDATED MATERIALS

There are no consolidated rocks younger than the Gladeville sandstone in the Big A Mountain area. Except for the residual soils above each formation and occasional float, there are no unconsolidated deposits. Stream gravels are lacking, and its seems apparent that the formation of residual soils in place and creep and slump on the slopes have been the only factors in producing unconsolidated deposits.

STRUCTURAL GEOLOGY

GENERAL STATEMENT

The complex structure of the rocks in the Big A Mountain area is the result of deformation in the Appalachian Revolution, which occurred during and possibly after Permian time. The deformational stresses appear to have been compressional and to have been directed from the southeast. Several folds and thrust faults were formed. (See Pls. 18 and 21.) Overlapping fault blocks occur, of which the one farthest to the northwest includes a cross-faulted syncline, a notable structural feature of the area.

MAJOR FOLDS

BIG A MOUNTAIN SYNCLINE

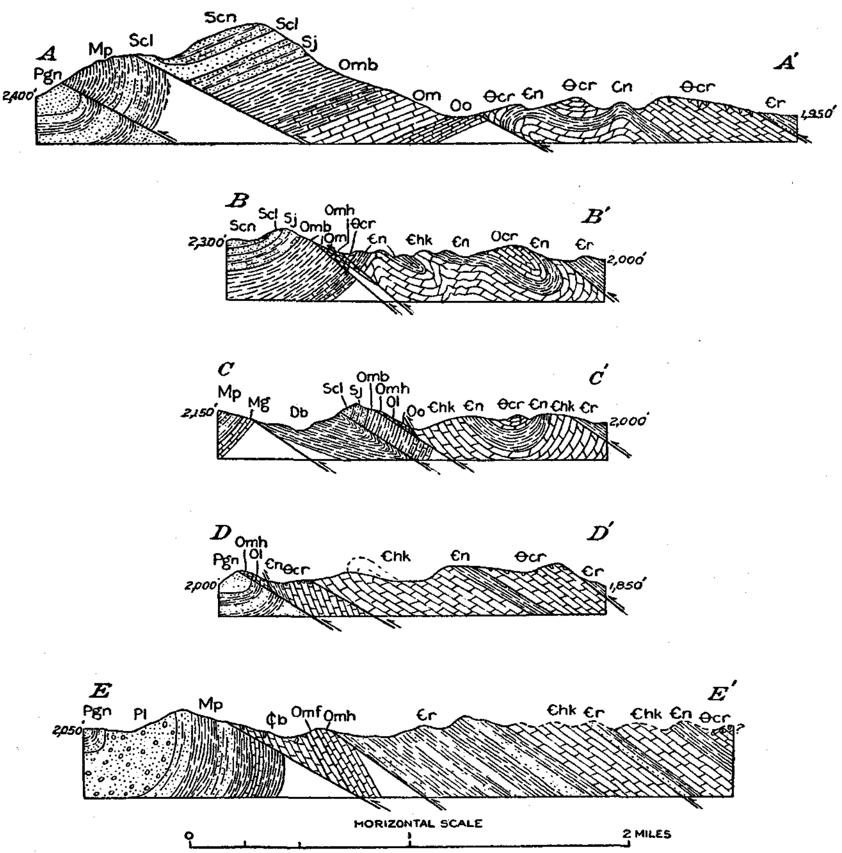
The prominent structural feature of the area is the syncline which forms Big A Mountain and a part of Sandy Ridge. (See Pl. 21, sections A-A′, B-B′, C-C′; also Pl. 18.) It is developed in Silurian rocks, plunges gently to the southwest, and owes its topographic importance to the fact that the resistant Clinch sandstone forms the crest of its enclosing rim. The syncline is open and shallow in the wide part west and southwest of the summit of the mountain, but the beds in the southeastern flank become more steeply tilted down the Clinch ridge to the southwest.

As shown on Plate 21, section A-A′, the whole syncline has been thrust onto younger rocks to the northwest. At the north-

[46] Hinds, Henry, The coal resources of the Clintwood and Bucu quadrangles, Virginia: Bull. 12, 1916.

.... The geology and coal resources of Buchanan County, Virginia: Bull. 18, 1918.

Wentworth, C. K., The geology and coal resources of Russell County, Virginia: Bull. 22, 1922.



STRUCTURE SECTIONS OF THE BIG A MOUNTAIN AREA, VIRGINIA.

Ꞓr, Rome shale; Ꞓhk, Honaker dolomite; Ꞓn, Nolichucky shale; Ꝋcr, Conococheague (Copper Ridge) dolomite; ₵b, Beekmantown dolomite; Omf, Murfreesboro limestone; Omh, Mosheim limestone; Ol, Lenoir limestone; Oo, Ottosee limestone; Om, Moccasin limestone; Omb, Martinsburg shale; Sj, Juniata formation; Scl, Clinch sandstone; Scn, Clinton formation; Dh, Helderberg limestone; Db, Brallier shale; Mpr, Price formation; Msl, St. Louis limestone; Msg, Ste. Genevieve limestone; Mg, Gasper limestone; Mp, Pennington shale; Pl, Lee conglomerate; Pgn, Gladeville sandstone and Norton formation.

east end of the mountain the Juniata formation took the brunt of the thrust, but northwest of the junction of the Weaver Creek and St. Paul faults the Clinch and the Clinton formations bore the main thrust. In the thrust faulting, the synclinal block must have been pushed upward for a considerable distance as well as laterally, for the younger rocks which undoubtedly lay in the syncline have been worn completely away since the deformation ceased.

The compressional force which produced the Big A Mountain syncline came from the southeast, although the stress which broke it crosswise had a more easterly component, as shown in the orientation of the Weaver Creek fault.

COOMBS SCHOOL SYNCLINE[47]

In the southwestern corner of the Big A Mountain area, Devonian and Mississippian rocks are folded into a moderately open syncline, with Ste. Genevieve limestone at the center. (See Pl. 18.) This syncline extends southwestward from the Big A Mountain area for a distance of about 8 miles, where it is cut off by a branch of the St. Paul fault. Throughout the length of the syncline, the beds are essentially parallel and show little of the irregularity which characterizes the Clinch outcrop on Big A Mountain.

It is concluded that the Big A Mountain syncline and the Coombs School syncline are in reality one and the same. The Weaver Creek fault has cut across the original syncline, and the northeastern part has been shoved over the southwestern part. Before this cross-faulting, the Mississippian and Devonian rocks of the Coombs School syncline continued northeastward in the trough of the Big A Mountain syncline, overlying the Clinton. The gain in elevation, through faulting, of the northeastern part of the original syncline was sufficient to allow streams completely to erode away the continuation of the beds now seen in the Coombs School syncline.

The stresses which caused the original folding came from the southeast, as may be gathered from the orientation of the two synclines. The slight plunge of the axis of the Big A Mountain syncline flattens out in the Coombs School fold. A long canoe-shaped syncline seems to have been the original structural form.

[47] There are two "Coombs schools" on the map, one northwest of the mountain and the other southwest. The latter is always the one referred to in this paper.

CROSS-CREEK ANTICLINE

This anticline is so named by the writer because it cuts across three of the small southward flowing streams of the area. (See Pl. 21, section A-A'; also Pl. 18.) It involves the Nolichucky and the Copper Ridge formations. The Nolichucky has been brought to the surface by an upwarping of the Copper Ridge and erosion through it at the center of this upfold. A similar upfold has been formed parallel to the main one, crossing the Lambert Branch road to the north. The anticlines are the result of compressive stresses from the southeast, bowing up the Copper Ridge dolomite and its underlying formations.

MINOR FOLDS

The width of the outcrop of the Rome formation crossing the area in its southern part is due to an isoclinal fold within the formation. (See Pl. 21, section E-E'.) There are also numerous small folds within the formation, one of which may be seen on the road between map elevations 1728 and 1735, in the southwest portion of the Rome outcrop. At this point, the strike abruptly changes from parallel with the road to a sharp angle with it; a few yards farther, the strike is again along the road.

There is an isoclinal fold in the Honaker dolomite in the large outcrop southeast of Fullers Corners. (See Pl. 21, section D-D'.)

The Cross-Creek anticline plays out at both ends into a series of minor folds involving the Honaker, Nolichucky, and Copper Ridge formations. The shale has been tightly compressed and has yielded, especially at the southwest, in a series of folds which shows its incompetent character. The wide outcrop of Nolichucky northeast of Deskin School is due to a series of isoclinal folds within the formation. One of the folds having an elbow-like outcrop, in the Honaker and Nolichucky formations, may be observed on the road along the upper course of Breeze Creek. (See Pl. 21, sections B-B' and C-C'.)

Some contortion was observed in the Mosheim limestone in the infaulted wedge near Fullers Corners. It appears there that the strong vaughanite of the Mosheim has undergone sufficient deformation to cause a close fold.

MAJOR FAULTS

RUSSELL FORK FAULT

The Russell Fork fault is important for several reasons. (See Pl. 21, sections D-D′ and E-E′; also Pl. 18.) As may be seen from the map, it is a major fault which does not parallel the general trend of the structure of the area. It is, indeed, nearly at right angles to that trend, and maintains that orientation for some 20 miles to the northwest of the Big A Mountain area. Probably the best explanation of the presence of such a long fault in such a direction is that given by Wentworth[48] in his discussion of the Cumberland fault block. He states that Russell Fork fault is the northeastern boundary of a long nearly rectilinear block of the earth's crust which moved as a unit during the deformation of the southern Appalachian region. The southwestern end of the Cumberland block, more than 100 miles southwest of the Big A Mountain area, was "skewed" to the northwest for a considerable distance, with a point 15 miles or so northwest of the Big A Mountain area as a pivot; hence the first appearance of the Russell Fork fault was as a tensional break nearly parallel to the direction of compressive stress on the southwest. Subsequent to this turning, the whole Cumberland block was thrust to the northwest, closing the normal fault along Russell Fork. The movement at this time was small in a vertical direction but was some 2 miles horizontally, parallel to the trace of the fault surface.

This mode of origin for the Russell Fork fault is supported by the fact that in the coal measures immediately northwest of the Big A Mountain area, for some miles, it is a high-angle fault, such as would be expected of a normal break, the dips of the fault surface being between 75° and 90°. Furthermore, the relatively slight overthrust and the great compression revealed in the Russell Fork fault to the north, is in accord with Wentworth's interpretation.

ST. PAUL FAULT

(See Pl. 21, sections A-A′ and C-C′; also Pl. 18.) Two faults from the southwest enter the Big A Mountain area before intersecting the Russell Fork fault. One of these faults enters the area 1 mile due north of the southwestern corner, and meets the Russell Fork fault on Sandy Ridge north of the summit of the mountain. It is called the St. Paul fault. The other enters about half a mile east of the southwest corner and divides into three

[48] Wentworth, C. K., Russell Fork fault of southwest Virginia: Jour. Geology, vol. 29, pp. 351-369, 1921.

branches. They are designated, from east to west, the Cross-Creek fault, Fullers Corners fault, and Weavers Creek fault. (See Pl. 18.)

The St. Paul fault (Hunter Valley fault of Wentworth) is a low-angle overthrust along which Devonian and older beds have been thrust upon Mississippian and younger ones. Wentworth[49] interprets this fault as the southeastern boundary of the Cumberland block, making the Big A Mountain area just outside of the eastern corner of the block.

The maximum vertical displacement of this fault, between the Martinsburg and the Norton formations, is approximately 6,100 feet. The minimum, between the Gasper and the Brallier formations, is about 775 feet.

FULLERS CORNERS FAULT

This fault extends from a point half a mile north of the southern edge of the area, north for about 1 mile and then swings east till it intersects the Russell Fork fault on Laurel Branch. (See Pl. 21, sections A-A′, B-B′, and C-C′; also Pl. 18.) It brings together beds of widely different ages. At the southwestern end of the fault, the Juniata is in contact with the Honaker; this represents a displacement of about 5,000 feet. At its point of junction with the Russell Fork fault, its displacement, between the Lenoir and the Ottosee, is 100 feet or less.

The Fullers Corners fault is a low-angle thrust and in line with the general structural trends of the area. Its southwestern third bends southward, as does the other structure east of the Weaver Creek fault. This presumably was caused by relief of an eastward component of pressure.

CROSS-CREEK FAULT

This is the longest and most prominent fault in the area. (See Pl. 21, sections A-A′, B-B′, C-C′, D-D′ and E-E′; also Pl. 18.) It is the northern limit of a wide belt of Rome shale which for a long distance is thrust upon younger beds. The vertical displacement along most of the fault is not more than 1,500 feet, but at its extreme southwestern end there has been a vertical movement of nearly 7,000 feet, bringing the Rome formation (Cambrian) against the Brallier shale (Devonian).

The low angle of this fault is particularly apparent from the deep reentrants in its trace made by creek valleys, especially where the fault crosses Sykes and Thompson creeks.

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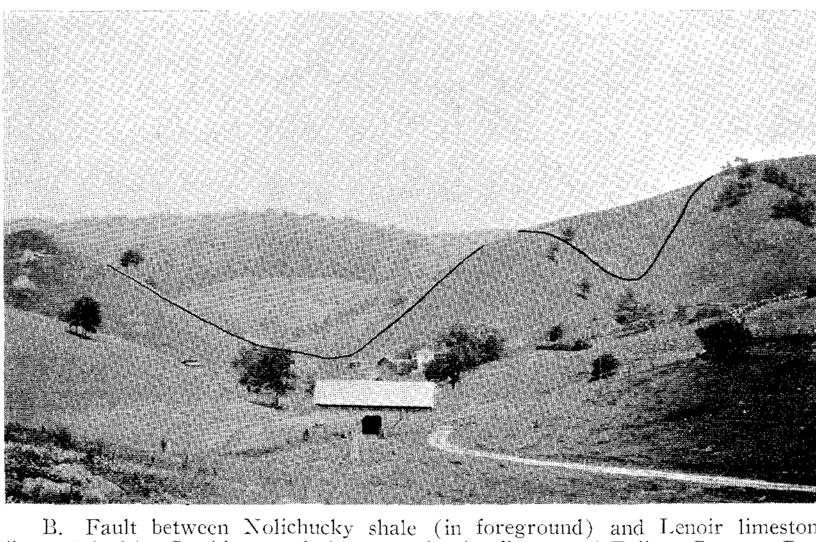
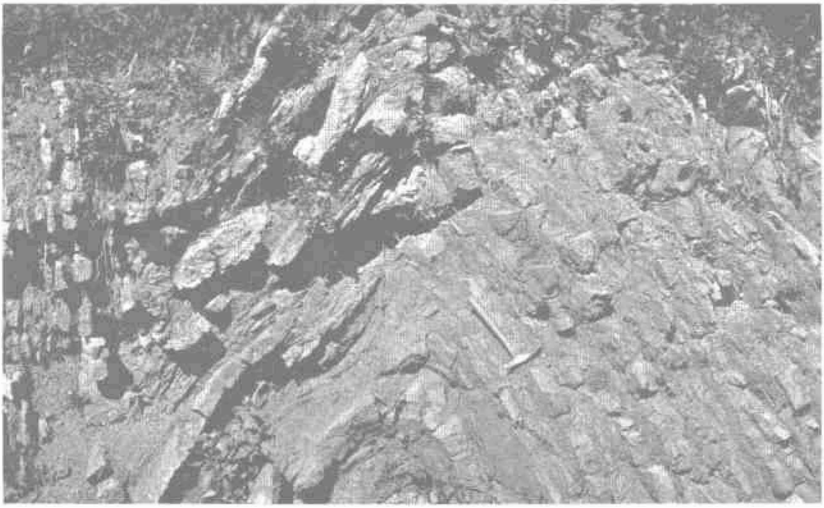
[49] Wentworth, C. K., op. cit.

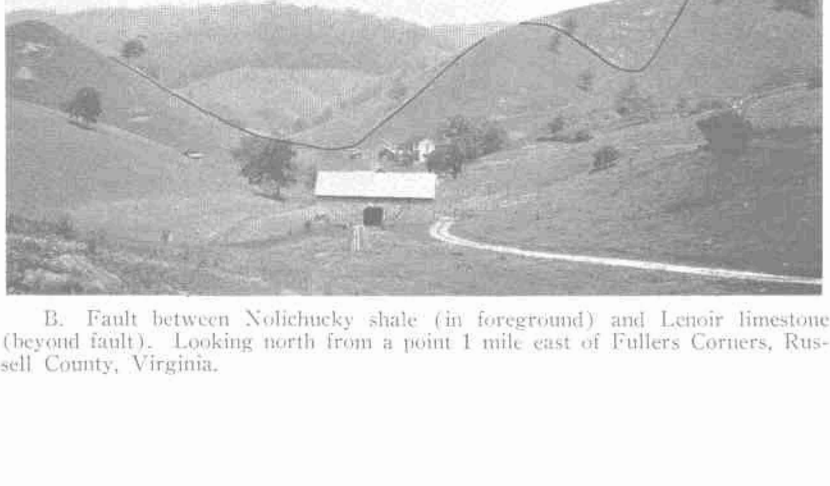
A. Typical fold in the Martinsburg formation about 3 miles southeast of Honaker, Virginia.



B. Fault between Nolichucky shale (in foreground) and Lenoir limestone (beyond fault). Looking north from a point 1 mile east of Fullers Corners, Russell County, Virginia.



A. Typical fold in the Martinsburg formation about 3 miles southeast of Honaker, Virginia.



B. Fault between Nolichucky shale (in foreground) and Lenoir limestone (beyond fault). Looking north from a point 1 mile east of Fullers Corners, Russell County, Virginia.

WEAVER CREEK FAULT

The Weaver Creek fault, like the Russell Fork fault, does not conform to structural trends in the region. (See Pl. 21, section C-C′; also Pls. 18 and 19, B.) It is a cross-fault connecting the Cross-Creek and St. Paul faults and offsetting the Coombs School-Big A Mountain syncline. Along this fault, older beds than the Devonian have ridden not only northwest but west over Devonian and Mississippian rocks. The southern flank of the original large syncline has been pushed, probably several miles, to the west and northwest so that the Clinch, which formerly paralleled the Mississippian rocks in the Coombs School syncline, now cuts across them at an angle of 50°. Further, the Helderberg limestone, which formerly covered the Clinton formation in the syncline, now lies at a lower elevation to the west, due to this fault.

HONAKER FAULT

The Honaker fault, passing across the southeastern corner of the area, is one of relatively small displacement. (See Pl. 21, sections E-E′; also Pl. 18.) It thrusts the Rome on the Honaker. Its course is in general parallel to that of the St. Paul fault to the southwest of the Big A Mountain area, and it meets a fault paralleling the Russell Fork fault a few miles northeast of the area. Like the other faults with its alignment, the Honaker is a low-angle overthrust.

MINOR FAULTS

A number of minor faults occur in the Big A Mountain area. Some are offshoots of major faults, some are short cross-faults connecting the latter, and one or two take the place of folds along the strike. (See Pls. 21 and 22, B.)

On the northwest side of Big A Mountain there is an offshoot of the St. Paul fault, which is a thrust between the Pennington formation and the Norton-Gladeville beds. To the southwest its place is taken by the gradually thickening Lee formation, and there ceases to be a fault.

Another fault somewhat similar to the one just mentioned is within the Martinsburg formation near the southwestern end of its outcrop. Wedged as the Martinsburg is between the heavy Cambrian and Ozarkian dolomites and the Clinch sandstone, its weak shales have yielded and slight overthrusting has taken place. This is soon compensated along the strike to the northwest, where the compression was less severe and the outcrop widens.

There are 5 small faults at intervals along the Fullers Corners and Russell Fork faults, each enclosing a small wedge of Ordovician limestone. (See Pl. 21, sections B-B′, C-C′, D-D′, and E-E′.) On the eastern edge of the area, some Canadian beds are included with the Ordovician ones. It is thought that these 5 faults are remnants of a single long fault that traversed the area along the approximate present line of the Fullers Corners fault. Probably this fault brought Beekmantown, Murfreesboro, Mosheim, and younger beds upon Ottosee and younger beds; subsequent to this faulting, the Fullers Corners thrust was formed and to a large extent covered the trace of the previously existing one.

A small amount of Clinch sandstone is faulted between Cambrian beds and the Brallier shale in the southwestern corner of the area. This is a remnant of the Clinch which formerly occupied the southeastern flank of the Coombs School-Big A Mountain syncline, and was left behind when the Weaver Creek cross-faulting took place.

There are 3 cross-faults in the eastern half of the area. One extends from the Fullers Corners fault to the east to join the Cross-Creek fault, and the others extend from the Russell Fork fault to the Cross-Creek fault. Both probably represent compressive stresses which acted in a northeast direction, thrusting in two places Honaker dolomite on Copper Ridge dolomite, and in the third, Copper Ridge on Mosheim.

A fault cuts off the southeastern outcrops of Nolichucky shale at both ends of its outcrop. Its trace passes under the Cross-Creek fault block of Rome shale. At the southwest, the Nolichucky was squeezed between the Cambrian and Ozarkian dolomites until it was overridden by the Cambrian beds. The continuation of this fault to the northeast represents a thrusting of the Honaker dolomite over the weak shale after a syncline had been started.

DEFORMATION OF THE BIG A MOUNTAIN AREA

It is evident from the structure of the rocks in the Big A Mountain area that the major force which caused the deformation came from the southeast. (See Pl. 21.) This is a generally accepted principle of Appalachian orogeny. It seems obvious from the geologic map that the compressive force from the southeast must have been excessive in this area, probably more powerful than for many miles to the northeast or the southwest. This is indicated by several facts. The folded and faulted older Paleozoic rocks of the area form a remarkable salient, extending as they do farther to the northwest at this point than for many miles along the boundary between folded and flat-lying sediments. The intersection of the St. Paul and Russell Fork faults probably aided in the formation of this salient, making it easy for the extensive overthrusting to occur. Beds in the Pennington and Lee formations were dragged on both sides of the salient but were buried at its extreme point of overriding. Another evidence of tremendous pressures along the line indicated is the squeezing of the Big A Mountain syncline, shown by the constriction near its middle part and by the narrowing at its northeasternmost end. The belt of Nolichucky shale in the Cross-Creek anticline is most narrow in its middle part, indicating intense pressure at right angles to the axis of the fold. The southwestern end of the Nolichucky outcrop disappears in a fault toward the center of the area, and the corresponding extension of the formation at the northeast is cut off by a fault instead of completing its curve in a syncline. The wide belt of Rome shale extends somewhat farther to the northwest here than in other places.

Although most of the pressure from the southeast was probably relieved in a northwest direction, it is thought that a part of it was resolved into subordinate pressures to the west and to the northeast. It seems to the writer that western and northeastern components of the original force were produced, perhaps due to the fact that all the stress from the southeast could not be relieved in a northwest direction and that other outlets had to be found. There is some evidence to support this hypothesis. Thrust faults occur both to the southwest and to the northeast of the main overthrust. The Weaver Creek fault shows that the Big A Mountain syncline was pushed not only northwest but also west over the Coombs School syncline. The Fullers Corners fault and the associated infaulted wedges of Ordovician limestones bend to the south instead of continuing to the southwest. The Clinch sandstone also does this, cutting across the Coombs School syncline at a high angle. To the northeast, there are 3 minor thrust faults, mentioned above, which occur between the Fullers Corners, Russell Fork, and Cross Creek faults. They indicate that the force which produced them came from the southwest. The Mosheim, Murfreesboro, and Beekmantown formations, on the eastern side of the area are mapped to conform to this interpretation.

The writer's attention has been called to the possibility that the Big A Mountain salient is not a structural feature but an erosional one, and that the syncline of resistant Clinch sandstone may not have been eroded back as far as the rocks to the northeast and southwest. This does not seem a valid argument, for there are tilted ridges of sandstone in the Pennington and Lee formations which are as highly resistant as the Clinch and yet do not stand out upon the flat coal measures so markedly as the Big A Mountain syncline does. It thus seems certain that in the original thrust faulting this sector was pushed farther to the northwest than adjoining ones, and still maintains that position.

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