COMMONWEALTH OF VIRGINIA

DEPARTMENT OF CONSERVATION AND DEVELOPMENT

VIRGINIA GEOLOGICAL SURVEY

WILLIAM M. McGILL, *State Geologist*

Bulletin 71

Geology and Oil Resources of the Rose Hill District—the Fenster Area of the Cumberland Overthrust Block—Lee County, Virginia

By

RALPH L. MILLER and J. OSBORN FULLER

PREPARED IN COOPERATION WITH THE GEOLOGICAL SURVEY OF THE UNITED STATES DEPARTMENT OF THE INTERIOR

CHARLOTTESVILLE, VIRGINIA
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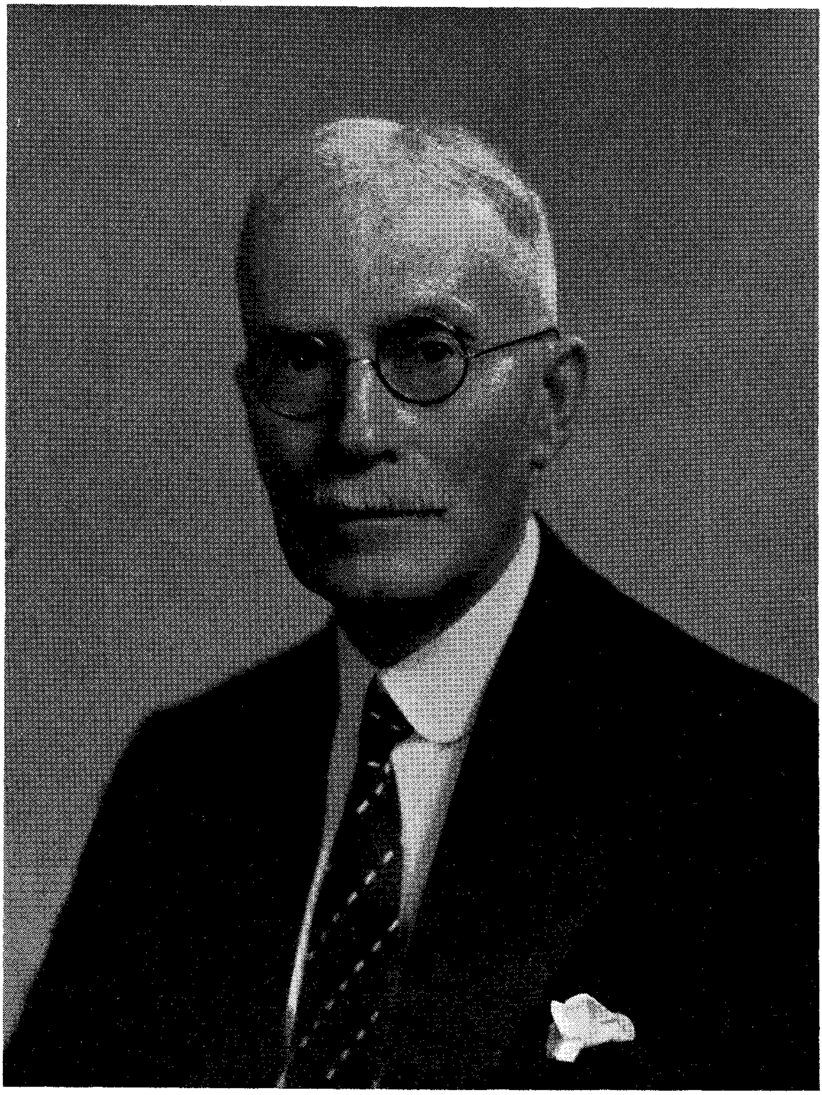
Division of Purchase and Printing
Richmond
1954

DEDICATED TO THE MEMORY

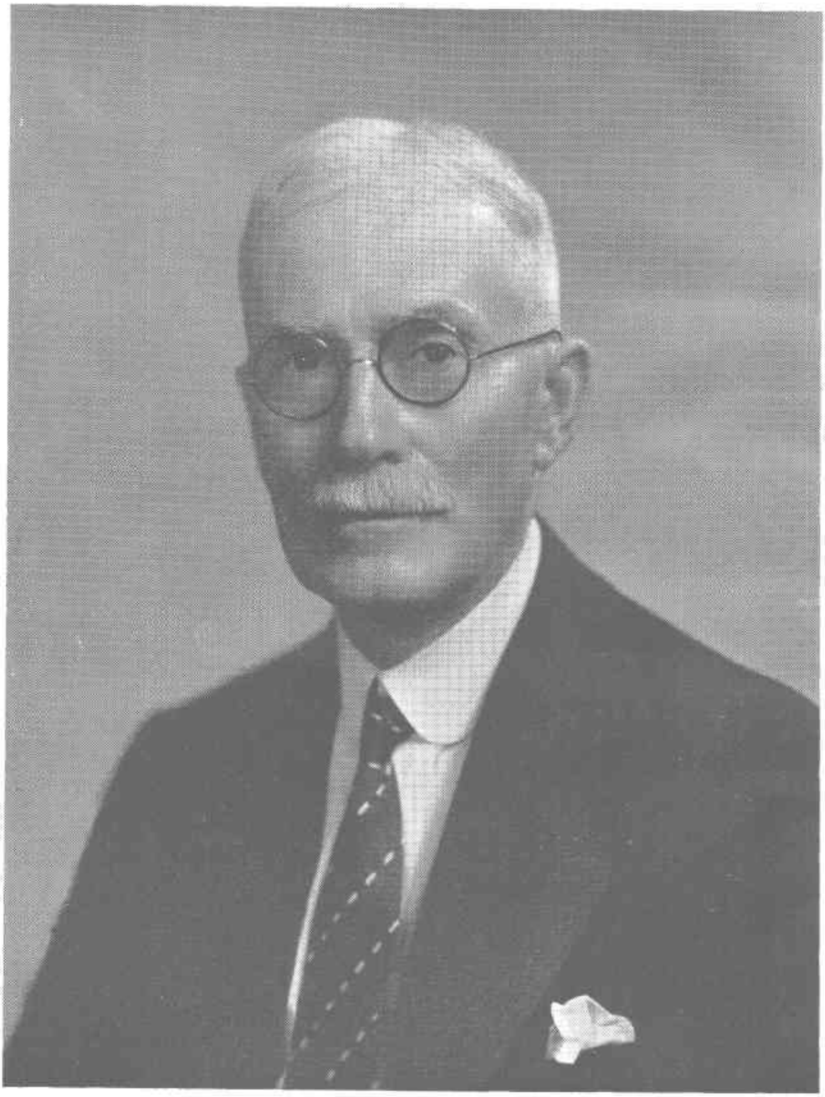
OF

Dr. Charles Butts

WHOSE MAJOR PUBLICATIONS ON THE GEOLOGY OF THE APPALACHIAN MOUNTAINS ARE MILESTONES IN THE PROGRESS OF THE SCIENCE TO WHICH HE DEVOTED A LIFETIME OF ENERGETIC RESEARCH.



DR. CHARLES BUTTS



DR. CHARLES BUTTS

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LETTER OF TRANSMITTAL

COMMONWEALTH OF VIRGINIA
DEPARTMENT OF CONSERVATION AND DEVELOPMENT
DIVISION OF GEOLOGY
VIRGINIA GEOLOGICAL SURVEY

CHARLOTTESVILLE, VA., AUGUST 31, 1953.

To the Department of Conservation and Development:

GENTLEMEN:

I have the honor to transmit for publication as Bulletin 71 of the Virginia Geological Survey, the text, geologic maps, and other illustrations of a report on *Geology and Oil Resources of the Rose Hill District—the Fenster Area of the Cumberland Overthrust Block—Lee County, Virginia,* by Doctors Ralph L. Miller and J. Osborn Fuller, of the United States Geological Survey.

The field work was done and the report prepared as one of a series of cooperative projects between the Fuels Branch of the United States Geological Survey and the Virginia Geological Survey. The report contains the results of detailed studies of the only district in southwestern Virginia in which petroleum has as yet been found in commercial quantity. Iron has been mined in parts of the Rose Hill district.

The information contained in this report should be of especial value to those interested in explorations for petroleum and natural gas, since the report contains much detailed information not heretofore available on the structural conditions in the fenster area of the Cumberland overthrust block. The exposed rocks in the mapped district range in age from Upper Cambrian to Upper Devonian and their total thickness exceeds 6,000 feet. In addition, approximately 2,000 feet of unexposed rocks of Lower and Middle Cambrian age were penetrated in one gas well. The mapped rock units have been divided into 21 formations, several of which have been subdivided into members.

The field work on which this report was based was done between December 1943 and January 1947, and the report and accompanying illustrations were submitted to the Virginia Geological Survey later in

1947. Printing difficulties have delayed the submission of the report for printing until now. Additional field work was done and information obtained on wells drilled between 1947 and 1950, to bring the report up to date as of March 1, 1950.

Respectfully submitted,

WILLIAM M. McGILL,
State Geologist.

Approved for publication:
Department of Conservation and Development,
Richmond, Virginia, September 2, 1953.
RAYMOND V. LONG, *Acting Director.*

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Geology and Oil Resources of the Rose Hill District—the Fenster Area of the Cumberland Overthrust Block—Lee County, Virginia

By RALPH L. MILLER and J. OSBORN FULLER

ABSTRACT

Petroleum is being produced and iron has been mined from rocks beneath a slice of the earth's crust known as the Cumberland overthrust block in an area near Rose Hill in Lee County, Virginia. Erosion of the overthrust block has exposed the oil- and iron-bearing rocks in fensters near the middle of Powell Valley. This valley is floored by rocks of the overthrust sheet, which has been warped into a broad anticline—the Powell Valley anticline—occupying the full width of the valley. The central upland of the valley is developed on Cambrian and Ordovician dolomites; two lowlands flanking the north and south sides of the upland are floored by Ordovician limestones; and two ridges bounding the valley are formed by sandstone of Silurian age. The ridge on the south is topographically prominent, but the one on the north is low and is overtopped by Cumberland Mountain, composed of very resistant conglomerate of Pennsylvanian age.

The exposed rocks in the mapped area, which includes a part of western Lee County, Virginia, and a small adjoining area in Hancock and Claiborne counties, Tennessee, range in age from Upper Cambrian to Upper Devonian, and their thickness totals 6200 feet. In addition 1900 feet of unexposed rocks of Lower and Middle Cambrian age were penetrated by the Brooks gas well. The rocks of the area have been divided into 21 formations, many of which have been subdivided into members.

In southwest Virginia long continued erosion in Tertiary time bevelled all but the most resistant rocks and produced a relatively even surface known as the Schooley peneplain, on which Powell River developed a meandering course. During subsequent uplift and dissection of the region, the Schooley surface has been destroyed, a partial peneplain has been developed at a lower level on the weak Cambrian and Ordovician limestones, and this in turn has been dis-

sected and partly destroyed. The meandering Powell River intrenched itself during the uplift, enlarging its meanders, and developing terraces at different levels.

In the area mapped the Cumberland overthrust block has moved nearly 6 miles to the northwest along the nearly flat-lying Pine Mountain fault. The broad gentle Powell Valley anticline of the overthrust block overlies an equally large anticline in the rocks of the stationary block, but the underlying anticline is truncated on its crest and southeast flank by the Pine Mountain fault; hence younger formations are present beneath the overthrust fault on the north flank of the anticline than occur along its crest or on its southeast flank. The axis of the anticline in the stationary block lies southeast of the axis of the Powell Valley anticline.

At 11 places along the axis of the Powell Valley anticline, erosion has removed all the overthrust rocks, exposing the rocks of the underlying stationary block in fensters. In parts of the area the Pine Mountain fault is not a simple fault, but has two branches between which lie slices of complexly faulted and contorted rocks. Slivers of rock have also been broken from the top of the stationary block, and have been dragged forward along the major fault planes for distances ranging from a few tenths of a mile to about two miles. Excellent exposures in the fenster area, coupled with evidence from drilling have made possible an accurate delineation of the geology of the overthrust block, of the stationary block, and of the complex slices between the two main branches of the Pine Mountain overthrust. The folding of the Powell Valley anticline began during the late stages of the overthrusting and was completed after overthrusting had ceased.

The principal mineral resources of the area are oil and iron. Beds of hematitic iron ore in the Clinch sandstone and Clinton shale of Silurian age were mined in several parts of the district, prior to the time of the First World War, but the deposits are no longer considered of economic importance because of their thinness and low grade.

Exploration for oil and gas along the Powell Valley anticline began in 1910, but the first well to obtain significant production was not completed until 1942. This well, termed the B. C. Fugate No. 1, is located in the westernmost fenster. It started in the rocks of the stationary block beneath the Pine Mountain overthrust, and obtained production of paraffin-base oil of premium grade in the Trenton limestone (Ordovician) at a depth of 1110 feet. Between the date of completion of the discovery well and March 1950, 32 more productive

wells and 25 dry holes have been drilled. Not all of the dry holes reached the Trenton limestone, the most productive formation in the district. In the early part of February 1947, the total production from the Rose Hill field was about 600 barrels a day. This included, however, large initial production from several recently completed wells, the settled production of which proved to be considerably smaller. In December 1949, the production was between 100 and 200 barrels a day. The life of most of the producing wells has been from three months to two years. In 1943 a well drilled two miles west of the oil field on the Eli Brooks farm obtained 225,000 cu. ft. of gas at a depth of 2030 feet. The well started in the overthrust block, but penetrated the overthrust fault plane and encountered the gas in the basal sand of the Cayuga dolomite (Silurian) near the top of the stationary block. The gas has not been utilized.

The discovery of oil in the Trenton limestone, in an area where the rocks of the stationary block are exposed in the westernmost fenster, is coincidental. The productive zone of the Trenton extends eastward and northeastward beneath the overthrust sheet. Other oil and gas pools may exist in the rocks of the stationary block in areas along the Powell Valley anticline remote from the fenster area.

INTRODUCTION

LOCATION AND SIZE OF DISTRICT

The district described in this report lies mainly in western Lee County in the extreme southwest corner of Virginia near the tristate junction of Virginia, Kentucky, and Tennessee (Fig. 1). It is roughly rectangular in shape, 9 miles long in a northeast-southwest direction and 7 miles wide. The southwest part of the mapped area extends a short distance into Hancock and Claiborne counties, Tennessee. Throughout this report the area covered by the geologic map (Pl. 1) will be referred to as the Rose Hill district, from the occurrence of the Rose Hill oil field within it.

PURPOSE AND SCOPE OF THE REPORT

The investigation of the Rose Hill oil field and the adjacent region was sponsored jointly by the Virginia Geological Survey and the United States Geological Survey. It was undertaken for the purpose of mapping and interpreting the geology of the complex fenster area near Rose Hill, with special emphasis on the oil resources of the region. Geologic mapping was extended several miles northwest and southeast of the fensters, to show the broad geologic setting in which the fensters occur, and also to work out the stratigraphy of the rocks in areas where they are in normal relation to one another. Detailed mapping (Pl. 2) was done chiefly in and near the fensters where the scale of the large geologic map (Pl. 1) was inadequate to show the complex geology. Stratigraphic sections of the formations were measured within the mapped area and also at favorable localities in the surrounding region. For some formations it proved desirable to visit critical localities considerable distances away, in order to determine the relations of the rocks of the mapped area to those previously described by other geologists. Comparative studies of this type were made in Tennessee near Knoxville, Nashville, and the Norris Reservoir; in Virginia, at places in Tazewell and Scott counties; and in Kentucky, along Kentucky River in Fayette County.

In working out the regional structure, brief studies were made of critical features outside the district. Much of the Cumberland overthrust block was traversed in reconnaissance and each of the four bounding faults of the block, namely the Pine Mountain fault, Russell Fork fault, Jacksboro fault and Hunter Valley fault, was examined in at least one locality.

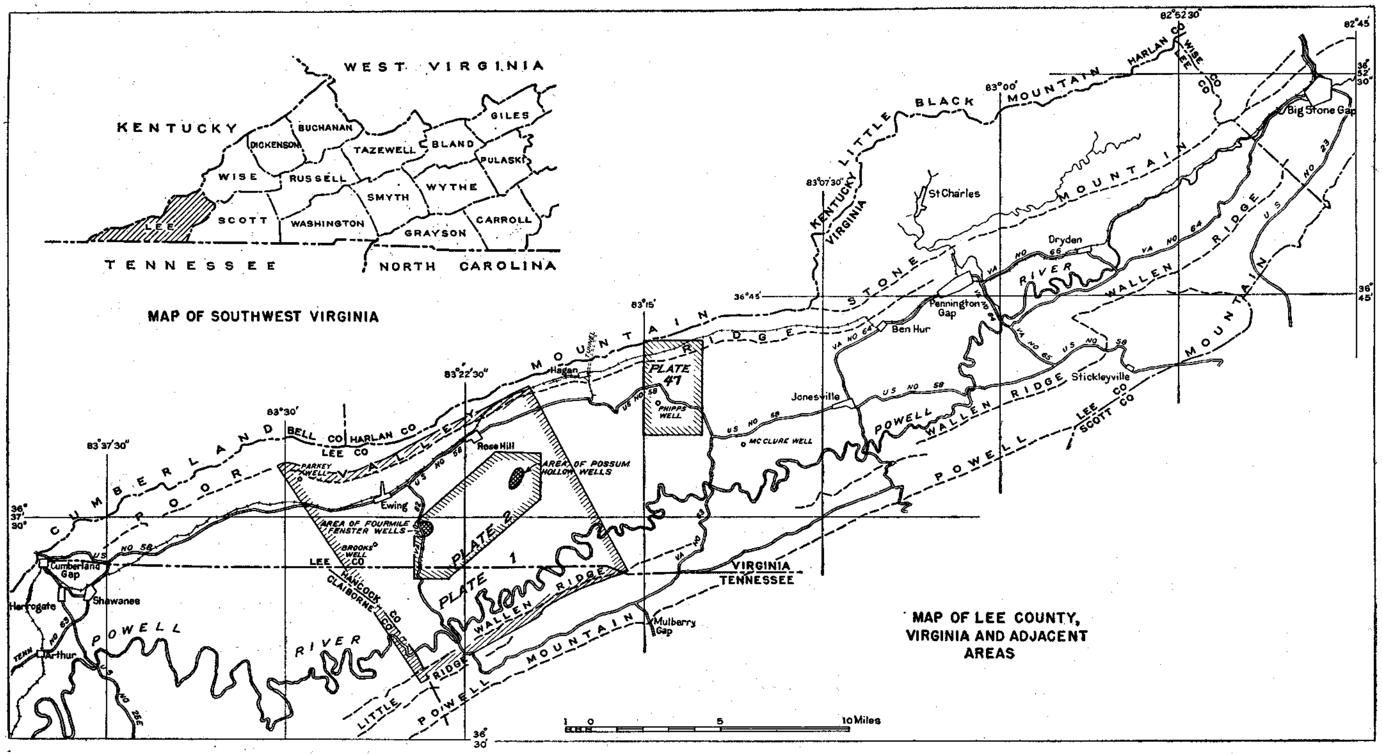

FIGURE 1.—Index maps showing the locations of Lee County, Virginia, and of the mapped areas in Lee County, Virginia, and adjacent Claiborne and Hancock counties, Tennessee.

The economic aims of the project were directed principally toward determining the structural and stratigraphic conditions of the occurrence of the oil, and also toward presenting the geology of the region in sufficient detail to serve as a guide for future drilling. All the wells, from which cuttings could be obtained, were logged, and such records as were available on the other wells, were studied. Records of wells outside the area were also studied for the information they might offer on regional problems.

Although the mining of iron ore in the vicinity was discontinued about 35 years ago, there were at one time many small mines working the Clinton iron ores. Because of their possible future importance and because of their historic interest, all the old mines were visited and information on the thickness of the ore beds and grade of ore was assembled. Other economic products were studied briefly.

PREVIOUS WORK

Only one geologic report has dealt specifically with the geology of the Rose Hill district. This is Bulletin 28 of the Virginia Geological Survey, entitled "Fensters in the Cumberland Overthrust Block in Southwestern Virginia," by Charles Butts.[1] (See frontispiece.) In this admirable report Butts calls attention, for the first time, to the existence of fensters near Rose Hill. He describes briefly the fensters that have been named by us the Possum Hollow fenster, Martin Creek fenster, Fourmile fenster, and the Blackberry Hollow part of the Dean fenster. He also describes the drilling of the first two oil wells in Possum Hollow, the occurrence of Clinton iron ore in the Fourmile and Dean fensters, and discusses the structural interpretation of the Cumberland overthrust block and of the fensters. The report includes a generalized map of the overthrust block on a scale of 20 miles to the inch and a structure section across the block, similar to but not identical with Pl. 5B of the present report. Butts' bulletin laid the groundwork for an understanding of the geology of the region, and his broad concepts have not been changed materially by the detailed studies on which the present report is based.

The only report containing a map of the regional geology of the area herein described is Butts' "Geologic Map of the Appalachian Valley of Virginia with explanatory text,"[2] which is on a scale of

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[1] Butts, Charles, Fensters in the Cumberland overthrust block in southwestern Virginia: Virginia Geol. Survey Bull. 28, 12 pp., 1927.

[2] Butts, Charles, Geologic map of the Appalachian Valley of Virginia with explanatory text: Virginia Geol. Survey Bull. 42, 56 pp. and map, 1933.

1:250,000. Four fensters are shown; they are the same as those described in his bulletin just cited.

Other contributions, which bear on the geology of the area here described, are principally of four types: (1) geologic studies of near-by areas, (2) stratigraphic papers dealing with formations that are present in the Rose Hill district or with correlative formations, (3) papers discussing the structural problems of the southern Appalachian Mountains and particularly of the Cumberland overthrust block, and (4) economic papers dealing with the geology of oil and gas, especially in the states of Virginia, Kentucky and Tennessee. A large number of titles fall under one or another of these categories. The papers that deserve special mention because of their direct bearing on problems discussed in this report are Butts'[3] comprehensive stratigraphic work on the Appalachian Valley of Virginia, Bates'[4] paper on northeastern Lee County, Oder's[5] paper on the Knox group, and Wentworth's[6] original description of the Cumberland overthrust block.

The authors have published two preliminary maps with accompanyin texts[7, 8] on the Rose Hill oil field.

FIELD AND LABORATORY WORK

Miller made a two weeks reconnaissance survey of the Rose Hill district in December 1943. In late April 1944, both authors began detailed field studies which were carried on continuously by Fuller to the middle of January 1945, and by Miller for all except two and one-half months of this time. Laboratory and library studies and the preliminary draft of this report occupied the full time of both authors from January to September 1945. Miller spent a week in May 1946, and another week in January 1947, studying new developments in the oil field, and spent several months revising and

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[3] Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, part I, Geologic text and illustrations, 568 pp., 1940; part II, Fossil plates and explanations, 72 pls., 271 pp., 1941.

[4] Bates, R. L., Geology of Powell Valley in northeastern Lee County, Virginia: Virginia Geol. Survey Bull. 51-B, pp. 31-94, 1939.

[5] Oder, C. R. L., Preliminary subdivision of the Knox dolomite in east Tennessee: Jour. Geology, vol. 42, no. 5, pp. 469-497, 1934.

[6] Wentworth, C. K., Russell Fork fault of southwest Virginia: Jour. Geology, vol. 29, no. 4, pp. 351-369, 1921.

[7] Miller, R. L. and Fuller, J. O., Geology of the Rose Hill oil field, Lee County, Virginia: U. S. Geol. Survey Oil and Gas Invest. Ser., Prelim. Map 20, 1944.

[8] Miller, R. L. and Fuller, J. O., Geologic and structure contour map of the Rose Hill district, Lee County, Virginia: U. S. Geol. Survey Oil and Gas Invest. Ser., Prelim. Map 76 (2 sheets), 1947.

editing the manuscript and illustrations, and preparing them for publication.

The geology of the fenster area was mapped on a topographic base map, having a scale of 1:10,000, specially prepared for the purpose by the U. S. Geological Survey and the Tennessee Valley Authority. The map as here published (Pl. 2) is on a scale of 1:12,000. Because of the complexity of the geology in and near the fensters, the location of small outcrop areas required special accuracy which was facilitated by the use of aerial photographs of the district.

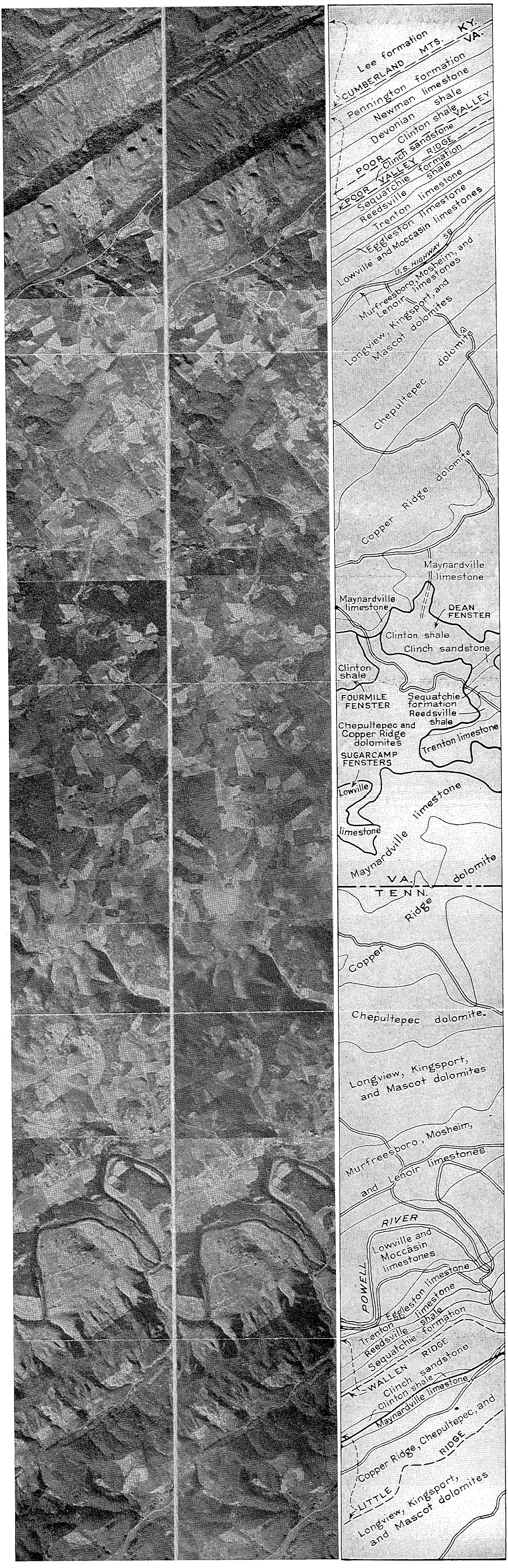
Mapping of the area beyond the limits of the topographic map of the fenster area was done on aerial photographs, whose approximate scale is 1:36,000. The geology was then transferred to planimetric maps of the Tennessee Valley Authority (scale 1:24,000) by means of a Buckmaster sketchmaster.

Stratigraphic sections were measured with a short tape in areas having good exposure of the beds, and with a 100-foot tape and Brunton compass across poorly exposed intervals.

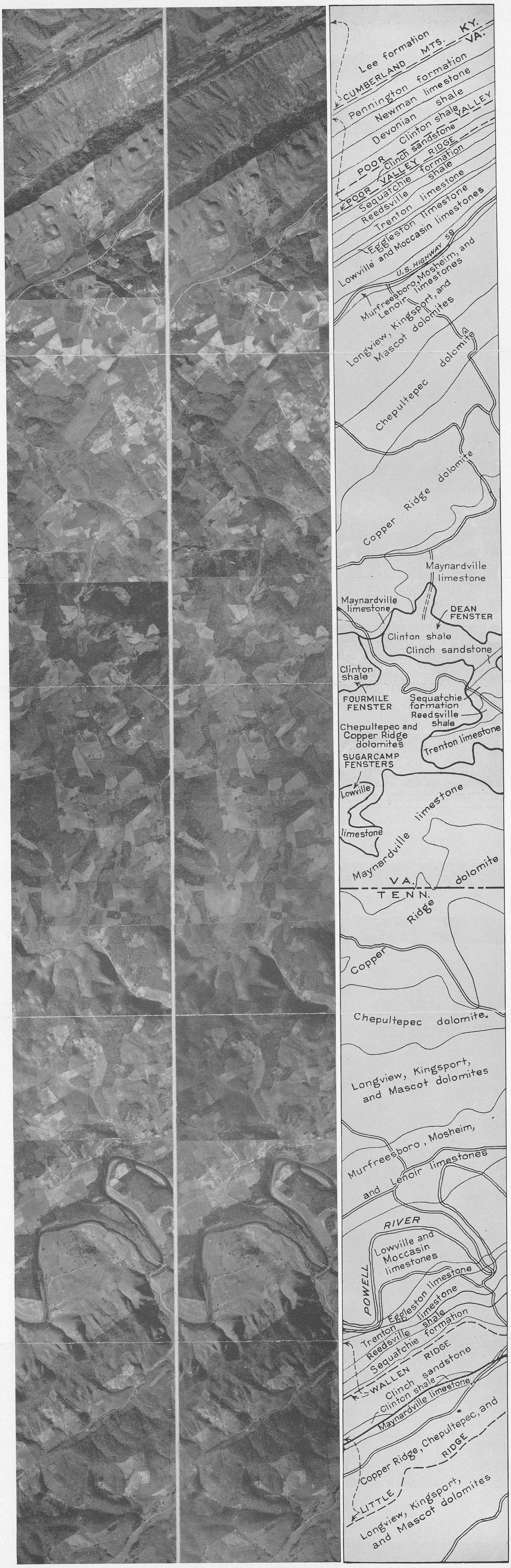
Cuttings of the oil wells were examined microscopically and samples that contained "pays," "shows," or possible "shows" of oil were tested with acetone. Cuttings of most of the wells drilled since May 1946 have not been made available for study. Porosity and permeability tests of unweathered rock samples of the potentially petroliferous formations were made in the laboratories of the U. S. Geological Survey at Casper, Wyoming. Microscopic studies of the important bentonite beds were made by C. S. Ross of the U. S. Geological Survey, and several mineral specimens were identified in the petrologic laboratories of the U. S. Geological Survey. R. M. Pinckney of the Bureau of Plant Industry, Department of Agriculture, made the chemical analyses of well cuttings, Paul H. Bird of the New York Board of Water Supply made the photomicrographs, and Ansel M. Miller made most of the "Craftint" sketches.

G. A. Cooper of the U. S. National Museum identified most of the Ordovician fossils and F. M. Swartz of Pennsylvania State College identified the Silurian fossils. A few fossils were identified by Charles Butts, R. S. Bassler and E. Kirk.

In 1947 the manuscript of this report was completed, the illustrations were drafted, and the colored geologic maps were printed. Unavoidable delays in publication ensued and the report did not go to press till 1953. In the interim many new wells were drilled in the Rose Hill district. Miller kept in touch with developments by occasional trips to the district. New information on wells drilled be-



Stereoscopic pair of strip photographs from north to south across the Rose Hill district. Strip map to right shows the geology of the area covered by the photographs. Compiled from aerial photographs of the Tennessee Valley Authority.



Stereoscopic pair of strip photographs from north to south across the Rose Hill district. Strip map to right shows the geology of the area covered by the photographs. Compiled from aerial photographs of the Tennessee Valley Authority.

tween 1947 and 1953 has not changed any of the important geologic concepts presented in the report, and very few and very minor refinements of subsurface information have resulted. The section on oil geology has therefore not been rewritten, but a section has been added summarizing more recent developments. The locations of the new wells have been added on Plates 1 and 2, and the table of wells has been brought up to date as of March 1, 1950. Because cuttings of most of the recent wells have not been available for study, and because information on depths of holes and location of pays and shows has also been withheld for many of the wells, the new wells are not discussed individually.

ACKNOWLEDGMENTS

We have been assisted during the course of the project by numerous individuals, whose contributions have been of great value. Conferences in the field with interested geologists have been helpful. We are especially indebted to B. N. Cooper and R. S. Edmundson, both formerly of the Virginia Geological Survey, for familiarizing us with the stratigraphic units of southwest Virginia at the outset of the project. Others whose counsel in the field has been especially helpful are H. D. Miser, A. A. Baker, Josiah Bridge, R. A. Laurence, Deane Kent, Arnold Brokaw, Frank Stead, and R. E. Bentall of the U. S. Geological Survey; also A. C. Bevan, former State Geologist, and W. M. McGill, present State Geologist, of the Virginia Geological Survey, James Walls of the University of Tennessee, and D. J. Jones and L. B. Freeman of the Kentucky Geological Survey.

We are indebted to Prof. P. B. Stockdale, who placed the laboratory and library facilities of the Geology Department of the University of Tennessee at our disposal. We have also received assistance and information from the late Charles Butts of the U. S. National Museum, C. W. Wilson, Jr., of Vanderbilt University, and John Collins, John Rodgers, and Allen Williamson of the U. S. Geological Survey.

Numerous oil operators have assisted us. Special thanks are due Floyd Fitch, who has furnished us with cuttings of many of the wells and with much data on the history of the Rose Hill oil field. We are also indebted to David Reger, E. Bruce Shade, R. D. Gardiner, R. Fulkerson, W. B. Fulton, F. M. Crockett, Gilbert Lee, R. F. Spear, E. R. Morris, B. C. Fugate, and White Moore for information on the oil wells.

GENERAL RELATIONS

REGIONAL GEOLOGY NEAR THE VIRGINIA-KENTUCKY-TENNESSEE STATE LINES

The exposed rocks in southwest Virginia and adjoining Kentucky and Tennessee are a part of a large overthrust block, which is one of the most unusual and interesting structural features of the Appalachians. The block, which is 125 miles long and 25 miles wide (Pl. 5A), is almost equally divided between the three states. In Virginia it includes nearly all of Lee, Wise and Dickenson counties and parts of Scott, Russell and Buchanan counties.

Wentworth[9] first recognized the significance of the fault relations in this part of the Appalachians and gave the name Cumberland block to the sheet of overthrust rocks. The block has moved northwestward along a nearly horizontal fault plane a distance estimated by Wentworth to be two miles at the northeast end of the block and ten miles at the southwest end. Where the overthrust fault beneath the block comes to the surface along the base of Pine Mountain in Kentucky and Tennessee, it is known as the Pine Mountain fault, or the Pine Mountain overthrust. At the two ends the Cumberland overthrust block is cut off by tear faults, namely, the Russell Fork fault in Virginia and the Jacksboro fault in Tennessee (Pl. 5A). In the Rose Hill district the block is interrupted on the southeast by the Wallen Valley fault, which, however, dies out eastward in Wise County. Because the Wallen Valley fault fails to span the entire southern side of the Cumberland block, the southeast border of the block is generally considered to be the Hunter Valley (St. Paul) fault, which is the next major fault to the southeast.

Within the Cumberland overthrust block are two major structural features, the Middlesboro syncline and the Powell Valley anticline. The exposed rocks in the Middlesboro syncline are Pennsylvanian in age, and include important bituminous coal seams in Virginia, Kentucky and Tennessee. Rocks of Cambrian age form the crest of the Powell Valley anticline, but have been breached by erosion in eleven places along the axis of the anticline near Rose Hill. Younger rocks beneath the Pine Mountain overthrust fault are here revealed in areas known as fensters.

Both the Middlesboro syncline and Powell Valley anticline are essentially broad gentle structures, in which the dips are almost

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[9] Wentworth, C. K., Russell Fork fault of southwest Virginia: Jour. Geology, vol. 29, no. 4, pp. 351-369, 1921.

everywhere less than 30 degrees. In a belt along the boundary between the syncline and anticline, however, the dips are much steeper, and in places are nearly vertical. This belt of steep dips is in reality the southeast limb of the syncline and the northwest limb of the anticline, but it is genetically and structurally somewhat independent of those folds, and is here designated the Cumberland Mountain monocline. In the vicinity of the Rose Hill district, the monocline is compound, with two belts of steep dips separated by a belt of flat dips. The relations of these different structural features are shown in the geologic section (Pl. 5B).

Up to January 20, 1947, only three wells, for which adequate records were kept, are known to have started in the rocks of the Cumberland overthrust block and to have penetrated into the stationary block beneath the overthrust. Two of them are in the Rose Hill district, and one is near Jacksboro, Tennessee. Only in and near the fensters, however, is enough information now available to map and interpret the geology beneath the overthrust fault. In parts of the fenster area the Pine Mountain overthrust fault is a zone bounded by two main fault planes, between which lie folded, faulted, and brecciated rocks. In addition, slivers of rock have been dragged along the lower fault plane and left in such positions that they are now exposed by erosion around the margins of some of the fensters. These structural features are well displayed by the good exposures of the rock strata in most of the fenster area.

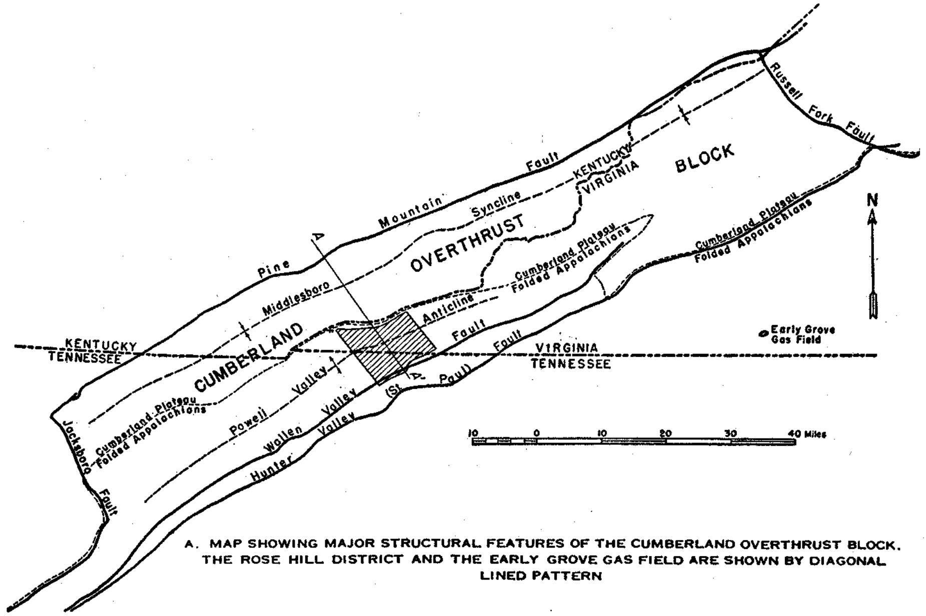
TOPOGRAPHY

The Rose Hill district is made up of linear topographic elements of three major types: a central upland, lowlands bordering the upland, and marginal ridges. The principal topographic elements and many topographic details are shown in the stereoscopic pair of strip photographs (Pl. 4), which crosses the central part of the district from north to south. The photographic strips are so arranged that they may be viewed with or without the aid of a stereoscope to obtain a three dimensional view of the topography. The strip map to the right of the photographs covers the same area, and shows the geology. Comparison of the map and photographs will bring out the close relationship between geology and topography. The Chestnut Ridge upland, which is the central element of the region, is developed largely on dolomites of Cambrian and Ordovician age (Pl. 31). Throughout most of the upland the dolomite beds dip gently away from the axis of the Powell Valley anticline, which runs more or less centrally from northeast to southwest through the upland belt. Despite its anticlinal structure this upland resembles a submaturely dissected plateau in many respects, because the differences in resistance to erosion of the various formations of dolomite are not sufficiently great to impart any strong lineation to the topography. The crests of the highest hills rise to about 1800 feet above sea level, but most of the hills average about 100 feet lower. Most of the hills are oval in shape with moderate slopes, except near the sharply incised major stream valleys. Only a few major streams drain the upland. Of these Martin Creek is the only one to cross the entire upland, but Fourmile Creek, which heads near the northwest edge of the upland, flows southeast across most of it (Pl. 31). These and several other smaller streams are intrenched from 300 to 500 feet below the crests of the hills. In general they flow in valleys whose walls are of only moderate steepness except where they are being strongly undercut on the outside of prominent bends of the streams. Stretches of valley floor with narrow but well-developed floodplains are interspersed with stretches having no appreciable floodplain.

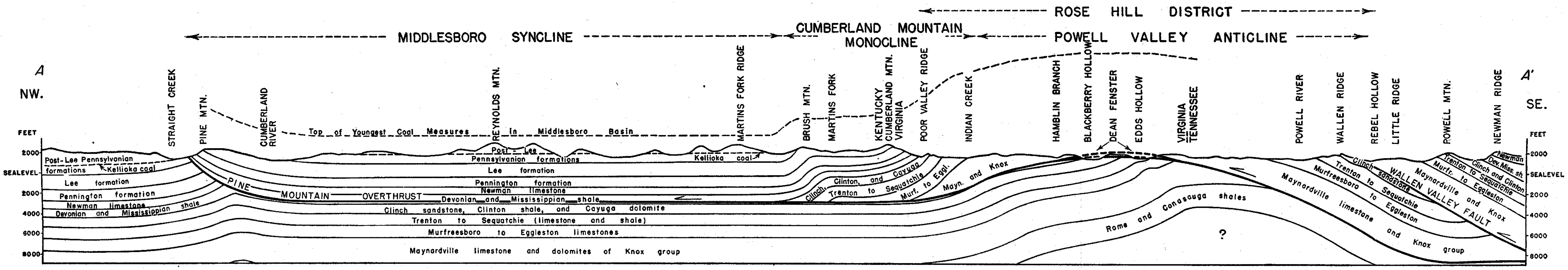
Plate 6 is an aerial photograph of a typical section of the Chestnut Ridge upland in the west central part of the Rose Hill district. Subparallel stream valleys drain southward into Powell River, which lies just beyond the south edge of the photograph. The checkerboard pattern of cultivated fields and wood lots is characteristic of the upland. Extensive wooded belts are confined principally to the walls of the major valleys, which are in most places too steep to be tillable.

The drainage of the Chestnut Ridge upland is not well integrated with the major stream system. Sinkholes abound, and much of the runoff descends into them to reappear at lower levels as springs or seeps (Pl. 31). In a few places long steep-walled valleys end in sinkholes. (See Pl. 35B.) Extensive areas with subsurface drainage have gentle topography and are at levels several hundred feet above the floors of the major stream valleys. Numerous sinkholes are visible in the aerial photograph (Pl. 6). They have the appearance of pock-marks, which show up especially clearly in the cultivated areas.

The Chestnut Ridge upland includes several areas of nondolomitic rocks, which erode to produce a different type of topography. None of these anomalous topographic areas is sufficiently large to alter greatly the overall appearance of the upland, but they form regions of special topographic and geologic interest. Most of the nondolomitic



A. MAP SHOWING MAJOR STRUCTURAL FEATURES OF THE CUMBERLAND OVERTHRUST BLOCK. THE ROSE HILL DISTRICT AND THE EARLY GROVE GAS FIELD ARE SHOWN BY DIAGONAL LINED PATTERN



B. GEOLOGIC SECTION THROUGH THE CUMBERLAND OVERTHRUST BLOCK ALONG THE LINE A-A' OF PLATE 5A. LENGTH OF SECTION, 27 MILES. DISPLACEMENT ON PINE MOUNTAIN FAULT, 5.8 MILES rocks appear in the fensters. They consist of limestone, shale, and sandstone representing almost all of the rock formations in the district. All these rocks, except the Clinch sandstone, are less resistant to weathering and erosion than the dolomites of the upland, so that the areas in which they occur have more open valleys and broader flood-plains along the streams than the surrounding region of dolomite. The larger fensters are thus quite distinctive topographically. The Martin Creek and Hamblin Branch fensters, for example, have unusually broad flat flood plains along the streams which drain them (Pl. 1), and the Possum Hollow fenster and the Blackberry Hollow part of the Dean fenster are especially well-developed basinlike areas lying below the upland level. Blackberry Hollow is shown in panoramic photograph on Plate 7A, and the position of the fault bounding the fenster is indicated on this same plate. The point from which the photograph was taken and the direction of the view are shown by an arrow on the geologic map (Pl. 1).

The Conasauga shale lies stratigraphically below the limestone and dolomite of the Maynardville limestone in the Chestnut Ridge upland, but has been removed by overthrusting throughout much of the district. In the southwestern part of the district, however, the Conasauga shale is preserved above the Pine Mountain overthrust, and underlies an irregularly shaped area along the axis of the anticline. The outcrop area of Conasauga along Fourmile Creek is characterized by conical, steep-sided hills rising abruptly from the valley floor. In the photograph (Pl. 7B) the area of Conasauga shale is confined to the region of knobby bare hills in the foreground and middle distance. Farther west the Conasauga shale has been levelled by erosion to a broad, gently sloping basin which is known to local residents as Frog Level. Long tonguelike areas and smaller isolated areas of resistant Maynardville limestone around the margins of Frog Level produce a dissected plateau-type of topography that is more striking than elsewhere in the upland.

On its southeast side the Chestnut Ridge upland slopes gently and evenly from its crest level to a lowland of limestone that is occupied by the Powell River, but on the northwest side the slope into the Indian Creek lowland is much steeper. The Powell River lowland and the Indian Creek lowland are comparable topographic features on opposite flanks of the Powell Valley anticline. Both are underlain by Ordovician limestones, but they differ considerably in appearance because the belt of limestone is much narrower on the northwest flank and because the southeastern lowland has been trenched by the Powell River, the master stream of the region.

The Indian Creek lowland is drained largely by the headwaters of Indian Creek, but partly by small tributaries of Martin Creek. It is an open valley varying from half a mile wide near Rose Hill to almost a mile wide in the northwest corner of the area. The lowland is continuous in both directions for many miles beyond the Rose Hill district, and is drained by various other streams. It is lower and flatter on its south side adjacent to the Chestnut Ridge upland, and is slightly higher and more hilly on its north side adjacent to Poor Valley Ridge.

The name Powell River lowland refers only to the lowland of limestone that lies between the Chestnut Ridge upland and Wallen Ridge. It is to be distinguished from the Powell Valley which refers to the entire area north of Wallen Ridge that is drained by Powell River, and which thus includes almost all the Rose Hill district. Powell River occupies the lowland in the district and for 15 miles to the east, but a few miles to the west of the district the river leaves the lowland and enters the Chestnut Ridge upland. The Powell River lowland formerly had a well-developed, fairly even erosion surface at about 1300 feet altitude, or about 150 feet above the present altitude of Powell River. Large parts of this surface are preserved where the lowland becomes much broader east of the Rose Hill district. Within the district, however, the sweeping meanders of Powell River occupy nearly the full width of the narrow lowland, and only small remnants of the surface have escaped erosion. Most of the lowland is occupied by slopes gently or steeply declining toward the river, or by vertical cliffs where the river has been actively undercutting resistant formations on the outside of its meanders. Long meander spurs project into the loops of the river. River terraces are numerous especially on the slip-off sides of the meanders. Terraces at the higher levels are poorly preserved, but a very perfect set of low terraces, which average about 200 feet in width, borders the river about 26 feet above low water level. The widest of the low terraces are located on the slip-off sides of the meander spurs, but in some straight stretches narrow low terraces lie on both sides of the river. The intrenched meanders, undercut and slip-off slopes, and terraces of Powell River are among the best developed features of this type in the Appalachians. Cut-off meanders also have been formed, but of five known or suspected from a study of aerial photographs of the general region, only one, and that the least well preserved, lies within the mapped area.

Two prominent ridges border the district on the northwest and southeast. Both are formed by resistant beds in the Poor Valley Ridge member of the Clinch sandstone. Poor Valley Ridge on the northwest rises 400 to 500 feet above the Indian Creek lowland, but is dwarfed by the steep face and craggy cliffs of the much higher Cumberland Mountain lying just beyond (Fig. 2). Near the west edge of the district Poor Valley Ridge exceeds 2000 feet in altitude in a few places, but it averages about 1800 feet throughout the district, whereas the highest point of Cumberland Mountain in this vicinity is at 3451 feet. The south slope of Poor Valley Ridge is distinguished by a row of perfectly alined knobs a short distance below the ridge crest. The knobs, which show very prominently near the upper part of the aerial photograph (Pl. 8), and also in the sketch (Fig. 2), are formed by the outcrop of resistant beds in the Reedsville shale. In the photograph the crest of Poor Valley Ridge is marked almost exactly by the woods line, with the north or backslope of the ridge entirely timbered. The undissected, cultivated Indian Creek lowland forms a prominent belt, which includes Rose Hill at the left edge of the picture, and the lower two-thirds of the photo is typical of the dissected Chestnut Ridge upland.

FIGURE 2.—Sketch looking westward along Poor Valley Ridge from Indian Gap. The three alined knobs near the center of the sketch are composed of Reedsville shale, with the ridge crest of Clinch sandstone above and to the right. Cumberland Mountain, which is capped by a high cliff of conglomerate at the base of the Lee formation, shows through Indian Gap at the right edge of the sketch. Indian Creek lowland appears in the left part of the sketch, with the hills of the Chestnut Ridge upland beyond. By Ansel M. Miller.

Poor Valley Ridge is pierced by water gaps at Ewing and Rose Hill; a third gap lies midway between Rose Hill and Ewing. The Louisville and Nashville Railroad makes use of the gap at Rose Hill for its main line along Powell Valley (Pl. 1) and of the gap at Hagan just east of the Rose Hill district for the switchback from its tunnel through Cumberland Mountain.

Wallen Ridge forms a nearly continuous barrier along the south side of the district, though only a few miles beyond the borders in either direction, the ridge-making Clinch sandstone of Wallen Ridge is cut out by the Wallen Valley fault and Wallen Ridge thus disappears or becomes much lower. In the Rose Hill district it averages about 2000 feet in altitude, with the high point 2150 feet. The north mountain face in places rises steeply almost 1000 feet above the meandering Powell River. The belt of Reedsville shale on the north face of Wallen Ridge is marked at the base and top of the formation by changes of slope. The knobs thus formed are much gentler and less prominent than the corresponding knobs formed by the Reedsville on the south slope of Poor Valley Ridge. The only breach in Wallen Ridge within the district is formed by Mulberry Creek, which cuts through the ridge in a prominent watergap that has no name. The name Mulberry Gap has been applied to a low windgap in Powell Mountain near the headwaters of Mulberry Creek southeast of the Rose Hill district. The features of Wallen Ridge described above are illustrated in the aerial photograph (Pl. 32A) and in the sketch (Fig. 3).

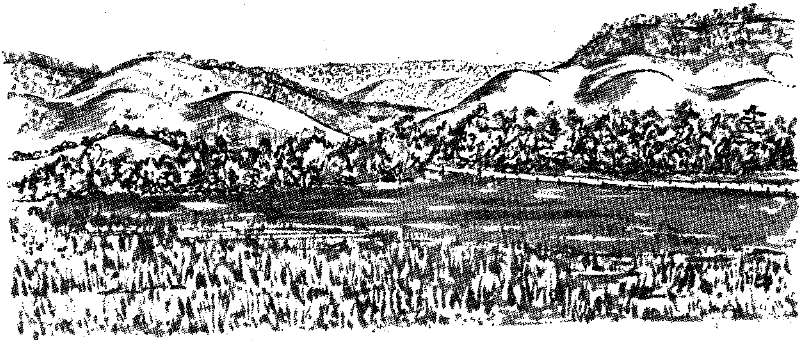


FIGURE 3.—Sketch of Wallen Ridge looking southward through the watergap of Mulberry Creek. Powell Mountain, which is formed by a belt of Clinch sandstone lying southeast of the Wallen Valley fault, appears in the distance through the gap. By Ansel M. Miller.

Subsequent valleys lie on the back sides of both Poor Valley Ridge and Wallen Ridge. The southeastern valley is locally called Sulphur Hollow and Rebel Hollow. A small part of it appears near the southeast edge of the geologic map of the district (Pl. 1). It is developed partly on the Clinton shale and partly on Cambrian limestones and dolomites, which are brought into contact with the Clinton by the Wallen Valley fault. Poor Valley, which is the corresponding valley on the northwest side of the area, lies just northwest of the limits of the geologic map (Pl. 1). It is formed by the Clinton shale, Cayuga dolomite and overlying Devonian shales.

VEGETATION

The mountainous character of Lee County makes it one of the heaviest timbered counties in the State in spite of almost constant lumbering for 85 years. In the Rose Hill district the greatest expanse of timber is on the broad Chestnut Ridge upland, about half of which has not been cleared for cultivation. Years ago the upland was covered by a thick stand of chestnut which gave rise to the name Chestnut Ridge, but lumbering and the blight have destroyed these trees. The only chestnut at present consists of a few sprouts that grow from old trunks at some places. The dominant trees of the upland are the yellow poplar or tulip tree, hickory, and oaks. Some of these trees are large, and isolated areas still have fine stands of timber. Because of its rapid growth, the yellow poplar forms good stands in the wet coves in spite of an almost constant cutting, and it is the most important tree of the area at present. Other sparsely distributed trees, which have some importance as timber, are beech, walnut, maple, locust and cedar. Sassafras, dogwood, and red bud or Judas tree are abundant but of no commercial value. Flame azalea is present on the sandy soil of the Chepultepec dolomite.

The next largest areas of timber in the Rose Hill district are on the back slopes of Poor Valley Ridge and Wallen Ridge and in their associated valleys, Poor Valley, and Sulphur and Rebel hollows. Over three-fourths of these areas are covered by timber. On the crest and north-facing slope of Poor Valley Ridge poplar, beech, maples, and rock, white, and black oak are the dominant trees and rhododendron, mountain laurel, and flame azalea are characteristic shrubs. Holly is also locally abundant. On Wallen Ridge and its south-facing slope, rock oak is the dominant tree with other species similar to those on Poor Valley Ridge in less abundance.

The Powell River lowland is practically all cleared except for a broad band of red cedar on the ledgy Lowville limestone, which extends continuously from one side of the area to the other. Associated trees are red oak, white oak, hickory, and black walnut. The Indian Creek lowland is completely cleared except for a few small isolated wood lots. Sycamore lines the larger streams throughout the area.

A much more extensive treatment of the forests of Lee County is presented by Baker[10] as a chapter in Bulletin 26 of the Virginia Geological Survey.

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[10] Baker, H. L., The forests of Lee County, Virginia, *in* Giles, A. W., The geology and coal resources of the coal-bearing portion of Lee County, Virginia: Virginia Geol. Survey Bull. 26, pp. 179-207, 1925.

CLIMATE

The nearest United States Weather Bureau station to the Rose Hill district is at Big Stone Gap 35 miles to the northeast. Records taken at this station indicate a mean annual temperature of 54° F., the highest temperature of 97° F. in July, and the lowest of -26° F. in January. The mean annual precipitation is 51.55 inches at Big Stone Gap and 50.78 inches at Middlesboro, Ky., southwest of the Rose Hill district. There is a desirable concentration of rainfall in the growing season and a range from the wettest to the dryest year of 20.9 inches. Average annual snowfall is about 18 inches, but snow seldom remains on the ground for more than a few days. The average date of first killing frost in autumn is October 13, and the average date of last killing frost in spring is April 25.

ROUTES OF TRAVEL

The Rose Hill district is traversed by numerous roads, which make most parts of the area readily accessible. The main routes of travel are U. S. Route 58 and the Louisville and Nashville Railroad, both of which follow the Indian Creek lowland. Secondary roads branch off southward from U. S. Route 58 and serve the Chestnut Ridge upland area and the Powell River region. Except in the southwestern part of the district, almost all of these are all-weather roads which are kept in good repair. The greatest barriers to travel in the district are Powell River and Wallen Ridge. The former can be crossed by car only at Parkey Bridge, and roads along the south side of the river are fair or poor and locally entirely lacking. Five suspension foot-bridges span the river, however, and make it possible to reach any part of the district south of the river and north of Wallen Ridge without walking more than a mile or two. The foot bridges are shown on Plate 1. Wallen Ridge can be crossed by car only along the road through the watergap of Mulberry Creek, which connects the Rose Hill district with Sneedville, Tennessee, and the intermontane valleys to the southeast. Local wagon roads, several of which formerly surmounted the ridge, have fallen into disrepair so that they are no longer usable. The only towns in the district are Rose Hill and Ewing, both located in the Indian Creek lowland of Lee County.

HISTORY

The Indian Creek lowland has been a thoroughfare through the southern Appalachians since man first entered the region. The Indians passed back and forth through it on their periodic travels to new hunting grounds. At one time a semipermanent Indian village was located in the lowland; its site is now marked by a small, oval, man-made mound lying near U. S. Route 58, 2 miles east of Ewing (Pl. 1). The mound was partly excavated by a field party of the Peabody Museum in 1876, and the results of the exploration were described in a publication of that institution.[11] Early in the course of the excavations, one of the scientists was killed by the collapse of the walls of a shaft in which he was working, but, despite the accident, considerable digging was done in the mound. Many layers of charcoal and many bones of animals were found in the lower levels, showing that the mound was frequently a village site. The only evidences of burial were confined to the upper levels of the mound, where the skeletons of a man, a woman, and two children were unearthed. Implements and ornaments such as beads, shell pins, carved shells, spear points, and dagger points were also associated with the bones. The Peabody Museum archaeologists were unable to date the mound, other than to indicate that it may have persisted as a village site after white men entered the region.

The first recorded expedition of white men into the district was in 1756; it was led by Elisha Wallen, after whom Wallen Ridge is named. Some 12 years later Joseph Martin built a small fort on the banks of the creek now named Martins Creek, but he and his party were driven out by the Indians after a stay of only a few months. With the discovery of the rich hunting lands in central Kentucky, the trail through the Indian Creek lowland and Cumberland Gap became the route of travel from the Atlantic seaboard to that region. Daniel Boone traveled through the lowland many times, and U. S. Route 58, which now follows the lowland, is known as Boone's trail. A marker along the highway west of Ewing chronicles the death of Boone's son in 1773, when one of Boone's parties was attacked by Indians while on the way to Kentucky.

Permanent settlers began moving into the area shortly after the Revolutionary War, and in 1792 Lee County was formed and named for General Henry (Light Horse Harry) Lee, then Governor of Virginia. Settlement of the Rose Hill district was slow but steady until 1890, when a British land company bought large tracts near the tristate junction of Virginia, Kentucky, and Tennessee and founded the city of

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[11] Carr, Lucien, Report on the exploration of a mound in Lee County, Virginia, conducted for the Peabody Museum: Peabody Museum 10th Ann. Rept., pp. 74-94, 1877.

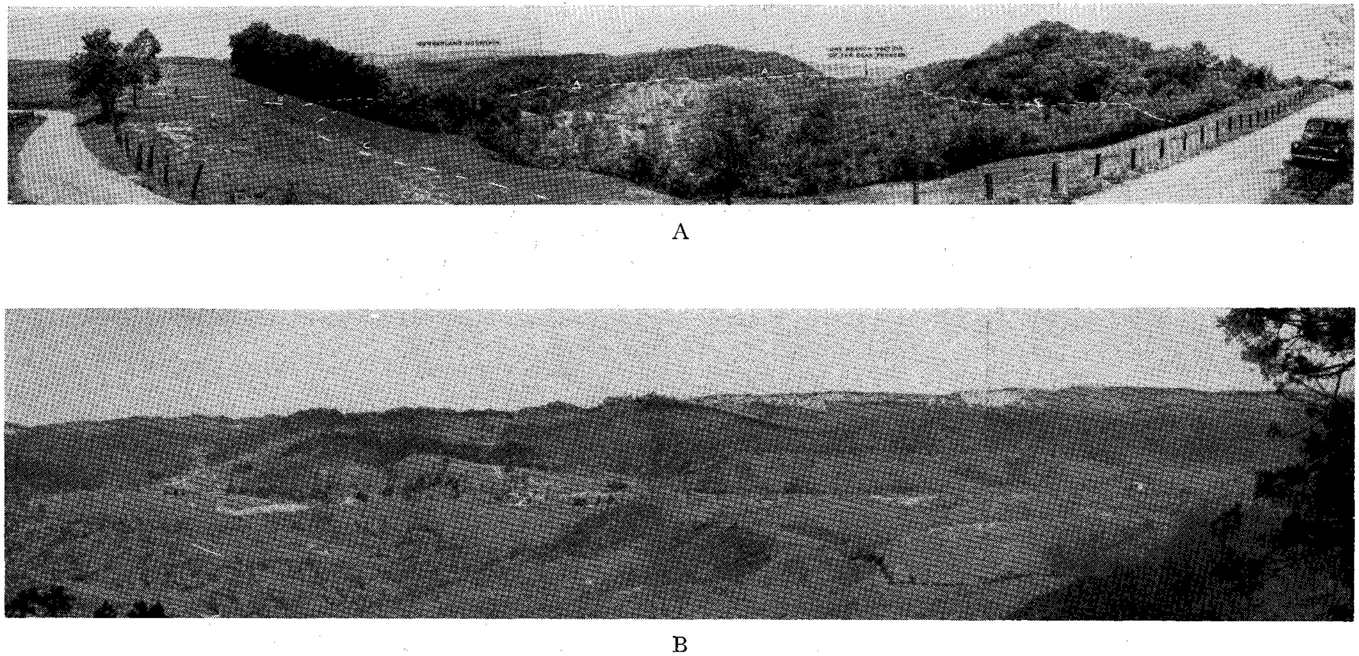
Middlesboro, Kentucky, just west of Cumberland Gap. The purchased land in all three states was supposed to contain rich mineral deposits, especially coal and iron ore. The coal deposits in Kentucky and adjoining Tennessee lived up to expectations and continue to be very large producers of bituminous coal. The iron ore deposits on which the new settlement pinned its hopes were principally the seams of Clinton iron ore in Poor Valley Ridge and Wallen Ridge and in the fenster area south of Ewing. With the building of the Louisville and Nashville Railroad about 1890, many mines were opened in these deposits, including a number in the vicinity of Rose Hill. Most of the mines were short lived, as the iron-ore beds proved to be thinner and lower in grade than advertised in the glowing accounts, which had brought many of the settlers to the Middlesboro district. Some mines, however, continued in operation for 15 or 20 years and one is said to have been operating up to the time of World War I.

Since the collapse of the iron-mining industry the residents of the Rose Hill district have depended almost entirely on agriculture for their income. Farming is quite diversified, but the principal sources of income are tobacco, corn, and live stock.

The first well drilled for oil in Lee County was started in 1910 and completed unsuccessfully about 1915. It was located near Jonesville east of the Rose Hill district. In 1922 a well drilled in Possum Hollow failed to produce but had sufficient shows of oil to encourage further drilling. Since that time, a well has been drilled every year or two somewhere in the Rose Hill district. All were unsuccessful until the Fugate No. 1 well was brought in as a producer in 1942. There has been almost continuous drilling activity in the district since that time. Altogether 75 wells have been started in Lee County up to March 1, 1950, of which 70 are within the area shown on Plate 1.

Aerial photograph of the west-central part of the Rose Hill district, showing typical appearance of the Chestnut Ridge upland.

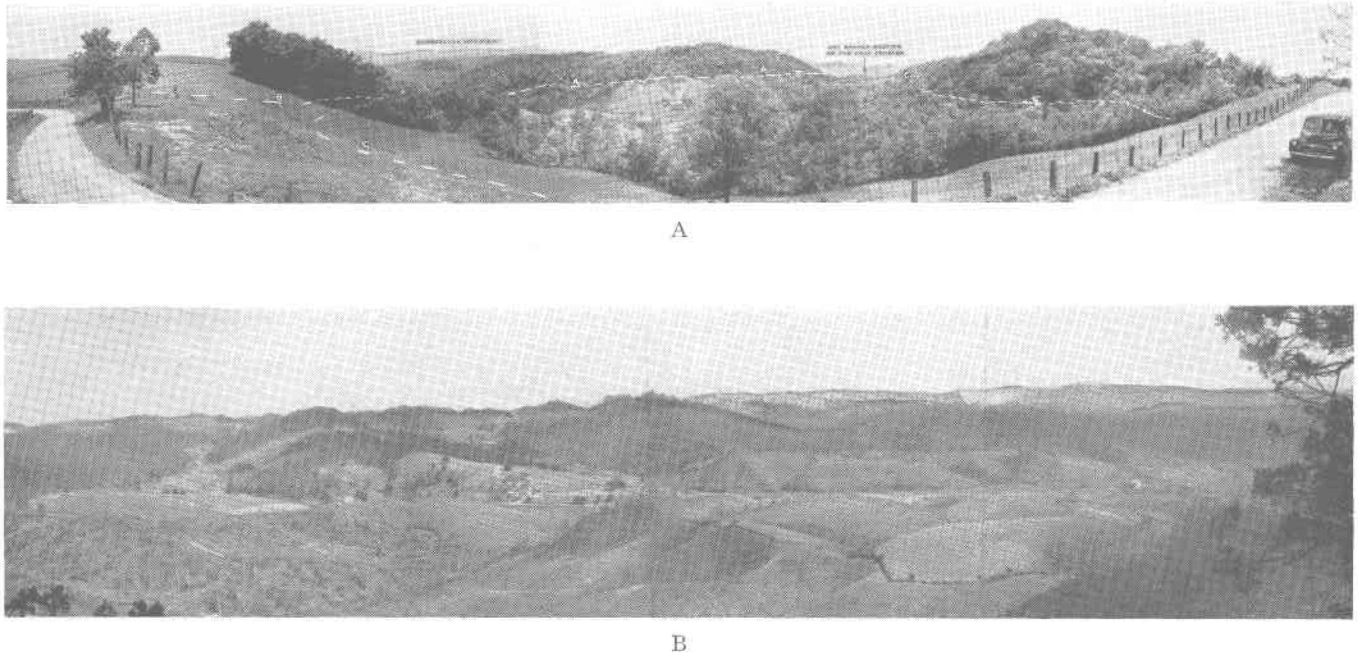
Aerial photograph of the west-central part of the Rose Hill district, showing typical appearance of the Chestnut Ridge upland.



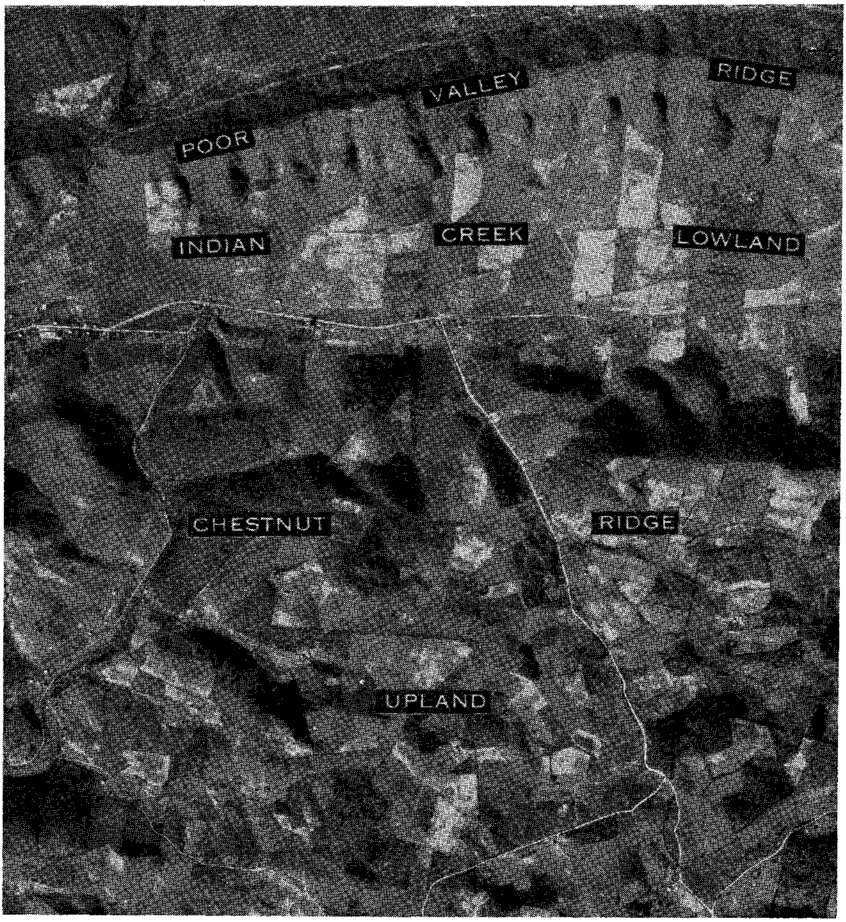
A

B

A, View across Blackberry Hollow in the Dean fenster. B, View eastward across Fourmile Creek Valley, showing knobby bare hills of Conasauga shale in the foreground and middle distance.



A, View across Blackberry Hollow in the Dean fenster. B, View eastward across Fourmile Creek Valley, showing knobby bare hills of Conasauga shale in the foreground and middle distance.



Aerial photograph of the northern part of the Rose Hill district, showing major topographic features.

Aerial photograph of the northern part of the Rose Hill district, showing major topographic features.

STRATIGRAPHY

GENERAL STATEMENT

The rocks of the Rose Hill district are of sedimentary origin and almost all of them are marine deposits. They have been divided into 21 formations, many of which have been subdivided into members. The bedrock formations range in age from Lower Cambrian to Upper Devonian. The Cambrian, Ordovician and Silurian systems have thick, well-exposed sections, but the Devonian system is represented at the surface by only a few feet of black shale in the Wilson fenster. The exposures of the Devonian rocks in the district are too small to appear on the geologic maps of the report, but the occurrence and character of these rocks are discussed.

The known sedimentary sequence totals nearly 8100 feet of beds. Of these the upper 6200 feet are exposed at the surface, and the lower 1900 feet are known from their occurrence in the Brooks well. Rocks of this unexposed sedimentary sequence are of Lower and Middle Cambrian age and belong to the Rome formation and the lower half of the Conasauga shale. In the eastern part of the Appalachian Valley, where the Lower Cambrian is well-exposed along the base of the Blue Ridge, it is about 8000 feet thick and consists largely of clastics, except for 1000 to 2000 feet of dolomite directly underlying the Rome. Undoubtedly the Lower Cambrian is thinner, and probably contains a smaller proportion of clastic beds in the Rose Hill district than it does along the Blue Ridge, but a considerable thickness of Lower Cambrian sediments probably lies between the Rome formation and the crystalline basement.

Nearly 7000 feet of Devonian and Carboniferous rocks are known to have been eroded from the Rose Hill district, as determined from the occurrence of this thickness of younger sediments in the near-by Middlesboro syncline. The thickness of still younger sediments, that have been entirely removed from this part of the Appalachians, is not known, but it probably amounts to at least several thousand feet more. These eroded sediments include younger rocks of Carboniferous age and possibly also rocks of Permian age. Thus the Paleozoic sedimentary sequence of the Rose Hill district was probably not less than 20,000 feet thick.

The Paleozoic rocks described in this report fall roughly into four lithologic divisions. At the base are about 2000 feet of shale and thin-bedded sandstone of Lower, Middle and Upper Cambrian age that belong to the Rome and Conasauga formations. These are overlain by nearly 2400 feet of massive-bedded carbonate rocks of Upper

Cambrian and Lower Ordovician age, which comprise the Maynardville limestone and the five formations of the Knox group. All except the lowest 100 feet of this sequence is dolomitic. Thin-bedded pure limestone and argillaceous limestone of Lower and Middle Ordovician age form the third lithologic division. This includes seven formations, from the Murfreesboro limestone through the Trenton limestone, and totals slightly more than 2000 feet of beds. The fourth division consists dominantly of shale but includes some limestone in its lower part, calcareous siltstone and sandstone in the middle part, and limestone and dolomite at the top. The formations, which range in age from Upper Ordovician to Upper Silurian are the Reedsville, Sequatchie, Clinch, Clinton and Cayuga. They are nearly 1900 feet thick.

A generalized columnar section showing the 21 formations, together with their lithologic descriptions, is given in Plate 9. The locations of measured stratigraphic sections in and near the Rose Hill district appear on Plate 13. The topographic expression of the formations is shown pictorially in the stereoscopic pair of strip photographs (Pl. 4), with the limits of each formation or group of formations indicated by the strip map to the right.

The manuscript of this report was transmitted for publication and the colored geologic maps were printed in 1947. The stratigraphic names used in this report by Miller and Fuller are for the most part those previously applied by Butts in Lee County. Subsequent work by Miller and Brosgé in the Jonesville district, which adjoins the Rose Hill district on the east, and by other geologists in other parts of southwest Virginia and in eastern Tennessee, has shown that some of the names used by Butts and others in Lee County should be abandoned. Eight new stratigraphic names have been introduced by Miller and Brosgé in the Jonesville district for mapped and/or described units which are identical or nearly identical to units described in this report under old names. If the Rose Hill report could be rewritten and the maps reprinted in the light of the additional stratigraphic knowledge gained between 1947 and 1954, the stratigraphic names in the Jonesville report would also be applied in this report on the Rose Hill district. The comparison of the names used in the reports on the two regions is as follows:

Miller and Fuller Rose Hill district, this report (written 1947, published 1954)	*Miller and Brosgé* Jonesville district (published 1950, 1954)
DEVONIAN	
Brallier shale	Upper Devonian shale

Miller and Fuller		*Miller and Brosgé*	
		SILURIAN	
Cayuga dolomite		Hancock dolomite	
Clinton shale		Clinton shale	
Clinch sandstone		Clinch sandstone	
Poor Valley Ridge member		Poor Valley Ridge member	
Hagan member		Hagan shale member	
		ORDOVICIAN	
Upper Ordovician		Upper Ordovician	
Sequatchie formation		Sequatchie formation	
Reedsville shale		Reedsville shale	
Middle Ordovician		Middle Ordovician	
Trenton limestone		Trenton limestone	
Eggleston limestone		Eggleston limestone	
Moccasin limestone			
Hardy Creek member		Hardy Creek limestone	
Lower member		Ben Hur limestone	
Lowville limestone			
Platy member		Woodway limestone	
Redbed member		Hurricane Bridge limestone	
Lower Ordovician			
Lenoir limestone (after Charles Butts)		Martin Creek limestone	
Mosheim limestone (after Charles Butts)		Rob Camp limestone	
Murfreesboro limestone (after Charles Butts)			
Cherty member*		Poteet limestone	
		Dot limestone	
Limestone member*		Upper limestone member*	
Dolomite member*		Lower dolomite member*	
		Lower Ordovician	
Mascot dolomite*	Knox group	Mascot dolomite†	Knox group
Kingsport dolomite*		Kingsport dolomite†	
Longview dolomite*		Longview dolomite†	
Chepultepec dolomite		Chepultepec dolomite	
		CAMBRIAN	
Upper Cambrian		Upper Cambrian	
Copper Ridge dolomite		Copper Ridge dolomite	
Maynardville limestone		Maynardville limestone	
Chances Branch dolomite member		Chances Branch dolomite member	
Low Hollow limestone member		Low Hollow limestone member	
Conasauga shale (lower part Middle Cambrian)		Not exposed	
Middle Cambrian			
Rome formation (lower part Lower Cambrian)		Not exposed	

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*Not mapped separately.
†Mapped separately only in local areas.

CAMBRIAN SYSTEM

ROME FORMATION

Name.—The Rome formation of Lower and Middle Cambrian age is the oldest known formation in the Rose Hill district. It was named from northwest Georgia,[12] but is present also in numerous long narrow belts in the Appalachian Valley of northern Alabama, western North Carolina, eastern Tennessee and western Virginia. The name Russell was applied to this formation in the Estillville folio,[13] which covers an area lying 15 miles east of the Rose Hill district, and the name Watauga has been applied in some reports to the same rocks in eastern Tennessee. Both of these names postdate the name Rome, and since they are in synonymy with it they are no longer used.

Distribution.—In the Rose Hill district, the Rome formation does not crop out nor is it exposed anywhere in the Cumberland overthrust block northwest of the Wallen Valley fault (Pl. 5A). It was penetrated by the Brooks gas well, however, where it lies between the Conasauga shale above and the Pine Mountain overthrust fault below. Within the overthrust block the Rome is confined to that part of the Rose Hill district lying west of the Fourmile and Sugarcamp fensters. Farther east in the district it has been cut out by the Pine Mountain overthrust. In the stationary block beneath the overthrust fault, the Rome probably underlies the entire district but at a depth nowhere less than 3500 feet and greatly in excess of this for the northern half of the area.

The outcrops of the Rome formation nearest the Rose Hill district are in the vicinity of Sneedville, Tennessee (Pl. 13), about 4 miles southeast of the part of Wallen Ridge shown on Plate 1. This belt of the formation is, however, cut off from the Rose Hill area by both the Wallen Valley and Hunter Valley (St. Paul) faults.

Character.—The Rome formation of southwest Virginia and northeast Tennessee consists dominantly of alternating shale and sandstone, with occasional beds or zones of limestone and dolomite. A sandy zone in the lower part of the formation makes prominent, sharply serrated ridges, which have been aptly described as "comby."

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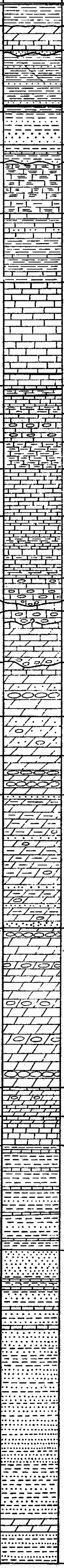
[12] Hayes, C. W., The overthrust faults of the southern Appalachians: Geol. Soc. America Bull., vol. 2, pp. 143-146, 1891.

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

System	Series		Formation	Mapped Members	Columnar Section	Thickness in Feet		Description
Dev.	U. Dev.		Brallier shale			5+		Interbedded black and greenish-gray shale.
SILURIAN			Cayuga dolomite			3-90		Basal pebbly sandstone, overlain by blue, ribbon limestone, with thick zone of light-brown fine-crystalline dolomite at top.
			Clinton shale			320-330		Interbedded bluish-gray and red shales and a few platy greenish-gray fine-grained sandstones. Some beds of "Clinton-type" hematitic iron ore, the best bed of which is near base.
			Clinch sandstone	Poor Valley Ridge Member		183	257	Ridge-making, massive sandstones in lower part; interbedded greenish-gray shale and fine-grained platy sandstone in upper part.
				Hagan member		70-77		Greenish-gray shale with interbedded siliceous limestone.
ORDOVICIAN	Upper Ordovician		Sequatchie formation			274		Green and red calcareous siltstone; zones of fossiliferous argillaceous limestone in lowest 85 feet.
			Reedsville shale			327-357		Greenish-gray shale, with interbedded steel-gray fine-crystalline siliceous limestone and light-gray to brownish-gray coarse-crystalline coquinal limestone.
	Middle Ordovician		Trenton limestone			549-562		Dark-gray, coarse-crystalline, even-bedded limestone with abundant fossils in lower part; medium-crystalline pure limestone and fine-crystalline siliceous limestone in upper part. Bentonite one foot thick 70 feet above base.
			Eggleston limestone			135-165		Buff-weathering, earthy, calcareous siltstone at base and near top; platy limestone in middle and at top. Two thick bentonites in upper part.
			Moccasin limestone	Hardy Creek member		141-154	279-297	Even-bedded limestone and siliceous limestone, with abundant chert nodules in a few beds.
				Lower member				Buff-weathering, highly fossiliferous, argillaceous limestone.
			Lowville limestone	Platy member		244-256	583	Gray cryptocrystalline and medium-crystalline limestone in thin even beds.
				Redbed member		331-336		Gray cryptocrystalline limestone, with zones of massive birdseye limestone, and of argillaceous limestone which weathers red or buff.
	Lower Ordovician		Lenoir limestone			128		Light to dark gray, chert-bearing and chert-free, cryptocrystalline limestone. In places a zone of fragmental limestone at base.
			Mosheim limestone			29-136		Light brownish-gray cryptocrystalline massive birdseye limestone.
			Murfreesboro limestone			135-274		Basal conglomerate, overlain by light-gray fine-crystalline argillaceous buff-weathering dolomite and interbedded limestone, which increases in quantity upward. Limestones in upper part contain abundant chert nodules.
		Knox Group	Mascot dolomite			170-462		White fine-crystalline dolomite with a pinkish cast. Some interbedded tan coarse-crystalline saccharoidal dolomite, sandy dolomite, and thick-bedded chert. A few beds of limestone near top.
			Kingsport dolomite			180-250		Light-gray medium- to coarse-crystalline saccharoidal dolomite containing scattered sand grains. Some interbedded white fine-crystalline dolomite, most abundant near top.
			Longview dolomite			98-272		Interbedded white fine-crystalline dolomite and white to tan, medium- to coarse-crystalline saccharoidal dolomite. Abundant chert as beds and nodules.
			Chepultepec dolomite			697-776		Lower or sandy member composed of interbedded light-brown medium- to coarse-crystalline saccharoidal dolomite, light-gray to tan fine- to medium-crystalline dolomite, and white medium-grained sandstone which is limonite stained. Thickest sandstone at base. Upper or argillaceous member has similar rocks, but argillaceous dolomite is dominant. Both members contain small amounts of chert as nodules and beds.
CAMBRIAN	Upper Cambrian		Copper Ridge dolomite			840		Lower member composed dominantly of brown and gray, coarse-crystalline dolomite with petroliferous odor. Upper member composed dominantly of white and light-gray, cryptocrystalline to coarse-crystalline dolomite. Lower member has some light-colored dolomite in upper part, and upper member has some dark-colored dolomite. Thin beds and lenses of white chert throughout, but especially abundant near top of upper member.
			Maynardville limestone	Chances Branch dolomite member		142-172	249-302	Gray fine-crystalline laminated dolomite, with mottled limestone interbedded near base, and dark coarse-crystalline dolomite interbedded near top.
				Low Hollow limestone member		160-206		Gray cryptocrystalline ribbon limestone in lower part, and mottled limestone in upper part. Fine-crystalline dolomite interbedded near top.
	—?— Middle Cambrian		Conasauga shale			560±		Green sericitic shale, with local zones of red shale, and with interbedded, coarse-crystalline, gnarled and veined, glauconitic limestone.
	—?— Lower Cambrian		Rome formation (not exposed)			1660±		Gray and green, fine- to medium-grained, micaceous and glauconitic sandstone; green and red shale; prominent zone of dolomite near base, and thin beds of limestone in upper part. Base of formation not penetrated by wells.

Generalized columnar section of the rocks exposed and drilled in the Rose Hill district

An excellent section of a part of the Rome is exposed on Tennessee State Highway 33, 23 miles southwest of the Rose Hill district and one-fourth of a mile north of Clinch River bridge. Here the lowest Rome next to the Wallen Valley fault consists of gnarled, impure, fine- to medium-grained sandstone and greenish shale. A prominent zone of limestone, more than 30 feet thick, lies 80 feet above the base of the section. It consists of dark-gray, finely crystalline limestone containing irregular-shaped stringers and patches of slightly coarser crystalline dolomitic limestone. The dolomitic limestone weathers brown and gives the rock a strongly mottled appearance on weathered surfaces. Overlying the limestone zone is a thick sequence of alternating beds of green and red shale and fine- to medium-grained impure sandstone. Although there are no sharp distinctions, this sequence is roughly divisible into lithologic zones. The lowest zone consists of green shale with some interbedded red shale and micaceous sandstone. A zone of red shale with interbedded platy sandstone overlies the green shale and is in turn overlain by a zone dominantly of white, buff and greenish impure sandstone, with considerable interbedded green and red shale. The sandstone zone is a persistent ridge-forming unit and has been mapped separately in the U. S. Geological Survey folios of northeast Tennessee.[14] A few score feet of weathered yellow sandy shale overlie the sandstone zone, and are the highest beds of the Rome formation exposed in the section. The thickness of the exposed beds totals about 850 feet, which represents approximately the lower half of that part of the Rome preserved above the Wallen Valley fault at this locality. The upper half, together with the Conasauga shale, forms a persistent lowland which is here largely covered by the waters of Norris Reservoir.

Both the red and green shales of the Rome are fissile and smooth, due to sericite and chlorite. The sandstones are white, buff, brown, and dirty greenish brown. The darker-colored sandstones are more micaceous and tend to be finer grained, whereas the white sandstone is made up almost entirely of quartz grains, the large ones of which are well rounded and approach medium-grain size. Most of the sandstones contain glauconite as finely disseminated grains barely visible with the hand lens, or as medium sized nodule-like grains of either bright green or deep greenish-black color. Almost all of the sandstone has a calcareous cement. Occasional beds of siliceous limestone

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[14] U. S. Geol. Survey Geol. Atlas, Knoxville folio (No. 16), 1895; Morristown folio (No. 27), 1896; Briceville folio (No. 33), 1896; Maynardville folio (No. 75), 1901; Greeneville folio (No. 118), 1905.

are present, but the only prominent limestone zone is the one near the base of the section. Keith[15] notes that the limestone units "occur chiefly along the northwestern parts of the areas, or the basal portion of the formation," in those belts of the Rome formation that are nearest the Rose Hill district. All of the Rome exposed in this section is in even lenticular beds, rarely more than a few inches thick. Ripple marks are common.

In the Brooks well, 1660 feet of rocks were penetrated that were assigned to the Rome formation. Except near the base of the Rome where the beds directly overlying the Pine Mountain overthrust are probably faulted, crumpled, and overthickened for a few score feet above the fault plane, the sequence in the well is believed to be in its correct order and with approximately its true stratigraphic thickness. This belief is based on the fact that the regional attitude of the rocks near the well, as shown by structure contours on the Maynardville limestone (Pl. 1), is practically flat, and also that the succession and thickness of lithologic units of the Rome encountered in the well agree closely with the exposed section described above.

In the Brooks well, the Rome is predominantly green and red shale and white, green and brown sandstone. The most prominent carbonate unit is a zone of dolomite, 67 feet thick, lying near the base of the section (Geologic Section 1, Unit 3). This dolomite is medium crystalline and light brown, and contains scattered grains of glauconite. Other carbonate units higher in the Rome are much thinner and much less prominent in the cuttings. They are of blue-gray, fine-grained limestone or brown crystalline limestone. A zone consisting dominantly of medium- to coarse-grained, glauconitic sandstone about 300 feet thick (Geologic Section 1, Unit 7), and lying 850 feet below the top of the formation, seems to correspond with the ridge-forming sandstone member of the Rome.

In well cuttings, the abundance of large glauconite grains throughout the Rome is very striking and distinguishes it from all other formations in the district except the Conasauga shale. The glauconite is most abundant in the sandstone, but is also found in the dolomite, limestone, and shale. The local abundance of sizeable flakes of white or bronze mica in the sandstone is quite characteristic of the Rome, as very little visible mica exists in other sandy formations of the district.

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[15] Keith, Arthur, U. S. Geol. Survey Geol. Atlas, Maynardville, Tennessee, folio (No. 75), p. 2, 1901.

Stratigraphic relations.—In the western part of the Appalachian Valley, the oldest exposed beds of the Rome formation are everywhere in fault contact with younger rocks. The base of the formation has, therefore, not been seen, nor has it been penetrated by drilling. In the eastern part of the Appalachian Valley the Shady dolomite underlies the Rome, and is in turn underlain by a thick sequence of Lower Cambrian clastic rocks.

Throughout most of southwestern Virginia, the Rutledge dolomite overlies the Rome and is readily distinguished from it. In the Rose Hill district, and in adjacent Tennessee, however, the Conasauga shale rests on the Rome. Both the lower part of the Conasauga and the upper part of the Rome are nonresistant, so that the beds near this contact are very poorly exposed and the contact relations between the two are almost unknown. In the Brooks well, there is very little distinction between the shales of the Conasauga and the Rome, and the contact is placed with difficulty. The Rome formation contains a greater proportion of interbedded sandstones than the Conasauga, however, and limestone beds in the Conasauga are more coarsely crystalline than the limestone in the Rome and may show fossil fragments. In the Brooks well the contact was drawn at the top of a thick sandstone unit and below a coarse-crystalline, oolitic limestone which seemed to mark the first upward appearance of Conasauga-type limestone.

Thickness.—In the Brooks well, 1660 feet of beds overlying the Pine Mountain overthrust are assigned to the Rome formation. This thickness is believed to be not greatly in excess of the true stratigraphic thickness, and is very nearly the same as the thickness along Clinch River where 1600 feet of the Rome is preserved above the Wallen Valley fault. These are the greatest thicknesses of the Rome reported from southwest Virginia and northeast Tennessee, and they thus probably represent nearly the whole formation.

Paleontology.—The Rome formation is sparingly fossiliferous. Butts[16] reports 15 species of trilobites, one pteropod and one brachiopod from the formation in Virginia. No fossils were seen in the cuttings of the Rome from the Brooks well.

Age and correlation.—The presence of *Olenellus* in the lower part of the Rome indicates that this part of the formation is of Lower Cambrian age. The upper 600 feet, however, carry trilobite genera

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[16] Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. 1, Geologic text and illustrations, p. 66, 1940.

believed to be restricted to the Middle Cambrian.[17] Rodgers and Kent[18] propose to confine the name Rome to the Lower Cambrian and to designate the Middle Cambrian part of the formation the Pumpkin Valley shale. The lower part of the Rome formation is correlated with the Waynesboro formation of Pennsylvania, Maryland, and northern Virginia.

CONASAUGA SHALE

Name.—The Conasauga shale received its name from northwest Georgia.[19] It is also present in northern Alabama and along the western side of the Appalachian Valley in Tennessee. The name is here applied to beds in western Lee County, Virginia, which previously have been called the Nolichucky shale.

Distribution.—Only the upper half of the Conasauga is exposed in the Rose Hill district. It crops out along the crest of the Powell Valley anticline in the southwestern part of the district, where it forms a more or less oval-shaped area about a mile wide and three miles long. Because the beds near the axis of the anticline are nearly flat-lying, the outcrop area of the Conasauga is quite irregular, with outliers and promontories of Maynardville limestone within the Conasauga area. Several narrow tongues of the Conasauga overlie the younger rocks of the Sugarcamp fensters and represent the easternmost occurrence of the Conasauga. In the central and northeastern parts of the Rose Hill district, the Conasauga is cut out by the Pine Mountain overthrust.

Character.—The Conasauga shale is considerably less resistant than the overlying limestones and dolomites, and therefore forms a prominent lowland in the midst of the Chestnut Ridge upland. An unusually broad and flat part of the lowland near the west edge of the district is known as Frog Level. Along Fourmile Creek the eastern part of the Conasauga outcrop area also forms an extensive lowland, which contains, however, some conical, steep-sided hills. These hills contrast strongly with the topography of adjacent exposed formations with which the Conasauga is in fault contact (Pl. 7B). Some of the steep hills of the Conasauga shale have been cultivated and many are

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[17] Butts, Charles, op. cit., p. 66.

[18] Rodgers, John, and Kent, Deane, Stratigraphic section at Lee Valley, Hawkins County, Tennessee: Tennessee Dept. Cons., Div. Geol. Bull. 55, vi + 47 pp., 1948.

[19] Hayes, C. W., The overthrust faults of the southern Appalachians: Geol. Soc. America Bull., vol. 2, pp. 143-148, 1891.

now so badly gullied that the value of the land even for pasture has been greatly impaired.

Good exposures of the Conasauga shale are relatively scarce and are confined mainly to road cuts and the channels of vigorous streams. Even the very steep conical hills are practically devoid of outcrops. Such natural outcrops as do exist are almost entirely of limestone interbeds, which are a distinctive but quantitatively insignificant part of the formation. The best exposures of the formation are along the road at the extreme western end of the Conasauga outcrop area, and along the Fourmile Creek road.

Shale forms about 80 percent of the exposed part of the Conasauga. Most of the shale is medium to dark green or greenish gray, and is smooth, fissile, and sericitic or micaceous. It weathers to a greenish-yellow color and disintegrates readily. Red shale is interbedded with the green shale in some places, notably in the valley just east of the elongate outlier of the Maynardville limestone (Pl. 1), but red shale is subordinate in amount. It seems to be most abundant near the middle of the formation. Thin lenticular beds of fine-grained, gritty, nonresistant sandstone are interbedded with the shale at some places. The lower half of the formation, which is known only from the Brooks well, appears from the cuttings to contain a much higher proportion of interbedded sandstone than the exposed upper half of the formation. This is partly due to the pulverizing of the shale into such small fragments by the drill that much of the shale residue was removed in suspension in the water with a consequent increase in the relative proportion of sandstone in the cuttings. However, the lower half of the Conasauga shale may contain somewhat more interbedded sandstone than the upper half. Large bronze mica flakes are conspicuous in cuttings of some of the sandstone beds in the lower part of the formation.

Limestone is interbedded with the shale throughout the Conasauga. Though it is quantitatively subordinate, it forms the most conspicuous and distinctive rock type both in outcrops and in cuttings. Some of the limestone beds near the top of the formation are a foot thick, but throughout most of the formation they average only an inch or two in thickness and are separated from one another by much greater thicknesses of noncalcareous shale. The limestone beds are platy and lenticular. Their outer surfaces commonly have a gnarled or hackled appearance due to the fracturing of the limestone in response to stresses which have caused the enclosing shale to crumple and flow. Much of the limestone is crisscrossed by calcite veinlets, which have filled the fractures. Many of the platy beds of limestone have coatings of green shale.

The limestone is of three lithologic types. The most conspicuous and abundant of these types is a gray, medium- to coarse-crystalline limestone, which locally contains small unzoned oolites. The oolites are abundant but do not touch one another, and the limestone breaks around rather than across them. Some of the coarser crystalline limestone beds contain numerous trilobite fragments, but few of them are large enough to be identified. Some beds contain abundant smooth chips which probably represent trilobite fragments but are not definitely recognizable as such. Much of the coarse-crystalline limestone contains specks of glauconite, and a few beds are peppered with bright-green glauconite grains as large as pin heads. The second type of limestone is a light-gray to tan, cryptocrystalline, dense limestone in platy beds. It may also be fractured and veined, but is not as hackled on weathered surfaces as is the coarse-crystalline limestone. The third type is a silty, laminated variation of the fine-grained limestone. Edgewise conglomerate is present locally in all three types of limestone.

The coarse-crystalline type of limestone is distinctive of the Conasauga shale, but the two fine-grained types are similar to limestones interbedded in the middle and upper parts of the Rome formation. All three types differ markedly from the massive-bedded, fine-grained, ribbon limestone of the overlying Maynardville limestone. In a few places, however, ribbon limestone of Maynardville type is present in the top few feet of the Conasauga, showing a local transition between the two formations.

The Conasauga shale weathers to form a yellowish-brown soil, which contains numerous soft greenish shale chips on steep and moderate slopes. On flatter surfaces, however, the shale has decomposed completely, and the resulting clay is hardly distinguishable from that derived from the overlying Maynardville limestone.

Because the Conasauga is so largely composed of nonresistant shale, it has yielded readily to the compressional stresses to which the region has been subjected. It is commonly folded and locally it is intricately crumpled. Away from the major faults, however, the deformation is not severe and the formation does not appear to be greatly thinned or thickened by the squeezing. The incompetency of the shale, as contrasted with the interbedded limestones, is excellently shown in a road cut 200 yards northeast of the Brooks well (Fig. 4). Here the shale between two parallel zones of relatively resistant limestone has been strongly squeezed and crumpled. The bedding in the shale is entirely obliterated but several thin beds of limestone, only one of which is shown in the sketch, have been very tightly folded and moved without actual rupture, so that they now cut diagonally across the shale zone between the undisturbed lower and upper limestones. Several small faults cut the outcrop.

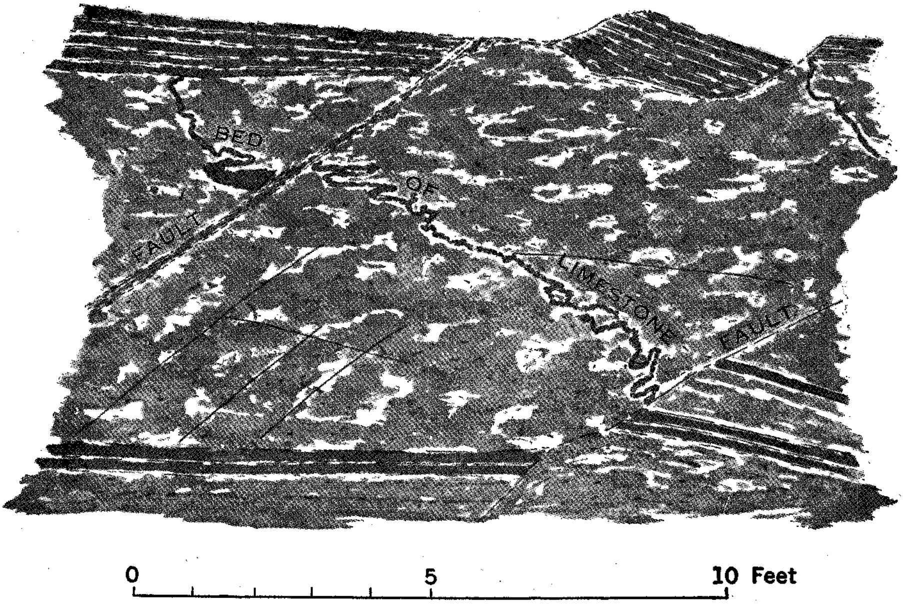

FIGURE 4.—Sketch of a roadcut in Conasauga shale east of the Brooks well, showing a thin, intricately folded and faulted bed of limestone enclosed in mottled shale, in which all traces of bedding have been destroyed by squeezing and flowage. The more massive limestone beds near the base and at the top have also been faulted.

Because of poor exposures and abundant folding, no good section of the outcropping part of the Conasauga shale exists in or near the Rose Hill district.

Stratigraphic relations.—The contact of the Conasauga shale with the underlying Rome formation is known only from the Brooks well, and as previously explained, is drawn with difficulty on the basis of the cuttings alone. It was placed at the base of the lowest bed of coarse-crystalline, oolitic limestone typical of the Conasauga.

The upper contact with the Maynardville limestone is almost everywhere sharp and is drawn at the base of the lowest massive zone of fine-crystalline, ribbon limestone. Exposures of this contact are discussed in the section on the Maynardville.

Elsewhere in southwestern Virginia, the interval between the Rome formation and the Maynardville limestone is occupied by separately mapped units of shale and of limestone. The top unit, the Nolichucky shale, is lithologically identical with the beds here described as Conasauga, and is underlain either by a thick limestone unit named the Honaker limestone, or by two limestone units, the Rutledge and Maryville, that are separated by a shale unit named the Rogersville (Table 1). The Rutledge and Maryville limestones are also present in the eastern and central belts of the Appalachian Valley of Tennessee, but in the northwestern belts the limestone has changed to shale indistinguishable from the Nolichucky and Rogersville shales. Hence in these northwestern belts the whole sequence from the top of the Rome to the base of the Maynardville is a homogeneous unit, which was named by Keith[20] the Conasauga shale.

The shale beds underlying the Maynardville limestone in western Lee County were called Nolichucky by Butts,[21] but the drilling of the Brooks well in 1943 has demonstrated the absence of any thick carbonate units at the base of the shale sequence, which would correspond to the Rutledge and Maryville limestones. The section of the post-Rome and pre-Maynardville beds of the Rose Hill district is thus the equivalent of the Conasauga shale, whose nearest exposures are in Tennessee 16 miles to the southwest, rather than of the Nolichucky shale, which is exposed 4 miles southeast of the Rose Hill district near Sneedville, Tennessee, and which also crops out in Scott and eastern Lee counties, Virginia.

Thickness.—The base of the Conasauga shale is not exposed in the area, hence no measured section of the shale is possible. An approximation of the thickness, however, may be gained at the Brooks well. Here the contact with the Rome formation was penetrated at a depth of 262 feet and the base of the Maynardville limestone as determined from the structure contours of Plate 1 would have lain 305 feet above the casing head. The interval occupied by Conasauga shale is thus 567 feet. Despite the crumpling and squeezing of the Conasauga, which may be observed in some places, the available evidence in the vicinity of the Brooks well indicates that the beds in general are nearly flat-lying and have not been greatly thickened or thinned. Probably,

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[20] Keith, Arthur, U. S. Geol. Survey Geol. Atlas, Maynardville, Tennessee, folio (No. 75), p. 2, 1901.

[21] Butts, Charles, Fensters in the Cumberland overthrust block in southwestern Virginia: Virginia Geol. Survey Bull. 28, p. 7, 1927.

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

therefore, 567 feet approximates the true thickness of the Conasauga shale.

Paleontology.—Fragments of trilobites are common in the crystalline limestone interbeds of the Conasauga shale, but fragments large enough and well enough preserved to be identified are extremely rare. In this respect the Conasauga differs from the partly equivalent Nolichucky shale, which in many places contains abundant identifiable trilobites.

The only locality in the Rose Hill district where recognizable Conasauga fossils were obtained is on the bank of Fourmile Creek on the Virginia-Tennessee State line, where fair-sized trilobite fragments were found in beds near the top of the shale. The following were identified:

Blountia cf. *B. mimula* Walcott

Crepicephalus sp.

Fucoids are also present in some of the limestone beds.

Age and correlation.—The lower part of the Conasauga is believed to be of Middle Cambrian age because of its equivalence to the Rutledge, Rogersville and Maryville formations.[22] These formations were considered by Keith to be Middle Cambrian on the basis of scanty fossils and their occurrence below the Nolichucky shale, which contains the oldest known Upper Cambrian fauna.[23] The upper part of the Conasauga is assigned an Upper Cambrian age, from the occurrence in it of *Crepicephalus* and from its unquestioned equivalence to the Nolichucky shale which carries an abundant Upper Cambrian fauna.

The Conasauga is correlated by Butts with the Elbrook limestone of Pennsylvania and the eastern part of the Appalachian Valley of Virginia.

MAYNARDVILLE LIMESTONE

Name.—The Maynardville limestone was named by Oder[24] from the town of Maynardville, Union County, Tennessee. In the Rose

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[22] Keith, Arthur, op. cit., p. 2.

[23] Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. I, Geologic text and illustrations, pp. 68-70, 85-86, 1940.

[24] Oder, C. R. L., Preliminary subdivision of the Knox dolomite in east Tennessee: Jour. Geology, vol. 42, no. 5, pp. 475-476, 1934.

Hill district limestone beds here placed in the Maynardville were called "Upper Cambrian limestone" by Butts[25] and were placed by him in the Nolichucky shale (Conasauga of this report). The dolomites in the upper part of the Maynardville of the present report were included by him with the overlying Copper Ridge dolomite.

The Maynardville is here divided into two members, the Low Hollow limestone member below and the Chances Branch dolomite member above. Descriptions and typical sections of the members are given. The original type section of the Maynardville limestone is now covered by the waters of Norris Reservoir. In the newly designated typical section on State Highway 33 along Clinch River 5 miles north of Maynardville, the two members of the Maynardville described in the Rose Hill district are also recognizable and have similar lithologic features and thicknesses.

Distribution.—Because it crops out in a region of gentle dips at or near the axis of the Powell Valley anticline, the Maynardville limestone, though relatively thin, is one of the most widespread formations in the district. The two main belts of Maynardville are in the Cumberland overthrust block above the Pine Mountain fault on opposite sides of the axis of the anticline. In most places they are from a quarter to half a mile wide. In the central and eastern parts of the district the Maynardville forms the surface rock across the crest of the anticline, except where it has been eroded to expose the underlying rocks in fensters. Three small klippen of the Maynardville limestone lie in the northwest, west-central, and southeast parts of the Chestnut Ridge fenster.

The Maynardville limestone is also preserved in the fault slices that lie between the upper and lower branches of the Pine Mountain overthrust fault. It makes up almost all of the Wilson fault slice, and it, together with formations of the Knox group, forms the Chestnut Ridge fault slice. At most places in these slices the Maynardville is exposed in narrow belts, which are in fault contact with the adjacent formations.

In the western half of the area shown on Plate 2, the two members of the Maynardville limestone were mapped separately in order to bring out the complex fault relationships in and near the Chestnut Ridge fenster. To the east, however, where abundant but relatively

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[25] Butts, Charles, Fensters in the Cumberland overthrust block in southwestern Virginia: Virginia Geol. Survey Bull. 28, pp. 1-2, 7 and pl. 1, 1927.

unimportant reverse faults repeat the Maynardville many times at the surface, the formation was not divided.

Low Hollow limestone member.—The Low Hollow limestone member includes the part of the Maynardville that is predominantly limestone and comprises approximately the lower half of the formation. The lower part of the member is excellently exposed at many places in the district because it overlies much weaker formations either by normal contact or by fault contact. The most spectacular outcrop of the Low Hollow limestone member is a vertical cliff, 56 feet high, which overlooks the lowland of Conasauga shale near Fourmile Creek. The photograph of the lowland (Pl. 7B) was taken from the top of this cliff.

Because the lower part of the member normally forms massive ledges, it has been left almost everywhere in timber, and the border of the woods commonly is a few score feet downslope from the contact of the Low Hollow member with the underlying rocks. The middle and upper parts of the member crop out less persistently and form a more subdued topography. Good exposures of these beds are largely confined to narrow and deep stream valleys.

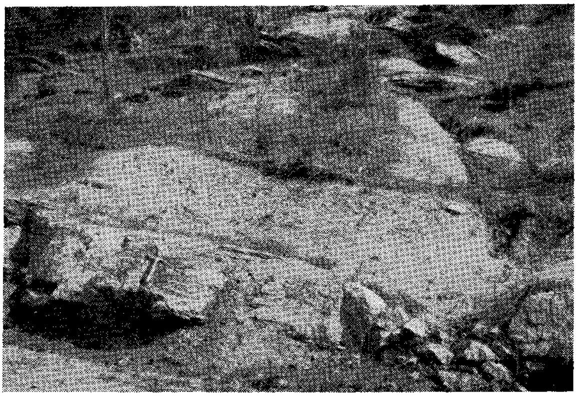
Almost the entire member is perfectly exposed along the road in Low Hollow 4½ miles south of Rose Hill and 1 mile south of Deans Store. Unfortunately the member is here cut off near its base by the Chestnut Ridge branch of the Pine Mountain overthrust, which causes it to rest on a small slice of the Chances Branch dolomite member of the Maynardville. For this reason the type section of the Low Hollow member (Geologic Section 2) is taken along Fourmile Creek at the Virginia-Tennessee State line, where the member is less perfectly exposed but where it lies normally between the Conasauga shale below and the Chances Branch dolomite member above.

The Low Hollow limestone member is roughly divisible into three lithologic zones—a lower ribbon limestone zone, a middle mottled limestone zone, and an upper zone of interbedded mottled limestone and laminated dolomite. In the ribbon limestone zone, the limestone is medium to dark gray, fine grained, and is composed of wavy beds from a quarter of an inch to 1½ inches thick. These beds are separated from one another by silty limestone layers which range in thickness from mere films to beds half an inch thick. In the fresh rock the distinction between pure limestone and silty limestone is faint, but on weathered surfaces it is very striking, with the pure beds weathering to bluish-white bands and the silty interbeds weathering to buff or brown and normally standing out in relief. In thin section (Pl. 11A), the silty bands are seen to be more coarsely crystalline and darker colored than the pure limestone bands.

Gray shale or shaly limestone is locally interbedded with the ribbon limestone. It is absent in many sections and is very conspicuous in others. Interbedded shale is most abundant along the road south of the Martin Creek fenster. In the photograph (Pl. 10A) taken at this locality, the limestone forms prominent ledges with shale underlying the slopes between the ledges. Most of the shale units are only a few inches thick but in a few places they are several feet thick and one shale zone, 7 feet thick, is known.

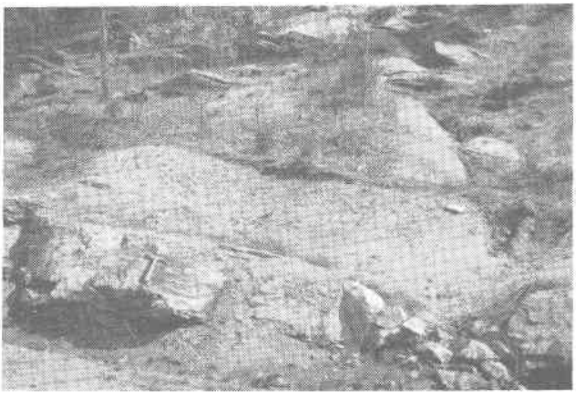
The zone of ribbon limestone is overlain by a zone of gray or tan mottled limestone in beds several feet thick. The mottled limestone is similar to the ribbon limestone except that the areas of silty and nonsilty limestone are irregularly and intimately commingled. The pure limestone normally is more abundant, with the silty limestone appearing to ramify through it. Weathering accentuates the differences between the two types of limestone, and causes the silty limestone areas to stand out in relief. In thin section the silty and nonsilty limestones are seen to have sharp boundaries between them, usually with concentrations of impurities causing a darker color along the contacts. There are all gradations between ribbon limestone and mottled limestone but, in their typical development, the two types differ markedly in appearance. A ledge of mottled limestone along the Martin Creek road, in which the mottled character has been especially well emphasized by weathering, is shown in Plate 10B.

Both the ribbon and mottled limestones contain beds of edgewise conglomerate in which flattened pebbles of the pure limestone lie subparallel in a matrix of the silty limestone. Both also contain beds of oolitic limestone. The oolitic grains are relatively inconspicuous in the fresh limestone and can be detected only by very careful examination. Where the limestone has been chertified, however, the oolitic grains stand out prominently. The grains are of nearly uniform size, averaging about 1/50 inch in diameter, and are normally about the same distance apart. Spherical grains predominate, but oval or flattened shapes are common. Some of them are concentrically zoned, but the zoning is normally observed only in the chertified beds, for the oolitic limestone breaks around the grains, whereas the oolitic chert breaks across them. Chertified beds of oolite are uncommon in the bedrock, but pieces of oolitic chert are quite abundant in the soil

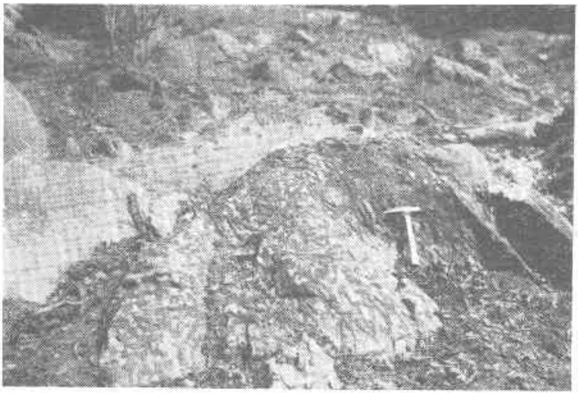


A, Interbedded ribbon limestone and shale in the lower zone of the Low Hollow limestone member of the Maynardville limestone.

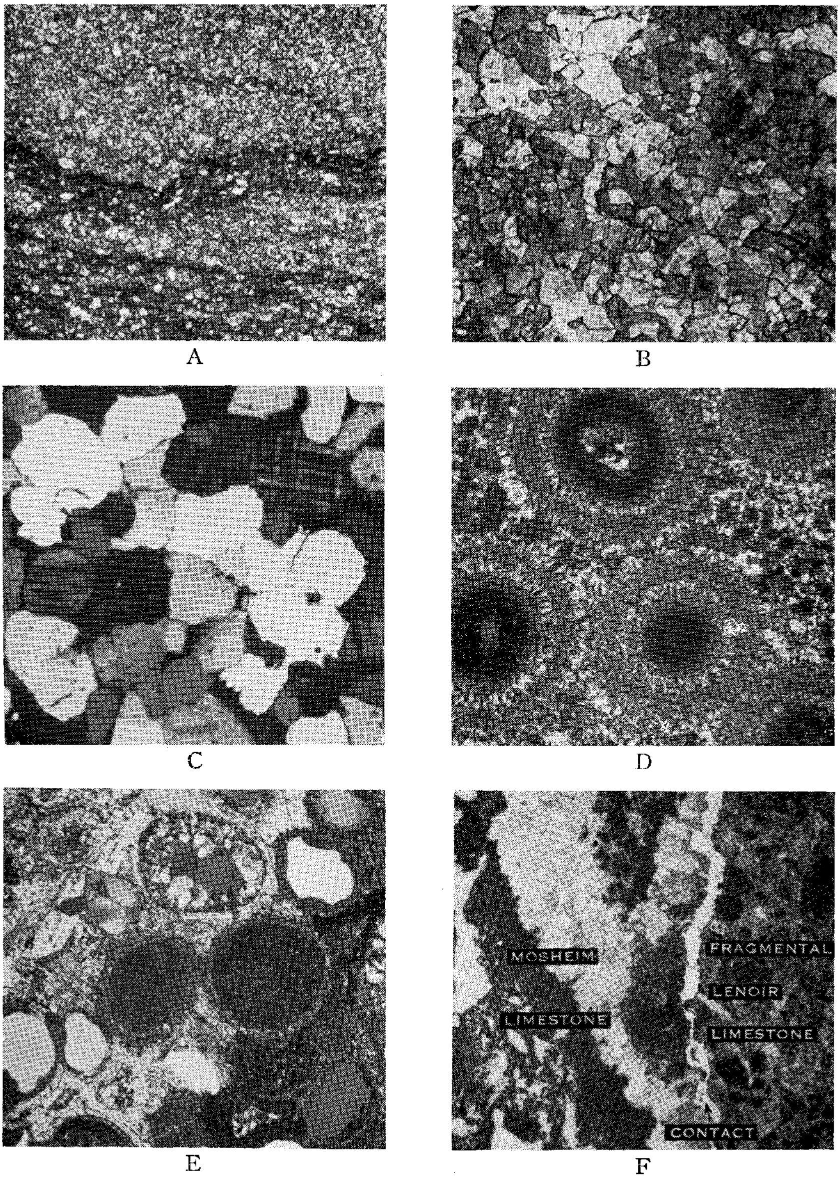
B, Mottled limestone in the middle zone of the Low Hollow limestone member of the Maynardville limestone.



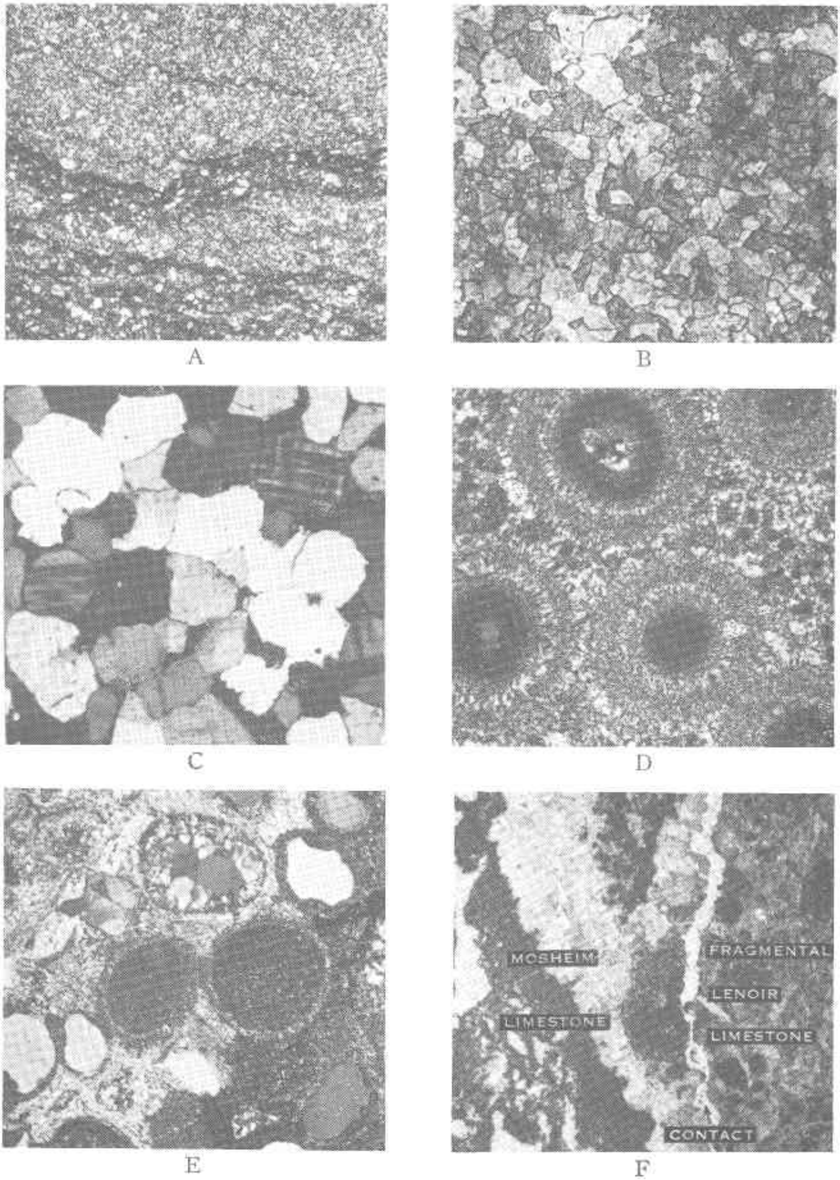
A, Interbedded ribbon limestone and shale in the lower zone of the Low Hollow limestone member of the Maynardville limestone.



B, Mottled limestone in the middle zone of the Low Hollow limestone member of the Maynardville limestone.



A, Ribbon limestone of the lower part of the Maynardville limestone. x60. B, Dark saccharoidal dolomite ("stinkstone") of the lower part of the Copper Ridge dolomite. x30. C, Sandstone in the lower part of the Chepultepec dolomite. Polarized light, x40. D, Zoned oolites in chert beds of the Chepultepec dolomite. Polarized light, x30. E, Silicified bed of oolitic dolomite from the Chepultepec dolomite. Polarized light, x15. F, Contact of birdseye limestone of the basal Mosheim limestone and fragmental limestone of the basal Lenoir limestone. x20.



A, Ribbon limestone of the lower part of the Maynardville limestone. x60. B, Dark saccharoidal dolomite ("stinkstone") of the lower part of the Copper Ridge dolomite. x30. C, Sandstone in the lower part of the Chepultepec dolomite. Polarized light, x40. D, Zoned oolites in chert beds of the Chepultepec dolomite. Polarized light, x30. E, Silicified bed of oolitic dolomite from the Chepultepec dolomite. Polarized light, x15. F, Contact of birdseye limestone of the basal Mosheim limestone and fragmental limestone of the basal Lenoir limestone. x20.

overlying the Low Hollow limestone member owing to the concentration of the less soluble rock types during weathering.

The topmost zone of the Low Hollow member is composed of mottled limestone similar to that previously described, which is interbedded with laminated dolomite of the type that makes up the overlying Chances Branch member. This zone thus represents a transition from the Low Hollow limestone member to the Chances Branch dolomite member. The contact between the two is taken at the place where the dolomite becomes more abundant than the limestone.

A common feature near the contact with the Chances Branch member is the appearance of beds of conglomerate consisting of very small flattened chips of silty dolomite in a matrix of gray limestone (Geologic Section 2, Unit 7 and Geologic Section 3, Units 1 and 2). Apparently the laminated silty dolomite was deposited under quiet water conditions. Some of the earliest thin layers of this dolomite interfinger with the blue limestone, and were broken up into very small thin chips by the greater turbulence that accompanied the deposition of the limestone.

The Low Hollow limestone weathers to a tough yellow clay, which may contain locally derived chert cobbles. Most of the chert cobbles on the surface overlying this member, however, have worked downslope from the upper part of the Maynardville limestone or from the Copper Ridge dolomite above.

The Low Hollow member is 142 feet thick in the State Line section on Fourmile Creek (Pl. 13) and 172 feet thick on Lick Branch. It probably averages about 150 feet in thickness. In the type section of the Maynardville limestone, the Low Hollow member is about 30 feet thinner than it is in the Rose Hill district.

Chances Branch dolomite member.—The Chances Branch dolomite member forms approximately the upper half of the Maynardville limestone. It takes its name from Chances Branch in the western part of the Rose Hill district, where a complete section of the member is exposed in a roadcut a few hundred feet east of the creek and just south of Smith Chapel (Geologic Section 3). It is also excellently exposed along Low Hollow, and along Fourmile Creek both north of the Fourmile fenster and south of the Virginia-Tennessee State line. In each of these sections the transition zone at the contact between the two members is well exhibited.

The Chances Branch member has numerous outcrops in some parts of the district, but throughout most of the district it is poorly exposed. It forms gentle to moderate slopes, which are cultivated in most places. It is made up dominantly of a light-gray, fine-crystalline dolomite or dolomitic limestone in even beds 1 to 3 feet thick. Near the base of the member, beds of edgewise conglomerate similar to those described at the top of the Low Hollow member are common. In the lower part of the member, the dolomitic limestone is silty and shows fine laminae on weathered surfaces. A few thin lenses of fine sandy dolomite were noted in several places, but no beds or lenses of true sandstone were seen in the bedrock outcrops. Apparently lenses of medium-grained dolomitic sandstone occur locally in the member, however, because sandstone float derived from it is conspicuous at several places in the district, notably on the crest and slopes of several hills near the Tennessee State line east of Fourmile Creek. Shale is interbedded with the dolomitic limestone in some places, as along Martin Creek just north of Edds Mill, but it is much less common in this member than in the Low Hollow member. Stylolites occur throughout the Maynardville limestone, but unusually fine ones are present in some of the fine-grained dolomites of the Chances Branch member.

Massive beds of dark-gray limestone, less distinctly mottled than beds in the Low Hollow member, are interbedded with the dolomitic limestone in the lower part of the Chances Branch member. They become less abundant upward, although locally a few beds of dark limestone may be present in the upper half of the member. Much of this limestone is oolitic, although the oolitic grains are conspicuous only in blocks of chertified limestone found in the soil. Most of the pieces of oolitic chert in the soil of the Chances Branch member seem to have been derived from these interbedded limestones, although a few oolitic grains have been seen in the dolomitic limestone. In a few places surfaces of dolomitic limestone are coated with asphaltic films, and a few vugs partly filled with asphalt were found.

In the upper half of the member beds of dark-gray, fine- to medium-crystalline dolomite of Copper Ridge type are present, and they become increasingly abundant upward. The top of the member, which is also the top of the Maynardville limestone, is taken at the place where the dark-gray crystalline dolomite that is characteristic of the lower Copper Ridge dolomite exceeds in relative amount the light-gray, fine-grained dolomite of Chances Branch member type. The Chances Branch dolomite member of the Maynardville thus consists essentially of light-gray, fine-grained dolomite, which is interbedded, in the lower part of the member, with limestone of the Low Hollow member type, and in the upper part with dolomite like that of the overlying Copper Ridge dolomite.

The Chances Branch dolomite, on weathering, gives rise to a tough clay, which is normally yellow but locally is bright orange. Through the clay are scattered cobbles of white chert, most of which is oolitic. Where the mixing of the soils on slopes has not been great, the Maynardville-Copper Ridge contact may be located approximately by the change of the clay from the yellow color of the Chances Branch soil to the deep-red color of the Copper Ridge soil.

Three measured sections of the Chances Branch dolomite member gave thicknesses of 78, 160 and 209 feet. The 78 foot thickness was obtained in a region of low dips and long covered intervals and is probably not reliable, since elsewhere the member seems much thicker. The variations in thickness may be accounted for in part by inconsistency in the location of the contacts, which show gradation into both the underlying and overlying stratigraphic units. Considerable changes in measured thicknesses of the member may result from changes in the character of a comparatively few beds near the contacts. Throughout the Rose Hill district the Chances Branch dolomite member probably averages about 160 feet thick.

Stratigraphic relations.—The Maynardville limestone conformably overlies the Conasauga shale. Although fairly massive beds of limestone are interbedded near the top of the Conasauga shale, and shale may be interbedded in the lowest part of the Maynardville limestone, there is considerable contrast between the coarse-crystalline, veined and gnarled limestone of the Conasauga shale and the fine-grained, ribbon limestones of the basal Maynardville (Low Hollow limestone member). The contact is drawn at the base of the lowest beds of ribbon limestone. This normally coincides exactly with the boundary separating the part of the section below that is mainly shale from that above which is almost entirely limestone. The Maynardville-Conasauga contact is covered almost everywhere, but it can be seen in a gully on a hillslope on the Virginia-Tennessee State line just east of Fourmile Creek, and also in a ravine above a large spring 0.3 mile due west of the Fugate No. 2 well.

As described previously, the Maynardville limestone is transitional by interbedding into the Copper Ridge dolomite, and no clear-cut contact can be drawn between them. Thus in the Rose Hill district, the Maynardville seems more closely allied to the overlying Copper

Ridge dolomite into which it grades than to the underlying Conasauga shale, with which it has a sharp, clear contact.

The Maynardville limestone as here described is identical with that near Maynardville in east Tennessee, where the two-fold division of the formation is also present. As pointed out by Oder, the Maynardville is a distinctive and persistent unit deserving of formation status. Beds that seem from their description to be the same as the Maynardville of this report have been described in Virginia near Bristol in Washington County, at Brookside Inn in Russell County, and at Saltville in Smyth County by Butts,[26] and in Bland County by Cooper.[27]

Thickness.—Two complete measured sections of the Maynardville limestone gave thicknesses of 249 feet and 302 feet. The greater thickness is probably more representative of the formation in the Rose Hill district. In its type region 25 miles southwest of the Rose Hill district, the Maynardville is about 250 feet thick, and at Thorn Hill, Tennessee, 15 miles south of the Rose Hill district, it is 172 feet thick. Thus it seems to thin both to the south and southwest.

Paleontology.—The Maynardville is sparingly fossiliferous in the Rose Hill district. Trilobites were found near the top of the Low Hollow limestone member in the road cut at Harris Store on Fourmile Creek. Most of them were too fragmentary to be identified, but a species of *Aphelaspis* was recognized. Butts[28] reports species of *Blountia* and *Maryvillia* from beds believed to be the equivalent of the Maynardville at Bristol, Virginia. These genera of trilobites are found also in the Nolichucky shale.

The only fossil known in the upper or Chances Branch dolomite member of the Maynardville is *Cryptozoon,* which is rarely seen in outcrop but is fairly common in the chert float derived from the member. *Cryptozoon* also is found in the overlying formations of the Knox group.

Age and correlation.—The Maynardville is of Upper Cambrian age as shown by its fauna and by the fact that it lies between beds also considered to be of Upper Cambrian age.

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[26] Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. I, Geologic text and illustrations, pp. 80, 81, 94, 1940.

[27] Cooper, B. N., Geology and mineral resources of the Burkes Garden quadrangle, Virginia: Virginia Geol. Survey Bull. 60, p. 21, 1944.

[28] Butts, Charles, op. cit., p. 80.

TABLE 1.—*Subdivisions of the Knox group by various authors*

Tennessee J. M. Safford Geology of Tenn. 1869		Southwest Virginia and East Tennessee G. W. Hayes G. S. A. 1891		Southwest Virginia and East Tennessee A. Keith, M. R. Campbell U.S.G.S. folios 12, 16, 27, 33, 59, 75 1894-1901		East Tennessee E. O. Ulrich G.S.A. 1911		Rose Hill district Charles Butts Va. G.S. Bull. 28 1927			Grainger Co., Tenn. G. M. Hall and H. C. Amick Tenn. Acad. Sci. 1934		East Tennessee C. R. L. Oder Jour. Geology 1934			Southwest Virginia Charles Butts Va. G.S. Bull. 52 1940		Hancock and Grainger Counties, Tenn. John Rodgers U.S.G.S. Prelim. Map 1944			Rose Hill district R. L. Miller and J. O. Fuller This report			
Knox* group	Knox* dolomite	Silurian (Ordovician)	Knox dolomite	Silurian (Ordovician)	Knox dolomite	Canadian	Jonesboro* limestone (not found with Knox and Chepultepec)	Ordovician		Beekmantown dolomite	Ordovician	Thorn Hill* formation	Ordovician	Knox group	Cotter-Powell beds	Ordovician	Beekmantown group	Ordovician	Knox group	Mascot* dolomite	Ordovician	Knox group	Mascot dolomite	
												Forked Deer* formation			Jefferson City formation					Kingsport* limestone			Kingsport dolomite	
												Nittany dolomite			Nittany dolomite					Longview dolomite			Longview dolomite	
															Stonehenge limestone									
						Ozarkian	Chepultepec* chert	— ? — Cambrian		Copper Ridge dolomite	Cambrian	Copper Ridge dolomite	Cambrian		Chepultepec formation		Chepultepec limestone (not identified in Lee County)			Chepultepec dolomite			Chepultepec dolomite	
							Upper division of Knox dolomite																	
		Cambrian		Cambrian			Copper Ridge* chert								Copper Ridge dolomite	Cambrian	Copper Ridge dolomite	Cambrian		Copper Ridge dolomite	Cambrian		Copper Ridge dolomite	
							Basal division of Knox dolomite		Nolichucky	limestone					Maynardville limestone				Nolichucky shale	Maynardville limestone member			Maynardville limestone	Chances Branch* dolomite member Low Hollow* limestone member
	Knox* shale		Conasauga* shale		Nolichucky* shale	Cambrian	Nolichucky shale			shale		Nolichucky shale			Conasauga shale		Nolichucky shale			shale			Conasauga shale	
					Maryville* limestone		Maryville limestone			covered		Maryville limestone					Maryville limestone			Maryville limestone				
					Rogersville* shale		Rogersville shale					Rogersville shale					Rogersville shale			Rogersville shale				
					Rutledge* limestone		Rutledge limestone					Rutledge limestone					Rutledge limestone			Rutledge limestone				
	Knox* sandstone		Rome* formation		Rome formation or Russell* formation		Rome formation or Russell formation or Watauga shale					Rome shale			Rome formation		Rome formation			Rome formation			Rome formation	

*Indicates first use of name.

FORMATIONS OF THE KNOX GROUP

GENERAL STATEMENT

The thick sequence of carbonate rocks underlying the beds corresponding to the Murfreesboro limestone of this report and overlying the Conasauga or Nolichucky shale was designated the upper part of the Knox group by Safford.[29] The lower and middle parts of Safford's Knox were later given other names by Hayes[30], and the Knox group now includes only beds referred by Safford to the upper Knox.

The Knox has been subdivided by various authors. The different classifications are shown in the accompanying chart (Table 1). In the Rose Hill district five formations have been recognized in the Knox group, namely, the Copper Ridge, Chepultepec, Longview, Kingsport, and Mascot dolomites. These formations are themselves capable of subdivision, and lithologic members of the Copper Ridge and Chepultepec have been recognized, but they have not been given formal names. In the Rose Hill district, the thickness of the Knox group totals 2300 feet and practically all of it is dolomite.

COPPER RIDGE DOLOMITE

Name.—The Copper Ridge dolomite is named from Copper Ridge in northeast Tennessee and southwest Virginia.[31] Its best exposure and type section is along the valley of Forked Deer Creek through Copper Ridge at Thorn Hill in Grainger County, Tennessee, 15 miles south of the Rose Hill district (Pl. 13).

Distribution.—The Copper Ridge dolomite forms two belts, about half a mile wide, on opposite flanks of the Powell Valley anticline. The belts join around the plunging ends of the anticline near both the eastern and western edges of the Rose Hill district, and thus entirely enclose the areas of Maynardville limestone. A few small outliers of the Copper Ridge dolomite cap higher hills in the outcrop area of the Maynardville limestone. One sizable belt and several smaller areas of the Copper Ridge dolomite also occur in

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[29] Safford, J. M., Geology of Tennessee, pp. 151, 158-159, 203-226, Nashville, Tennessee, 1869.

[30] Hayes, C. W., The overthrust faults of the southern Appalachians: Geol. Soc. America Bull., vol. 2, pp. 141-154, 1891.

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

the Fugate fault slice and another small area of the Copper Ridge forms part of the Wilson fault slice. These slices lie between the upper and lower branches of the Pine Mountain overthrust. The Copper Ridge dolomite in the slices is much folded, faulted, and brecciated.

Character.—All the formations of the Knox group combine to form a broad upland of dolomite, which in the Rose Hill district is called Chestnut Ridge, but the lower and middle parts of the Copper Ridge dolomite form especially high hills or short ridges, because of their abundant chert. The upper part of the Copper Ridge is less resistant than the lower part and tends to form swales or valleys, of which the most striking is a series of alined valleys on the south flank of the anticline drained by Speaks Branch and unnamed tributaries of Martin and Low Hollow creeks.

In the Rose Hill district the Copper Ridge is divisible into two lithologic members of approximately equal thickness (Geologic Section 3). The lower member is characterized by a dominance of dark-gray or brown, medium- to coarse-crystalline dolomite in massive beds, and the upper member, by light-colored cryptocrystalline to coarse-crystalline dolomite. In the lower member both brown and gray varieties of dolomite have a resinous luster. In the more coarsely crystalline brown and gray dolomite, there is a bunching of larger crystals surrounded by slightly finer crystalline areas, giving a faint mottled effect. This is visible in the photomicrograph of a typical specimen from the lower member of the Copper Ridge dolomite (Pl. 11B). The nearly equidimensional interlocking crystals give the dolomite a marble-like texture, which is termed saccharoidal. Vugs lined with dolomite crystals are common in many of the beds, and veins and crescent-shaped areas of white dolomite crystals are also common. A few vugs are lined with quartz crystals and a very few are lined with manganese oxide crystals.

Freshly broken pieces of this rock yield a strong petroliferous odor. This is probably the most distinctive feature of the rock, and it is aptly called "stinkstone." The petroliferous odor is always confined to the dark-colored dolomites and conversely practically all the dark-colored dolomites have a petroliferous odor. The lower member of the Copper Ridge dolomite is composed almost entirely of this type of lithology. The "stinkstone" beds are uncommon in higher parts of the Knox group.

The massive beds of the lower member of the Copper Ridge dolomite weather with rough pitted surfaces, which have a dark-gray color partly due to dust and lichens adhering to them (Pl. 12A). In many weathered exposures, the beds are so massive and the surfaces so irregular that bedding is very obscure. Measurements of the attitude of these beds are thus subject to considerable error.

Light-gray, cryptocrystalline dolomite of the Chances Branch type is interbedded with the "stinkstone" near the base of the lower member of the Copper Ridge dolomite, and lighter colored, medium-crystalline dolomite typical of the upper member of the Copper Ridge is interbedded throughout the lower member but is more abundant near the top of the member.

Beds and areas of oolite are common in the lower member of the Copper Ridge dolomite, but the oolitic spherules are seen with difficulty in the unaltered rock. Oolitic beds that have been replaced by chert are, however, very distinctive. The oolitic grains are smaller and more closely packed than those in the Maynardville limestone. Most of them are spherical, but oval or lens-shaped grains are not uncommon. Some have concentric color bands, whereas others are of uniform color throughout but show an onionlike structure. The zoned grains have a structureless or fibrous core, or else have hollow centers. The oolitic grains are gray or white and occur in a matrix of white chert. Cobbles of oolitic chert are abundant in soil derived from the Copper Ridge dolomite, but another variety of chert, which is also prominent as float, is almost never seen in the bedrock. This chert shows a crystalline structure, which is inherited from the dolomite it has replaced. It is white and porous and may be either fine or coarse crystalline depending on the texture of the original dolomite. This rock type is termed silicified dolomite to distinguish it from the textureless chert.

The lower member of the Copper Ridge dolomite produces a deep-red clay soil, which is very distinctive. Inasmuch as other parts of the Knox group normally produce yellow or orange clays, this distinctive color of the soil is very helpful in identifying the lower Copper Ridge in areas that have no rock exposures.

The upper member of the Copper Ridge dolomite is not well exposed in the Rose Hill district. In the section at Chances Branch (Geologic Section 3) more than half of it is covered. Representative parts of it are exposed, however, in a quarry on Speaks Branch and in another on Martin Creek south of Edds Mill, and a fairly good section of it occurs along Mullins Branch at and just beyond the west edge of the Rose Hill district.

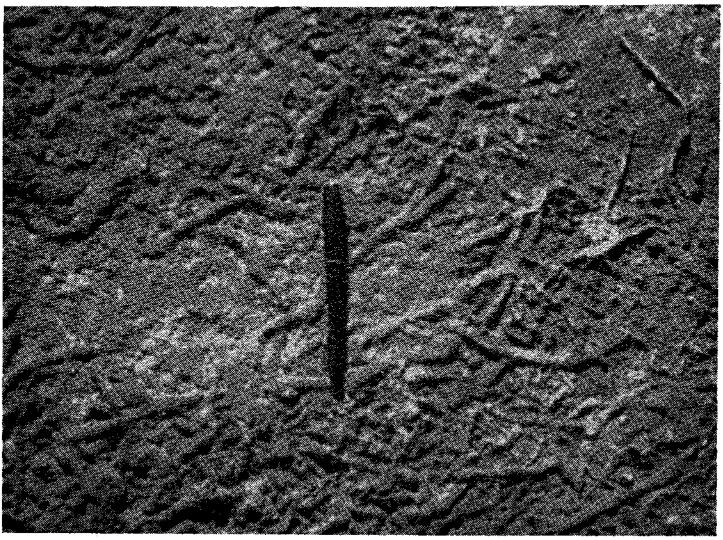
The upper member of the Copper Ridge dolomite is made up almost entirely of light-colored dolomites. They vary from cryptocrystalline dolomite to medium- and coarse-crystalline saccharoidal dolomite. The rock is white or light gray, but weathers to a bluish white. The dolomite occurs in even beds, with smooth surfaces which contrast strongly with the rough outer surfaces of the "stinkstone." A few beds of "stinkstone" are included in the upper member of the Copper Ridge dolomite, but they are increasingly rare upward and are absent near the top of the formation. Chert on the other hand is prominent in the upper Copper Ridge, and is especially abundant near the top. Almost all of it is white and much of it is oolitic. It occurs in beds and lenses, which are not more than a few inches thick throughout most of the member, but which approach a foot in thickness near the top. Silicified dolomite is also present in the soil of the upper member of the Copper Ridge but is less abundant than in the lower part of the formation.

Scattered sand grains and sandy lenses are present in the upper member of the Copper Ridge, but the lenses are much thinner and less abundant than in the overlying Chepultepec dolomite. In the Phipps well (Pl. 1), sand grains are more abundant and more evenly distributed through the cuttings than one would expect from an examination of surface sections of the member. Many samples of cuttings also contain small percentages of pyritiferous shale not observed in surface outcrops. The pyritiferous shale probably occurs as thin partings between the dolomite beds.

In the Phipps well the division between the upper and lower members of the Copper Ridge dolomite was better observed than in any surface section. The upper Copper Ridge is here 390 feet thick. The base of the Copper Ridge was not reached in the well, but, if the dolomite had its normal thickness at this locality, the lower member would be about 450 feet thick. The Copper Ridge is typically though incompletely exposed in the section along Chances Branch, and the lower member of the formation is well exposed along a roadcut near the head of Fourmile Creek.

Stratigraphic relations.—The Copper Ridge dolomite conformably overlies the Maynardville limestone. Dolomites of the types common

A, Algal reef (?) in the lower part of the Copper Ridge dolomite.



B, Fucoids near the top of the Mascot dolomite in the Walnut Hill School section.

A, Algal reef (?) in the lower part of the Copper Ridge dolomite.

B, Fucoids near the top of the Mascot dolomite in the Walnut Hill School section.

to the two formations intergrade through as much as 100 feet of beds in some places, and the contact is arbitrarily drawn at the horizon above which the "stinkstone" makes up more than 50 percent of the rock. This horizon is also approximately marked by an increase in the amount of oolitic chert and silicified dolomite and by the color change of the soil from the yellow-brown of the Maynardville to the deep-red of the Copper Ridge. *Cryptozoon,* which is sparingly present in the upper Maynardville, is much more common in the lower Copper Ridge.

The mapped contact of the Copper Ridge dolomite with the Chepultepec dolomite is also conformable, and is drawn at the base of a prominent sandy zone. An unconformity, which is described and discussed in the section on the Chepultepec dolomite, occurs below the mapped contact near Grabeels Mill on Hardy Creek (Pl. 13) and may represent the true base of the Chepultepec. If this position for the contact were used, about 150 feet of beds that have been included with the Copper Ridge dolomite in this report, would have to be placed in the Chepultepec dolomite.

Thickness.—In the Chances Branch section, the Copper Ridge dolomite is 840 feet thick. Thicknesses calculated elsewhere from the dip of the beds and the width of the outcrop are uniformly about 800 feet. The formation thus appears to be quite consistent in thickness throughout the area. Butts[32] gives thicknesses of from 1200 to 1400 feet for the Copper Ridge in southwest Virginia. Butts has drawn his contact differently, however, by including our Chances Branch dolomite member of the Maynardville limestone in his lower Copper Ridge and including also most of the lower sandy member of the Chepultepec dolomite of this report in his upper Copper Ridge. At the type locality at Thorn Hill, Grainger County, Tennessee, the Copper Ridge dolomite, as used in this report, is 907 feet thick. The available evidence indicates that the Copper Ridge dolomite in southwest Virginia and northeast Tennessee is fairly consistent in thickness. Geologists have differed greatly, however, in drawing both lower and upper contacts, so that discrepant published thicknesses are due more to changes in interpretation of the limits of the formation than to actual changes in its thickness.

Paleontology.—*Cryptozoon* is the only common fossil in the Copper Ridge dolomite. A small variety of *Cryptozoon* is quite

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[32] Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. I, Geologic text and illustrations, p. 95, 1940

abundant in the lower member of the dolomite, and a larger variety in the upper member. Most of the *Cryptozoa* have been chertified, and they are therefore much more conspicuous in the float than they are in the bedrock.

At several places large masses of dolomite have an outer pitted surface and a crude internal structure which suggest that they are of organic origin and perhaps algal reefs. The best of them is well exposed in a flat meadow along Chances Branch, 70 feet above the base of the formation (Geologic Section 3, Unit 14), and is shown in the photograph (Pl. 12A). Several similar reefs (?) were seen at nearly this same horizon in other parts of the area. On Chances Branch, the reef-like mass crops out for more than 200 feet along the strike and is 10 to 15 feet thick. In one direction the outcrops cease, but in the other the mass has a blunt end beyond which is found normal dolomite without the reef structure. The reef-rock is composed of coarse-crystalline dolomite of typical "stinkstone" lithology, but it has in addition numerous rude vertical tubes. In the fresh rock these tubes are extremely vague, but weathering accentuates them on the edges of the reef. On the top surface the tubes weather to give a rough surface of nodes and hollows. The tubes are grouped in bunches which are from a few inches to 2 feet in diameter, and crescent-shaped cracks and serrate ridges separate one bunch of tubes from the next. The tubular structure and the ridges of the supposed reef are visible in the photograph (Pl. 12A).

Scaevogyra cf. *S. swezeyi* has been reported from the Copper Ridge dolomite near Norris Dam, Tennessee, but was not found in the Rose Hill district.

Age and correlation.—The Copper Ridge dolomite is of Upper Cambrian age. It overlies formations containing early Upper Cambrian fossils, and underlies the Chepultepec dolomite whose fauna is now believed to be earliest Ordovician, though it has in the past been placed by some in the Upper Cambrian. Furthermore *Scaevogyra swezeyi,* which has been reported from the Copper Ridge dolomite, occurs in the Upper Cambrian of Wisconsin. The Copper Ridge dolomite is correlated with the Conococheague limestone of Maryland, Pennsylvania, and the eastern part of the Appalachian Valley in Virginia and Tennessee.

In northeast Tennessee, the Copper Ridge dolomite has been divided into the Morristown dolomite and Bloomingdale limestone members by Oder.[33] Rogers[34] has also made a twofold division of the Copper Ridge dolomite in its type region in Hancock and Hawkins counties, Tennessee, and has mapped separately the upper part of the formation which he calls the "upper light-colored member." Neither Oder's nor Rodgers' members are the exact equivalents of the lower and upper lithologic members of the Copper Ridge dolomite of the Rose Hill district. Oder's Morristown member includes several hundred feet of beds above the "stinkstone" part of the Copper Ridge. The sandy zones that mark the base of his Bloomingdale member in eastern Tennessee have not been recognized in the Rose Hill district. Rodgers' "upper light-colored member," which includes approximately the upper one-fourth of the Copper Ridge dolomite, contains no "stinkstone" whatever, whereas the upper lithologic member of the Copper Ridge, here described, includes approximately the upper half of the formation and contains occasional beds of "stinkstone."

ORDOVICIAN SYSTEM

CHEPULTEPEC DOLOMITE

Name and distribution.—The Chepultepec dolomite was named from exposures near Chepultepec, Blount County, Alabama.[35] In the Rose Hill district it forms roughly parallel belts on opposite sides of the axis of the Powell Valley anticline (Pl. 1). The northwestern belt averages 0.4 of a mile in width, and the southeastern belt, where the rocks dip more gently, averages 0.6 of a mile in width. In the areas along the northeast and southwest edges of the district the belts converge, the dips flatten, and the width of outcrop increases. In these areas numerous outliers of the Chepultepec dolomite cap the higher hills. A steeply dipping belt of Chepultepec, 0.4 of a mile long, forms part of a fault slice just south of the Dean fenster.

Character.—The belts of the Chepultepec dolomite lie near the edges of the high part of the Chestnut Ridge upland (Pl. 4). Sandy beds near the base of the Chepultepec form a prominent ridge adjacent to the small discontinuous lowland developed on belts of the upper Copper Ridge dolomite. The altitude of the ridge is approximately the same as the highest hills of the lower Copper Ridge dolomite. The

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[33] Oder, C. R. L., op. cit., pp. 476-479.

[34] Rodgers, John, Copper Ridge zinc district (east part), Hawkins, Hancock, and Grainger counties, Tennessee: U. S. Geol. Survey, Strat. Min. Invest., Prelim. Map, 1944.

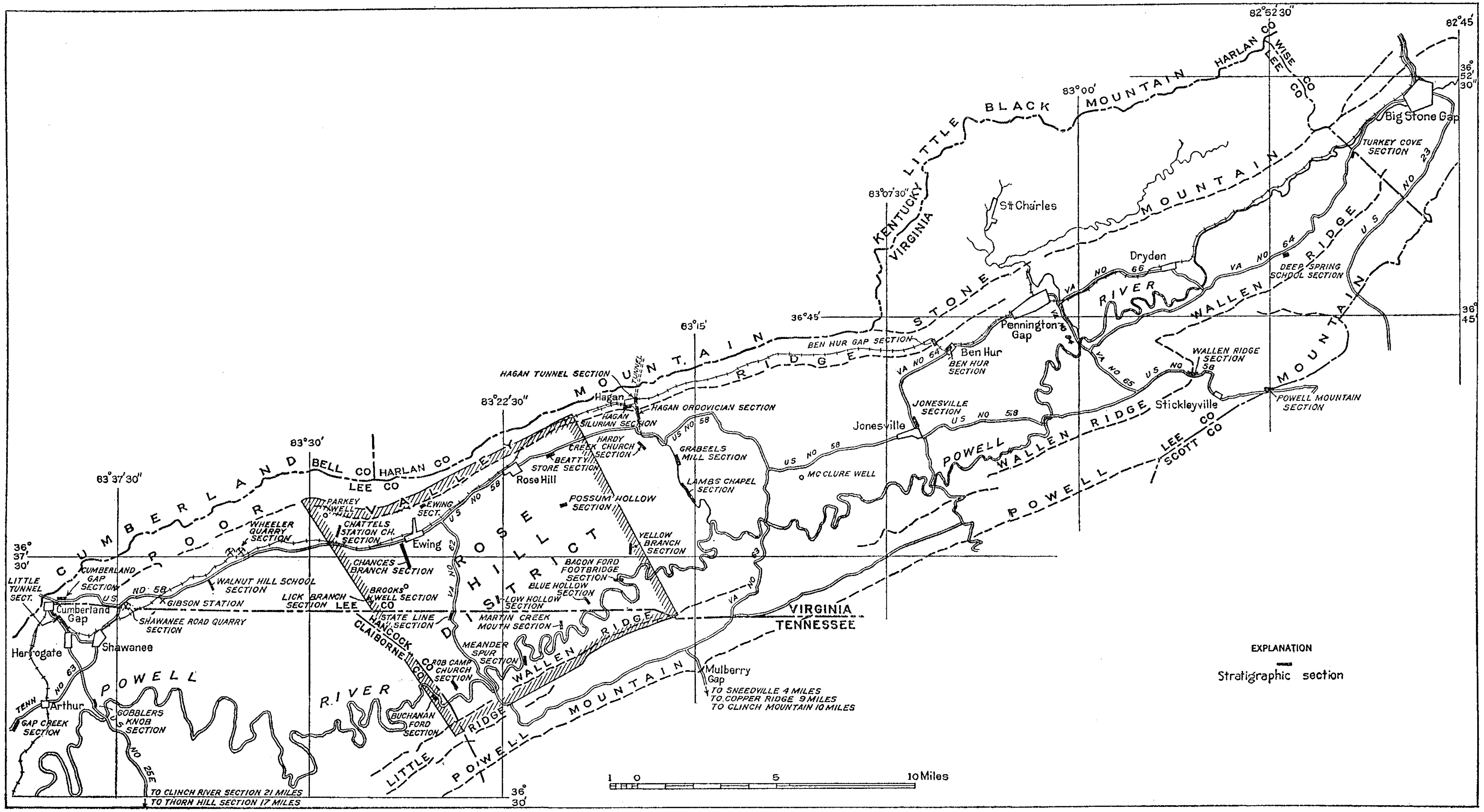
[35] Ulrich, E. O., Revision of the Paleozoic systems: Geol. Soc. America Bull., vol. 22, pp. 549, 638-640, Pl. 27, 1911.

Copper Ridge-Chepultepec contact normally lies a short distance down the inner slope of this ridge. On the opposite side of the ridge the main mass of the Chepultepec forms a slightly lower belt which is in places drained by small subsequent streams. The outcrop areas of the Chepultepec are not as finely dissected as the belt of the Copper Ridge dolomite. Near the northeast and southwest borders of the district where the dips are more gentle, the ridges formed by the basal sandy beds of the Chepultepec dolomite are not so prominent, and the contrast in the amount of dissection between the Copper Ridge and Chepultepec outcrop areas is not so striking.

The Chepultepec-Longview contact is also marked by prominent ridges, which overlook the lowlands underlain by Ordovician limestones. The position of the geologic contact on these ridges, however, is not everywhere consistent. Along most of the northwestern belt of the Chepultepec dolomite, the contact lies at the crest of the ridge, whereas along most of the southeastern belt the lowest Longview dolomite is at the crest with the Chepultepec just below. Near the northeast and southwest edges of the district, beds in the upper part of the Chepultepec dolomite form the ridges bordering the Chestnut Ridge upland and the contact with the Longview dolomite lies some distance down the long slope toward the lowlands. Most of the ridge crests and higher slopes of the Chepultepec dolomite are wooded, whereas the lower slopes and flat areas, which account for about two-thirds of the total outcrop area of the Chepultepec, are in fields or in pasture.

Outcrops of the Chepultepec dolomite are scarce, but the float is conspicuous and distinctive. Only on steep hillsides does the mixing of Chepultepec float with that from overlying or underlying formations make it impossible to locate the geologic contacts accurately. The lower contact with the Copper Ridge dolomite is marked by a change from clay soil (Copper Ridge) with large chert blocks to a sandy soil (Chepultepec) with large limonite-stained sandstone blocks and small oolitic chert blocks. The upper contact with the Longview dolomite is placed at the top of a less distinctive sandy soil containing infrequent small pieces of sandstone float (Chepultepec), and below large float blocks of white chert (Longview). Weathering of the main body of the Chepultepec dolomite produces an orange to red clay soil with sandy streaks and scattered masses of white oolitic chert.

In spite of the limited outcrops, there are several moderately good sections of the Chepultepec dolomite. One of them is along Chances Branch, half a mile southwest of Ewing, Virginia (Geologic Section 3),



Map showing locations of stratigraphic sections in and near the Rose Hill district.

LIST OF SECTIONS ON MAP, SHOWING FORMATIONS REPRESENTED IN SECTIONS

(Complete or partial measured sections of starred formations are given in text. Other sections are discussed in text.)

Name of Section	*Formations in Section*
Bacon Ford Footbridge section	Mosheim, Lenoir
Beatty Store section	Mosheim
Ben Hur Gap section	Clinch
Ben Hur section	Cayuga *
Blue Hollow section	Mascot-Murfreesboro contact *
Brooks Well section	Rome *
Buchanan Ford section	Mosheim
Chances Branch section	Maynardville *, Copper Ridge *, Chepultepec * Longview *, Kingsport, and Mascot
Chattels Station Church section	Eggleston and Trenton
Clinch River section	Rome and Maynardville
Cumberland Gap section	Clinton-Cayuga contact
Deep Spring School section	Mosheim *
Ewing section	Reedsville
Gap Creek section	Murfreesboro
Gobblers Knob section	Chepultepec
Grabeels Mill section	Copper Ridge *
Hagan Ordovician section	Murfreesboro, Mosheim, Lenoir, Lowville, Moccasin *, Eggleston *, Trenton * Reedsville * and Sequatchie *
Hagan Silurian section	Clinch * and Clinton *
Hagan Tunnel section	Cayuga and Brallier
Hardy Creek Church section	Chepultepec, Longview, Kingsport, Mascot, and Murfreesboro
Jonesville section	Murfreesboro
Lambs Chapel section	Chepultepec, Longview *, Kingsport *, and Mascot *
Lick Branch section	Maynardville
Little Tunnel section	Reedsville, Sequatchie, and Clinch *
Low Hollow section	Maynardville
Martin Creek Mouth section	Murfreesboro *, Mosheim *, and Lenoir *
Meander Spur section	Lowville *, Moccasin *. and Eggleston
Possum Hollow section	Cayuga
Powell Mountain section	Clinch
Rob Camp Church section	Murfreesboro *, and Mosheim *
State Line section	Maynardville *
Shawanee Road quarry section	Lowville
Thorn Hill section	Maynardville and Knox group
Turkey Cove section	Clinch
Wallen Ridge section	Clinch
Walnut Hill School section	Murfreesboro, Mosheim, and Lenoir
Wheeler Quarry section	Lowville, and Moccasin
Yellow Branch section	Murfreesboro and Mosheim

and three other sections lie a short distance outside the area mapped (Pl. 13). In all sections a two-fold division of the Chepultepec dolomite is apparent, consisting of a lower or sandy member and an upper or argillaceous dolomite member. These members have not been mapped separately on Plate 1.

Sandy member.—Interbedded sandstones, saccharoidal dolomites, and argillaceous dolomites compose approximately the lower 270 feet or the sandy member of the Chepultepec dolomite. The two types of dolomite are present in about equal amounts and both contain scattered sand grains and sandy lenses. A zone of sandstone, 2 to 11 feet thick, forms the base of the member (Geologic Section 4, Unit 10), and other thinner beds of sandstone, some of which is quartzitic, are present throughout the remainder.

The sandstones are composed of white medium-grained quartz sands cemented by dolomite. On weathering the dolomite dissolves and leaves a friable porous rock which generally is stained with limonite. Variation in quantity of limonite determines whether the color of the rock is white, tan, yellow or brown. A photomicrograph of a thin section of typical sandstone in the Chepultepec, taken with crossed nicols, is illustrated in Plate 11C. The dark and white rounded to subrounded grains, speckled with tiny impurities, are quartz grains which are about 0.325 mm. in size. Quartz composes about 75 percent of the rock and feldspar in more angular grains about 20 percent. Microcline is the principal feldspar, but orthoclase, albite, and soda microcline are present. Some crystals of twinned feldspar are clearly visible in the photomicrograph. The dolomite cement has largely been dissolved in the rock from which the thin section was cut and therefore the remaining matrix is mainly vein quartz and limonite with a few ghosts of dolomite crystals and zoned oolites. Secondary quartz has been deposited on some grains and has also produced the quartz veins. Some of the sandstones are laminated or contain shaly partings, and ripple marks of both the oscillation and current types are common.

One type of dolomite in the sandy member is a light-brown saccharoidal dolomite, which is medium- to coarse-crystalline. It weathers with rounded surfaces, thinly coated with friable dolomite. In thin section the interlocking dolomite crystals are about 0.39 mm. in size. Shadowy extinction of the crystals and cleavage fragments around the crystal borders suggest that the rock has been subjected to strain. Other recognizable constituents are a few scattered grains of quartz and a little limonite. Some beds of saccharoidal dolomite are very similar to the lower part of the Copper Ridge dolomite. They are darker brown than the average Chepultepec dolomite and some are mottled and have a petroliferous odor on fresh fracture.

The second type of dolomite in the sandy member is a fine- to medium-crystalline argillaceous dolomite, in even beds, from 1 to 5 feet thick. It is light gray to tan with scattered thin reddish streaks. Weathered surfaces commonly show thin laminations due to alined clay particles. Some beds have a sandy zone at the base grading upward through a zone of scattered sand grains into argillaceous dolomite. In thin sections the argillaceous dolomite shows an equigranular texture with an average crystal size of 0.022 mm. Dolomite and a little limonite are the only recognizable minerals.

Throughout the sandy member chert is present as irregular masses, nodules, lenses, and beds. Most of the fresh chert is white to light gray and some is dark gray in color, but it all weathers white. Most of the chert is chalcedonic and contains scattered medium-sized oolites. The chalcedonic type commonly occurs as irregular masses and lenses in the saccharoidal beds, whereas nodular chert is more abundant in the argillaceous dolomite. Some beds of silicified oolitic dolomite are scattered through the member. They are quite characteristic of the Chepultepec, but also are present in the uppermost part of the Copper Ridge dolomite and the lowermost part of the Longview dolomite. The closely packed oolitic spherules vary in size, but they average about 0.8 mm. The majority are perfectly round, but some are oval, flattened, or irregular in shape. Well-developed zoning of the spherules is visible in the photomicrograph (Pl. 11D). Most of the zones are caused by textural variations of the quartz from fine to very fine, with the outer bands usually colloform. A few spherules have a sand grain as a core, and some have hollow centers. The spherules grade into a matrix which is generally flamboyant feather-vein quartz. Plate 11E is a photomicrograph of a bedded oolitic chert, which apparently was originally a sandy oolitic dolomite. Both the spherules and the dolomitic matrix have been replaced by vein quartz and the sand grains have been enlarged by the introduced quartz. A few grains have grown with terminated crystal faces.

Brown to greenish-brown shale forms a very minor and inconspicuous part of the sandy member. One shale bed about 4 inches thick is associated with the basal sandstone along Chances Branch (Geologic Section 3, Unit 22), but normally the shale is in partings, less than a quarter of an inch thick. Weathering of the sandy member produces a yellow clay soil containing pieces of white oolitic chert, which are especially prominent in the upper half of the member. Float blocks of chert are in general smaller and less abundant than those derived from the Longview dolomite above and the Copper Ridge dolomite below.

Argillaceous dolomite member.—The argillaceous dolomite member consists of even-bedded argillaceous dolomites with a few interbedded sandstones especially near the top of the member. This member has rock types similar to those of the sandy member, but it contains more argillaceous dolomite and less saccharoidal dolomite, sandstone, and chert. Laminations and red streaks characterize the argillaceous dolomite. The saccharoidal dolomite is normally light colored, but some beds are brown and emit a petroliferous odor on fresh fracture. Chert of the argillaceous dolomite is nodular, but that of the saccharoidal dolomite is in irregular masses. The interbedded sandstones are similar to those of the sandy member except that those found at the top of the member are finer grained. Beds of closely-packed chertified oolite and thin, green shale partings are also similar to those in the sandy member. At several localities near the top of the member, there are beds approaching true limestones. The argillaceous dolomite member is about 435 feet thick.

Stratigraphic relations.—The Chepultepec dolomite, as here defined, has conformable contacts at the base and top. Butts[36] states that throughout Virginia the Chepultepec succeeds the Copper Ridge dolomite or its equivalent without known unconformity, and Oder[37] does not mention an unconformity at the base of the Chepultepec in Tennessee. The placing of the Copper Ridge-Chepultepec contact at the base of the first sandstone above the prominent oolitic chert beds in the top of the Copper Ridge dolomite conforms with recent practice of the U. S. Geological Survey in Tennessee.[38] The Copper Ridge and Chepultepec dolomites are believed to be of Cambrian and Ordovician age, respectively, so that a conformable contact between the two formations implies no recognizable hiatus between the deposits of two geologic systems.

In a measured section north of Grabeels Mill on Hardy Creek (Pl. 13 and Geologic Section 4), 2½ miles east of the Rose Hill

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[36] Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. I, Geologic text and illustrations, p. 98, 1940.

[37] Oder, C. R. L., Preliminary subdivision of the Knox dolomite in east Tennessee: Jour. Geology, vol. 42, no. 5, pp. 469-497, 1934.

[38] Rodgers, John, and Kent, Deane F., personal communication.

district, an unconformity is present 148 feet below the top of the mapped Copper Ridge dolomite. It consists of a somewhat undulatory surface separating brownish-gray medium-crystalline saccharoidal dolomite below, from light-gray fine-grained sandy dolomite above. Pebbles of light-gray dolomite, lenses of medium-grained sandstone, and scattered sand grains are present in the first 3 feet of beds overlying the undulatory contact (Geologic Section 4, Unit 4). Because this part of the formation is not exposed in other measured sections and because outcrops of this part of the Copper Ridge dolomite are very rare, we have not been able to establish whether the unconformity near Grabeels Mill is local or whether it represents a more widespread hiatus which has not been noted previously. If the unconformity proves to be widespread, it would make a stratigraphically more acceptable base for the Chepultepec dolomite than the one now used and also would be the first evidence from this part of the Appalachians for an unconformity between the Cambrian and Ordovician.

Thickness.—Three measured sections in and near the Rose Hill district showed thicknesses of 697, 705, and 776 feet of Chepultepec dolomite. The thickness at a locality 20 miles to the southwest in the Powell River zinc district is about 700 feet.[39]

Paleontology.—*Cryptozoa* were the only fossils found in the Chepultepec dolomite of the Rose Hill area. They are most abundant in the lower part of the sandy member. Elsewhere a characteristic though sparse fauna of brachiopods, gastropods, cephalopods, and trilobites has been found. At Gobblers Knob on U. S. Route 25E, 3½ miles southeast of Cumberland Gap village, Tenn. (Pl. 13), Butts[40] collected *Finkelnburgia?* sp., *Helicotoma uniangulata* (Hall), *Ophileta?* sp., and *Clarkoceras* sp. from rocks identical with our Chepultepec dolomite. Oder[41] has made an extensive study of the Chepultepec fauna found in the chert beds of the western part of the southern Appalachian Valley and in the limestones of the eastern part. He divides the formation into four faunal zones and considers *Helicotoma uniangulata* diagnostic of the Chepultepec.

Age and correlation.—Paleontologic evidence bearing on the correlation and age of the Chepultepec dolomite has not been found in the Rose Hill district, but the fauna described by Butts from Gobblers

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[39] Rodgers, John, and Kent, Deane F., personal communication.

[40] Butts, Charles, op. cit., p. 101.

[41] Oder, C. R. L., Preliminary subdivision of the Knox dolomite in east Tennessee: Jour. Geology, vol. 42, no. 5, pp. 480-481, 1934.

Knob (Pl. 13), 12 miles to the southwest, contains typical Chepultepec fossils. This fauna was collected in a small valley, from chert float which, according to our measurements, must have come from beds between 60 and 130 feet below the top of the Chepultepec as mapped in the Rose Hill district. The upper part of our Chepultepec dolomite is thus indirectly correlated with beds containing a typical Chepultepec fauna. The lithologic criteria used for determining the limits of the Chepultepec dolomite of the Rose Hill district are the same as those used by the U. S. Geological Survey in northeast Tennessee.[42] Inasmuch as the formation in both areas is also similar in thickness, we believe the Chepultepec dolomite of the Rose Hill area is exactly equivalent to the Chepultepec as recently mapped in Tennessee.

Correlation of our Chepultepec dolomite with the Chepultepec limestone of Butts is less clear because of lithologic changes of the formation in the Appalachian Valley of Virginia. In contrast with the dolomitic character of the entire Knox group in the southwestern part of the valley, the southeastern facies of the Chepultepec consists of 500 to 700 feet of blue fine-crystalline limestone with only a few beds of dolomite. In Tennessee, Oder[43] correlates these lithologically different sequences on the basis of fossils. In Virginia, Butts found Chepultepec fossils in the thick sequence of dolomites of the Knox group in the southwestern part of the Appalachian Valley, but he was reluctant to identify the Chepultepec formation because of the absence of limestone and because of his belief that the Chepultepec rarely contains sandstones. With regard to the lack of limestone in the Knox, he says: "Northwest of the Greendale syncline, in Washington County, Virginia, the Copper Ridge and Beekmantown form a continuous vertical mass of dolomite 2400 feet thick with no recognizable boundary between them."[44] Concerning the absence of sandstone, Butts says: "As no sandstone occurs in the Elbrook, or any resistant sandstone in the Nolichucky, and as such beds are exceedingly rare in the Chepultepec and Beekmantown, this feature becomes an almost infallible criterion for the identification of the Conococheague limestone, or its equivalent, the Copper Ridge dolomite."[45] Butts realizes, however,

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[42] Rodgers, John, Copper Ridge zinc district (east part) Hawkins, Hancock, and Grainger counties, Tennessee: U. S. Geol. Survey Strat. Min. Invest., Prelim. Map, 1944.

Rodgers, John, and Kent, Deane F., personal communication.

[43] Oder, C. R. L., op. cit., pp. 479-481.

[44] Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. I, Geologic text and illustrations, p. 90, 1940.

[45] Butts, Charles, op. cit., p. 87.

that some of this sequence of dolomites may be equivalent to the Chepultepec limestone. At one locality, where he found a Chepultepec fossil in beds which he had assigned on lithologic grounds to the Copper Ridge, he observes: "The horizon of the *Hemithecella* is high in the Copper Ridge and may mean that some of the Chepultepec has been locally included in the Copper Ridge."[46] Because he restricts the Chepultepec to limestones or interbedded limestones and dolomites which contain no interbedded sandstones, his Chepultepec formation changes thickness radically in short distances. For example, south of Glade Spring, Washington County, Virginia, his Chepultepec is 400 to 600 feet thick, whereas 7 miles to the north around Saltville it is 20 to 36 feet thick. A major fault, the Walker Mountain fault, does exist between these two localities, but the amount of displacement is not great and the two rock sequences are not much closer together than they were before faulting. Rapid thinning of a carbonate formation is not expectable in a short distance unless there is a major unconformity at the top or base. It seems far more probable that Butts has drawn the base and top of his Chepultepec at different time horizons in different localities, and that the Chepultepec of southwest Virginia is far more consistent in thickness than his figures would indicate.

Oder classified the Chepultepec as Cambrian, but most other recent workers consider it the basal formation of the Ordovician system, a procedure which is followed in this report.

LONGVIEW DOLOMITE

In southwest Virginia, the terms "Beekmantown group," "Beekmantown formation," and "formations of Beekmantown age"[47] have been used to designate rocks that in part are divided in ascending order into the Longview, Kingsport, and Mascot dolomites in this report. These formations have not been described previously in Virginia, but they have recently been mapped in northeastern Tennessee. In the Rose Hill district the three formations were recognized, but they are shown as an undifferentiated unit on the geologic maps because their mapping, which would be difficult owing to the scarcity of outcrops and mixing of float on the long steep outer slopes of the Chestnut Ridge upland, was not important to this investigation. In measured sections the formations have been separated and their dis-

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[46] Butts, Charles, op. cit., p. 95.

[47] Butts, Charles, op. cit., pp. 102-119.
Bates, R. L., Geology of Powell Valley in northeastern Lee County, Virginia: Virginia Geol. Survey Bull. 51, pp. 44-46, 1939.

tinguishing features noted, although their distinctive characteristics are less striking than those found in Tennessee. The formations are here described separately.

The Longview, Kingsport, and Mascot dolomites combined, form belts on either edge of the Chestnut Ridge upland adjacent to the lowlands of Ordovician limestones. On the northwestern flank of the Powell Valley anticline the thick chert beds of the Longview commonly form a ridge at the top of the slope and the upper contact of the Mascot lies at or near the base of the slope. On the southeastern flank the belt of the three formations is broader owing to more gentle dips. The formations here form part of the upland and the upper part of the long slopes into the Powell Valley. As a whole timber covers less than one-third of the belt of these formations and the woods are mostly at the level of the upland or along the steep valley walls of transverse streams which are more abundant on the southeastern flank. Outcrops of these three formations are scarce, but the float derived by weathering of the bedrock is characteristic and consists of abundant white chert in large blocks. In fields, the soil derived from the Chepultepec and Copper Ridge dolomites contains scattered small blocks of chert, but the soil in a field underlain by the Longview, Kingsport or Mascot dolomites is covered by a blanket of white chert blocks, many of which are quite large. In some fields, the farmers have collected and piled the large blocks of chert in isolated piles or cairns.

Name.—The name Longview seems to have first appeared in print on a chart compiled by W. A. Nelson from published and unpublished material prepared by E. O. Ulrich.[48] In this chart the Longview dolomite referred to 1,000 feet of beds in the Appalachian Valley of Tennessee overlying the Chepultepec dolomite and underlying Ulrich's Upper Canadian. Butts,[49] who later described the formation more extensively, says that it was named for the town of Longview, Shelby County, Alabama.

Character.—In the Rose Hill district, the Longview dolomite is approximately 265 feet thick (Geologic Section 5), and is composed of interbedded nearly white fine-crystalline dolomite and white to light-brown, medium- to coarse-crystalline, saccharoidal dolomite, with

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[48] Gordon, C. H., History, occurrence, and distribution of the marbles of east Tennessee: Tennessee Dept. Education, Div. Geology Bull. 28, p. 34, 1924.

[49] Butts, Charles, Geology of Alabama: The Paleozoic rocks: Alabama Geol. Survey Spec. Rept. No. 14, pp. 41-230, 1926.

the latter somewhat the more abundant. Both types contain chert nodules, lenses, and masses and there are in addition solid beds of chert. A few beds of green shale, with a maximum thickness of 3 inches, are present.

The white fine-grained dolomite occurs in massive beds which average 1 foot thick and which are generally less even bedded than the dolomites of the Chepultepec. The dolomite usually contains light-gray to white concentrically banded chert nodules and also chert lenses a few inches thick and less than 3 feet long. The chert appears to be primary. Some beds of dolomite are argillaceous and laminated, but these features are not nearly as conspicuous as they are in the argillaceous dolomite of the Chepultepec.

The saccharoidal dolomite differs from that found in the Chepultepec in being generally lighter in color and coarser in texture, and none of it has a petroliferous odor. It resembles that of the Chepultepec, however, in containing sandy lenses and in weathering with rounded surfaces covered with friable fine dolomite. In the upper part of the Longview dolomite, saccharoidal beds are streaked, owing to variations in crystallinity and to thin green clay partings. This rock also commonly has vugs lined with dolomite crystals. Chert is especially abundant in the saccharoidal beds; it is light blue-gray to gray chalcedonic chert in irregular masses commonly with molds of dolomite crystals (dolomolds) and it appears to be of secondary origin. The whole aspect of the saccharoidal dolomite and its chert suggests replacement and the dolomite may thus represent replaced limestone.

Besides the chert nodules and masses in the two types of dolomite just described, there is also bedded chert in layers ranging from a few inches to 4 feet thick and averaging 1 foot thick. This chert is light blue-gray to gray and chalcedonic, and contains scattered oolitic grains and dolomolds. Silicified fossils are found in these beds especially near the top of the formation. In places the bedded chert is brecciated, being made of subangular to rounded oval fragments of chert set in a matrix of the same material. On weathering, the Longview dolomite forms a clay soil containing abundant blocks of milky- to chalky-white chert. These blocks form a mantle over the surface, and are equaled in abundance only by the chert mantle derived from the Lenoir limestone, but are unequaled in their size and brightness of color.

Stratigraphic relations and thickness.—The contact of the Longview dolomite with the underlying Chepultepec dolomite appears to be conformable. A slight unconformity is present at the top of the Longview. In measured sections along Hardy Creek and Chances Branch and near Lambs Chapel (Pl. 13), the thickness of the Longview is 98, 239, and 272 feet, respectively.

Paleontology.—Fossils are sparse in the Longview dolomite, but occasional chert beds at some places contain abundant gastropods. All the fossils that were found occurred in cherts. The fossiliferous chert seems to be more abundant in the upper part of the Longview. The most abundant and diagnostic fossil is *Lecanospira.* Gastropods collected by us were identified as *Lecanospira conferta?, Ophileta* sp., *Helcionella* sp., and *Archinacella* sp. *Cryptozoa* are also present and some of them form striking ball-like masses.

Age and correlation.—The *Lecanospira* zone of the Longview dolomite is one of the most persistent and widespread fossil horizons of the Ordovician system. In the Appalachian Valley, according to Oder,[50] the *Lecanospira* zone is present in the Longview of Alabama and Tennessee, the Nittany dolomite of Pennsylvania and the lower part of Division C of the type Beekmantown limestone in New York. Cady[51] recently reported *Lecanospira* in the upper part of the Cutting dolomite and the lower part of the Bascom formation of west-central Vermont. One specimen of *Lecanospira* (not *Lecanospira* cf. *L. conferta*) was found near Rose Hill in the lower part of the Mascot dolomite.

KINGSPORT DOLOMITE

Name.—The name Kingsport was first used by Rodgers[52] on a preliminary map of the Copper Ridge zinc district in Tennessee. The name is taken from the city of Kingsport in Sullivan County, northeast Tennessee.

Character.—The Kingsport dolomite of the Rose Hill district is similar in character to the Longview dolomite. The chief differences are that the Kingsport has a greater proportion of coarse-crystalline, saccharoidal dolomite than the Longview, and a smaller amount of

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[50] Oder, C. R. L., Preliminary subdivision of the Knox dolomite in east Tennessee: Jour. Geology, vol. 42, no. 5, p. 483, 1934.

[51] Cady, W. M., Stratigraphy and structure of west-central Vermont: Geol. Soc. America Bull., vol. 56, no. 5, pp. 539-548, 1945.

[52] Rodgers, John, Copper Ridge zinc district (east part), Hawkins, Hancock, and Grainger counties, Tennessee: U. S. Geol. Survey, Strat. Min. Invest., Prelim. Map, 1944.

chert, especially of the bedded variety. The lower part of the Kingsport is composed of light-gray, medium- to coarse-crystalline, saccharoidal dolomite containing scattered sand grains and many vugs lined with dolomite crystals. The dolomite is in thick beds, which have a maximum thickness of 6 feet, and which weather with rounded surfaces covered with loose crystals of dolomite. The rock decomposes to a brown to reddish-brown soil containing irregular masses of chalky-white chert similar to that derived from the saccharoidal beds of the Longview. The coarse-crystalline dolomite in the Kingsport may represent replaced limestone. Instead of saccharoidal dolomite, the upper part of the formation is composed mainly of grayish-white fine-crystalline dolomite, which is in thinner beds, generally 1 to 3 feet thick. The dolomite contains lenses and nodules of blue chalcedonic chert. Chert beds with scattered oolites and a few thin green shale partings are present.

Stratigraphic relations.—The contact of the Kingsport dolomite with the underlying Longview dolomite is placed at an uncomformity which is well exposed in the Chances Branch section (pp. 37-39), where a distinctive conglomeratic bed, 3 to 4 feet thick, of gnarled and mottled limestone with dolomite and green shale partings rests on a slightly undulatory surface. A chertified sandy zone ("chert matrix sand") close above this unconformity forms a distinctive float and is helpful in locating the contact where exposures are poor (Geologic Section 5, Unit 12). The contact with the overlying Mascot dolomite, which is essentially conformable, is described in the section on the Mascot.

Thickness and paleontology.—In the Lambs Chapel section (Geologic Section 5), where the contacts at the base and top of the formation are clear, the Kingsport dolomite is about 180 feet thick and in the Hardy Creek Church section, where the contacts are less satisfactory, the Kingsport is 250 feet thick. As with the Longview dolomite, the sparse fossils of the Kingsport are mainly gastropods and are confined to the chert beds. Those identified from this area are: *Orospira bigranosa, Orospira* sp., and *Coelocaulus* sp.

Age and correlation.—The stratigraphic position and fauna of the Kingsport dolomite date the formation as Ordovician. The Kingsport correlates with Oder's Jefferson City formation, and Hall and Amick's Forked Deer formation of Tennessee. In Tennessee the lower part of Oder's Jefferson City and Hall and Amick's Forked Deer formations, which are approximate equivalents, contain dove-gray limestones. In the Rose Hill area the only limestone in the Kingsport dolomite is that found in the matrix of the basal bed. The coarse vuggy dolomites of the lower Kingsport may, however, have been limestones, which have been replaced by dolomite. The upper part of the Kingsport in both Tennessee and the Rose Hill district is composed mainly of fine-grained dolomite.

MASCOT DOLOMITE

Name.—The name Mascot, like Kingsport, was first used by Rodgers[53] on a preliminary map. The type region of the formation is the Mascot zinc district northeast of Knoxville, Tennessee.

Character.—The Mascot dolomite contains rock types similar to those of the Longview and Kingsport dolomites, but it contains a much smaller proportion of saccharoidal dolomite (Geologic Section 5). Most of the formation is composed of even massive beds, 1 to 4 feet thick, of fine-crystalline white dolomite with pinkish streaks and patches. These beds contain scattered chert nodules. The occasional beds of saccharoidal dolomite are coarse crystalline and thick bedded and contain scattered sand grains. A few sandy beds, some of which are quartzitic, are also present.

Thick-bedded chert is more abundant than in the Kingsport dolomite but less so than in the Longview dolomite. The thickest chert beds of the whole geologic column of the Rose Hill district are in the Mascot; one along Chances Branch is 8 feet thick. Chert also occurs as cavernous cauliflower-shaped heads and ball-like masses and it commonly replaces colonies of *Cryptozoa.* A few beds of limy dolomite are present throughout the formation and massive 3- to 4-foot beds of light-brown compact conchoidally fracturing limestone are common at some localities in the upper part. Near the top of the Mascot, there is a distinctive thick bed of white splintery chert and also in many places a bed of mottled tan to brown coarse-crystalline vuggy dolomite ("stinkstone"), about 4 feet thick, which emits a petroliferous odor immediately after being fractured. Thin green to gray shale partings separate most of the dolomite beds throughout the formation.

Minor unconformities have been noted near the top of the Mascot dolomite at two localities in the Rose Hill district. One of them is in a quarry along the Powell River road 0.15 of a mile south of the

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[53] Rodgers, John, op. cit.

mouth of Fourmile Creek. Here dolomites, 55 feet below the top of the Mascot, contain two unconformities 1½ feet apart. In the quarry the lower unconformity cuts across 5 inches of the underlying beds and the upper one cuts across 8 inches. Two similar unconformities are well exposed in the Johnson quarry along U. S. Route 58, a mile east of Ewing, Virginia. A minor unconformity has also been described by Hall and Amick[54] in their Thorn Hill formation, which correlates in part with our Mascot dolomite. The occurrence in Mascot time of breaks in sedimentation, accompanied by minor erosion, is thus established at several localities, but whether the unconformities are local or are areally extensive, and whether individual unconformities may be recognized in regions many miles apart is not yet known.

Along U. S. Route 58 near the mouth of Chances Branch, several peculiar geometric forms lie on a bedding-plane surface in the middle of the Mascot dolomite. The best developed examples of the forms consist of a series of concentric rings which are oval at the center and become more rectangular outward (Fig. 5). The larger forms are 3 inches in diameter and their rings, about a quarter of an inch apart, have a relief of about one eighth of an inch on a weathered surface. Smaller forms are triangular or diamond shaped with only one or two rings. W. T. Schaller[55] suggests that they represent salt crystal patterns.

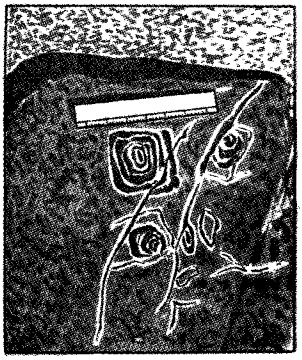

FIGURE 5.—Salt crystal patterns (?) on a bedding surface of Mascot dolomite. Length of scale 6 inches. By Ansel M. Miller.

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[54] Hall, G. M., and Amick, H. C., The section on the west side of Clinch Mountain, Tennessee: Tennessee Acad. Sci. Jour., vol. 9, no. 3, p. 214 (unit 671), 1934.

[55] Schaller, W. T., personal communication.

Stratigraphic relations.—The contact of the Mascot dolomite with the Kingsport dolomite is placed at the base of a zone of disturbed sedimentation. In the Lambs Chapel section, where the contact is best exposed, the bed above the contact is an intraformational conglomerate composed of fine-grained light-gray dolomite with scattered rounded sand grains and with a few rounded pebbles of chert and argillaceous dolomite. The contact of the Mascot dolomite with the overlying Murfreesboro limestone is the locus of the most prominent unconformity in the geologic column of the Rose Hill district. In places the Mascot was deeply eroded during the hiatus, and locally, as in the section at Hardy Creek Church (Pl. 13), it seems to have been nearly completely removed. The contact is readily recognized by the basal conglomerate of the Murfreesboro, or where this is concealed, by the contrast in lithology of the Mascot dolomite with the dolomite in the lower part of the Murfreesboro.

Thickness and paleontology.—In measured sections at Hardy Creek Church (Pl. 13) in the northeast part of the district and at Lambs Chapel (Geologic Section 5) in the southeast part, the Mascot dolomite is 169 feet and 460 feet thick, respectively. The thinness of the formation at Hardy Creek Church is due to pre-Murfreesboro erosion, which also accounts for other variations in thickness of the Mascot in the Rose Hill district. Within the area there is in general a thickening of the Mascot in a southwest direction, but the rate of change in thickness is not uniform.

Cryptozoa and a few silicified gastropods are present in the Mascot dolomite. Of the gastropods *Roubidouxia?* sp., and *Coelocaulus delicatula* have been identified. Plate 12B illustrates unusually well developed fucoids which are present near Walnut Hill School (Pl. 13), probably in the Mascot. One *Lecanospira* was found in the lower Mascot 710 feet above the base of the Longview dolomite. *Lecanospira* is considered a type fossil for the Longview, but this species is an unusual type which Bridge[56] says he and Ulrich have named in an unpublished manuscript. Bridge's specimens of the form were collected from beds of Longview age, but our discovery indicates that its range extends higher.

Age and correlation.—The character, sequence, and stratigraphic position of the Mascot dolomite in the Rose Hill district are almost identical with those of the Mascot of Tennessee. According to

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[56] Bridge, Josiah, personal communication.

Rodgers[57] the Mascot is Ordovician in age and correlates approximately with the Cotter-Powell beds of Oder[58] and the Thorn Hill formation of Hall and Amick.[59]

MURFREESBORO LIMESTONE

Name.—The Murfreesboro limestone was named from Murfreesboro in the Nashville basin of Tennessee.[60] Butts has used the name in southwest Virginia for a distinctive series of rocks, but correlation of his Murfreesboro with the type Murfreesboro of the Nashville basin is in question. In this report, Butts' use of the term Murfreesboro is followed. Possibly a new name or names should eventually be applied to the Murfreesboro of the Rose Hill district. New names have been applied by Cooper and Prouty[61] and Cooper[62] in and near Tazewell County, Virginia, to all formations from the top of the Knox group to the base of the Moccasin limestone. Some of the beds assigned to the Murfreesboro, Mosheim, Lenoir, and Lowville limestones of this report are unquestionably equivalent to the named formations of Cooper and Prouty, but exact correlations have not yet been established between Tazewell County and Lee County, and, as discussed later, we are not entirely in accord with some of the correlations that have been suggested. It seems advisable, therefore, to retain Butts' usage of the name Murfreesboro in Lee County until regional relations of these beds are worked out over a broader area including southwest Virginia and northeast and central Tennessee. This procedure was recently adopted in Lee County by Huffman,[63] who used "Murfreesboro" to indicate equivalence with the Murfreesboro of Virginia, but not necessarily with type Murfreesboro.

Distribution.—The Murfreesboro limestone forms continuous belts on opposite sides of the Powell Valley anticline. The northwestern

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[57] Rodgers, John, Copper Ridge zinc district (east part), Hawkins, Hancock, and Grainger counties, Tennessee: U. S. Geol. Survey Strat. Min. Invest., Prelim. Map, 1944.

[58] Oder, C. R. L., Preliminary subdivision of the Knox dolomite in east Tennessee: Jour. Geology, vol. 42, no. 5, pp. 486-489, 1934.

[59] Hall, G. M., and Amick, H. C., The section on the west side of Clinch Mountain, Tennessee: Tennessee Acad. Sci. Jour., vol. 9, no. 3, pp. 208-214, 1934.

[60] Safford, J. M., and Killebrew, J. B., The elements of the geology of Tennessee, pp. 105, 125, Nashville, Tenn., 1900.

[61] Cooper, B. N., and Prouty, C. E., Stratigraphy of the lower Middle Ordovician of Tazewell County, Virginia: Geol. Soc. America Bull., vol. 54, no. 6, pp. 819-886, 1943.

[62] Cooper, B. N., Geology and mineral resources of the Burkes Garden quadrangle, Virginia: Virginia Geol. Survey Bull. 60, 229 pp., 1944.

[63] Huffman, G. G., Middle Ordovician limestones from Lee County, Virginia, to central Kentucky: Jour. Geology, vol. 53, no. 3, pp. 145-174, 1945.

belt of the Murfreesboro is confined to the Indian Creek lowland, but the southeastern belt occupies the lower south-facing slopes of the Chestnut Ridge upland, though in places it includes the northern edge of the Powell River lowland. The Murfreesboro limestone is also present in the fensters in a complex area along the edge of the Dean fenster, in a small slice 0.1 mile north of Dean's Store, and in the south end of the Sugarcamp fensters.

Character.—In the northwestern belt of the Murfreesboro limestone, outcrops are generally scarce, although they are more abundant than outcrops of the Longview, Kingsport and Mascot dolomites. Along the meanders of Indian Creek, however, several partial sections of the Murfreesboro limestone are well exposed. In the southeastern belt the exposures of the Murfreesboro are much more abundant. Except for a few wooded tracts along the streams, most of the southeastern belt of Murfreesboro has been cleared of timber. The formation has been divided into three lithologic members, which have not, however, been mapped separately. The members and their thicknesses are:

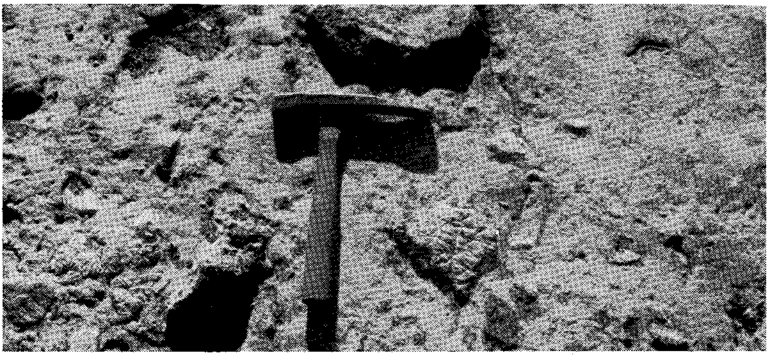
Cherty member, 40 to 100 feet
Limestone member, 50 to 120 feet
Dolomite member, 0 to 120 feet

The dolomite member is limited below by a conglomerate which is one of the most distinctive units in the Rose Hill district. The conglomerate is seldom over 3 feet thick, but it is resistant and has numerous outcrops. The matrix of the conglomerate is sandy and slightly argillaceous dolomite, which is light gray on fresh surface and weathers light gray to light buff. It is more nearly like the Mascot dolomite in color than it is like the overlying dolomites of the Murfreesboro, but it is somewhat more argillaceous than the typical Mascot dolomite. In this matrix are large angular and subrounded pebbles, cobbles, and boulders of gray to white chalcedonic chert and of light-gray fine-crystalline dolomite (Pl. 14A). The largest boulder of chert observed is 18 inches long and the largest boulder of dolomite 24 inches long, but the pebbles average from 1 to 6 inches in length. The dolomite pebbles and cobbles weather with coarse crisscross slashes or grooves along incipient joints ("butcher-block structure") and they stand in relief above the less resistant and smooth-weathering argillaceous dolomite of the matrix. At several localities some of the pebbles are a dark saccharoidal type of dolomite which is common in the lower part of the Copper Ridge dolomite but a few beds of which also occur near the top of the Mascot dolomite. Because of the angularity of even the dolomite pebbles and the lack of sorting or layering in the conglomerate, the pebbles are believed to have been moved only short distances and to have been derived largely if not entirely from the Mascot, which has all the requisite rock types. In a few places the basal bed of the Murfreesboro is not conglomeratic but consists of 1 to 5 feet of medium- to coarse-grained sandstone with well-rounded quartz grains.

Above the coarse basal conglomerate of the dolomite member, there commonly is a zone of greenish-gray dolomite containing scattered angular chert pebbles normally less than 1 inch in diameter. Not all the beds of this zone contain chert pebbles, but the deposition of the pebbles or chips seems to have been recurrent, and pebble-free dolomites, shaly dolomites, and shales are interbedded with the conglomeratic dolomite. The dolomites weather buff and are more argillaceous than the dolomitic matrix of the basal bed, probably because they contain less reworked material derived from the Mascot dolomite. Most of the chert-free beds are greenish-gray dolomite, but in places beds of pink, red, or red and green mottled dolomite are present. This conglomeratic zone attains a thickness of 20 feet in places but averages 5 to 10 feet thick.

The main part of the dolomite member is composed of beds, 1 to 3 feet thick, of fine-crystalline greenish-yellow or tan argillaceous dolomite with a crystal size of 0.03 mm. The dolomite weathers buff with a few red or green streaks. Unfractured beds weather with smooth rounded surfaces, of which an unusually fine example is shown in Plate 14B. Many of the dolomite beds, especially in quarries and road cuts, break during weathering along conchoidal surfaces, which have a very distinctive appearance (Pl. 14C). Where the incipient curving joints are intersecting and closely spaced, the dolomite disintegrates to a rubble of small subangular blocks many of which have dendrites on the joint faces. In the photograph (Pl. 14C), the bed on which the hammer rests shows a lace-like color pattern along incipient joints to the right of the hammer, but to the left of the hammer this massive bed has broken to pieces along the joints.

Thin beds of greenish-gray shale and beds of buff-weathering argillaceous limestone are interbedded with the dolomite, but they form only a small part of the dolomite member. The argillaceous dolomites of the dolomite member become less dolomitic and more limy upward. Near the top they are interbedded with light-gray limestones which



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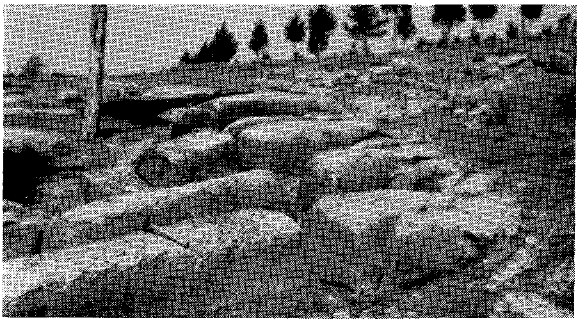

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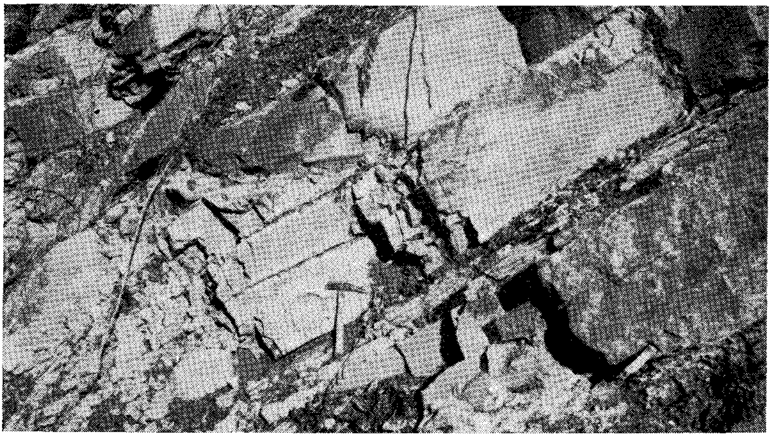
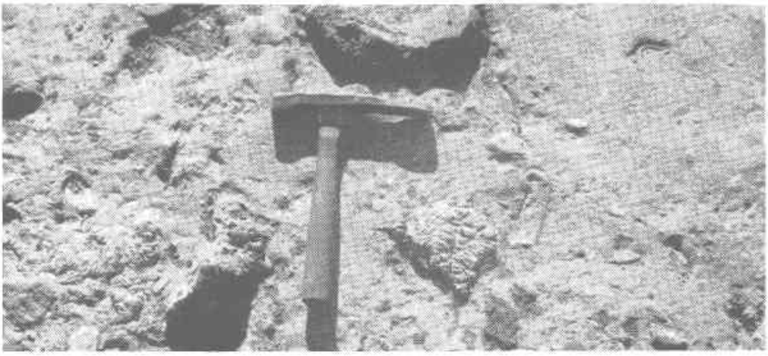


C

A, Basal conglomerate of the Murfreesboro limestone south of Walnut Hill School. B, Rounded weathering of jointed dolomite in the lower part of the Murfreesboro limestone near Wolfenbarger Church. C, Stages in the weathering of the dolomite of the lower part of the Murfreesboro limestone in railroad cut near Hagan, Lee County.



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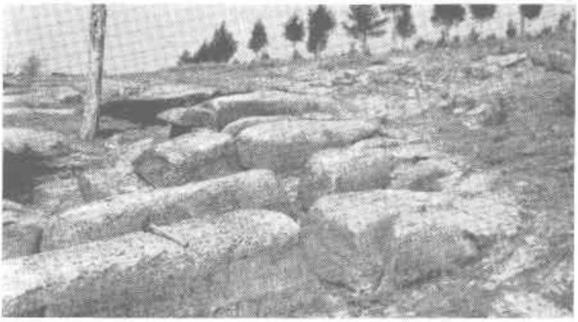

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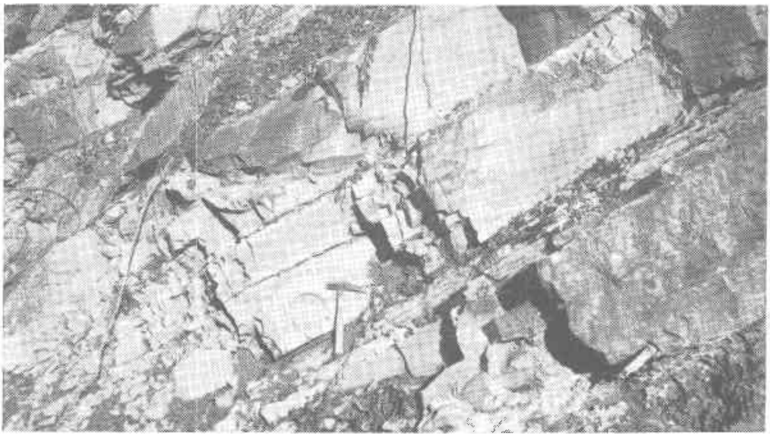
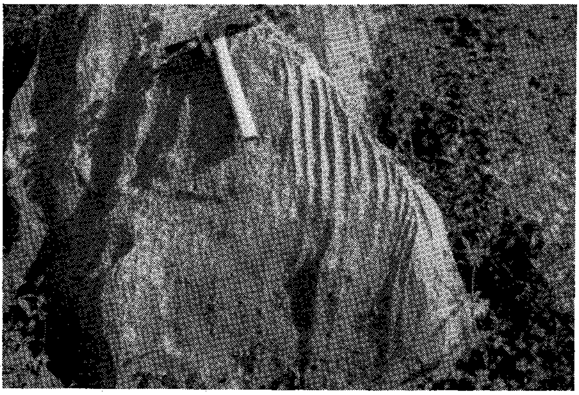


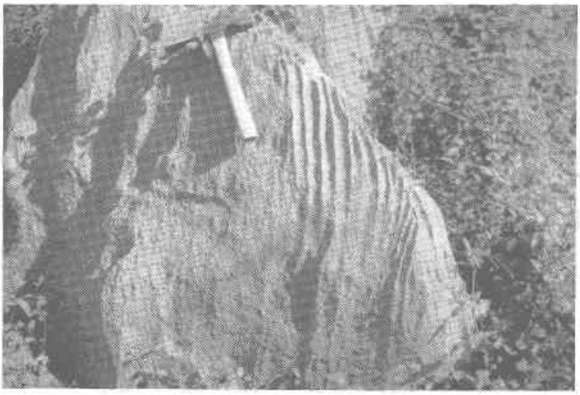
C

A, Basal conglomerate of the Murfreesboro limestone south of Walnut Hill School. B, Rounded weathering of jointed dolomite in the lower part of the Murfreesboro limestone near Wolfenbarger Church. C, Stages in the weathering of the dolomite of the lower part of the Murfreesboro limestone in railroad cut near Hagan, Lee County.



A, Massive birdseye limestone (Zone 4) in the Lowville limestone, showing characteristic fluted weathering. Near Hagan, Lee County.

B, Massive birdseye limestone (Zone 1) in Murfreesboro limestone in foreground, with Mosheim limestone (Zone 2) in the distance. Near the mouth of Blue Hollow.



A, Massive birdseye limestone (Zone 4) in the Lowville limestone, showing characteristic fluted weathering. Near Hagan, Lee County.

B, Massive birdseye limestone (Zone 1) in Murfreesboro limestone in foreground, with Mosheim limestone (Zone 2) in the distance. Near the mouth of Blue Hollow.

A, Conglomeratic zones at the Mascot-Murfreesboro contact along the Blue Hollow road.

B, *Tetradium cellulosum* from the chert member of the Murfreesboro limestone. x1.

A, Conglomeratic zones at the Mascot-Murfreesboro contact along the Blue Hollow road.

B, *Tetradium cellulosum* from the chert member of the Murfreesboro limestone. x1.

weather light blue-gray and contain the oldest fossils in the Murfreesboro limestone.

South of Walnut Hill School (Pl. 13) a bentonite, 1 foot thick, lies 11 feet above the base of the dolomite member. Its occurrence and character are described in the section on bentonites.

The limestone member of the Murfreesboro is separated with difficulty from the dolomite member. The contact, which is arbitrarily drawn, may occupy different stratigraphic positions in different sections. It is placed where gray-weathering limestone above, equals or becomes dominant in amount over the buff-weathering dolomite below. The limestone is light brownish-gray, cryptocrystalline, and so dense that it breaks with a conchoidal fracture. Many beds contain small scattered patches of white calcite crystals commonly called "birdseyes." Others have no "eyes" but do have scattered tiny calcite rhombohedrons 0.065 mm. in size which are visible in thin section. Limestones of this general type have been called vaughanites by Kindle[64] and this term has been used in Virginia by Bates[65] and Butts.[66] More recently these limestones have been called calcilutytes by Cooper and Prouty[67] and sublithographic limestones by Huffman.[68] The term birdseye limestone, which is more generally understood, is used in this report. Much of the limestone in the Murfreesboro, Mosheim, and Lowville formations is of the birdseye type. Throughout these formations most of the birdseye limestone is in beds less than a foot thick, but a number of zones of massive-bedded birdseye limestone form distinctive units, which may be traced for many miles, and thus form extremely valuable horizon markers. The beds in these zones are from 2 to 6 feet thick, are chemically more pure than most of the thin-bedded limestone, and weather with very characteristic fluted surfaces not seen in the thin-bedded limestone (Pl. 15A). These zones of massive birdseye limestone in the Rose Hill district have been numbered in order upward, beginning with massive birdseye limestone No. 1 in the Murfreesboro limestone. Zone No. 2 is the Mosheim limestone and zones Nos. 3 to 6 are key horizons of the Lowville limestone. Beds of similar massive

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[64] Kindle, E. M., Nomenclature and genetic relations of certain calcareous rocks: Pan-Am. Geologist, vol. 39, no. 5, pp. 370-372, 1923.

[65] Bates, R. L., Geology of Powell Valley in northeastern Lee County, Virginia: Virginia Geol. Survey Bull. 51-B, pp. 42, 46, 1939.

[66] Butts, Charles, op. cit., pp. 136-137.

[67] Cooper, B. N., and Prouty, C. E., Stratigraphy of the lower Middle Ordovician of Tazewell County, Virginia: Geol. Soc. America Bull., vol. 54, no. 6, pp. 819-886, 1943.

[68] Huffman, G. G., Middle Ordovician limestones from Lee County, Virginia, to central Kentucky: Jour. Geology, vol. 53, no. 3, p. 150, 1945.

birdseye limestone occur near the top of the Mascot dolomite but they do not seem to be persistent.

The No. 1 zone of massive birdseye limestone occurs near the top of the limestone member of the Murfreesboro. Where recognizable it ranges in thickness from 3 feet 9 inches to 11 feet 6 inches. It is less pure than most of the zones of birdseye limestones, and in some localities it contains a few small chert nodules near the base and some thin shale partings, both of which are rare or absent in the younger zones of this type of limestone. The zone forms a readily recognizable unit in the northern and southeastern parts of the district, but seems to change to the southwest so that it is no longer distinguishable from other limestones in the Murfreesboro. In Plate 17 it will be noted that No. 1 zone of massive birdseye limestone appears to lie at different horizons in the Blue Hollow and Yellow Branch sections. Although the zone was mapped between these two sections, the exposures of the zone were interrupted by several long concealed intervals, so that it was not possible to walk the zone continuously from one section to the other. This massive birdseye zone in the sections from Blue Hollow westward may possibly be a different and higher unit than the one at Yellow Branch and eastward. We suspect, however, but cannot prove, that the zone of massive birdseye limestone in the upper part of the limestone member of the Murfreesboro represents the same stratigraphic unit wherever recognized in the area. It will be so considered in the remainder of the report. Plate 15B shows a typical exposure of massive birdseye limestone No. 1 in the foreground of the photograph with the much thicker ledges of the Mosheim limestone (massive birdseye limestone No. 2) in the distance.

The upper or cherty member of the Murfreesboro limestone consists of chert-bearing, dense, fine-grained limestones with a few interbedded argillaceous limestones, dolomitic limestones, and argillaceous dolomites. The base of the cherty member is placed at the bottom of a distinctive, dark-colored, fragmental, coquinal limestone or, if this is absent, at the base of a zone of limestone containing abundant chert. The fragmental bed is several feet thick and is composed of numerous small limestone chips, most of which seem to be fragments of fossils. Most of the fossils are too macerated to be identified, but small complete cystid plates are characteristic. On weathered surfaces the fragmental bed may show cross-bedding, and locally it contains chert nodules. The bed is well exposed in sections at Hagan, Yellow Branch, and Jonesville (Pl. 13). It seems to be limited to the extreme eastern part of the area (Fig. 6). The fragmental character and cross-bedding suggest that there is a small unconformity at the base of the bed, but if this unconformity is present at approximately the same horizon in the western part of the area, it is indicated only by variations in thickness of the cherty member. Above the fragmental beds are dense, fine-grained limestones in beds less than 1 foot thick, which contain abundant chert nodules. The limestone is light brownish-gray but weathers light blue-gray, and the chert is dark gray to black in irregular nodules 2 to 4 inches thick and in lenses 2 inches thick and less than 40 inches long. Interbedded with the limestones are a few beds of dolomitic limestone which, on weathering, become buff in color and have the rounded surfaces that are typical of the dolomite beds of the Murfreesboro. A few beds of argillaceous limestone are also present, some of which are very shaly and have mud cracks. The argillaceous beds seem to be more abundant in the western part of the area, whereas the chert nodules become less abundant westward.

Stratigraphic relations.—The Murfreesboro limestone has a well-defined unconformity at its base. In many places the basal beds cut across the Mascot dolomite, but the contact is exposed only for short distances, so that the amount of cross-cutting is not readily apparent in the field. The presence of an unconformity is readily proved, however, by a basal conglomerate containing pebbles of typical rocks of the Mascot dolomite, by the absence in places of the lowermost beds of the Murfreesboro limestone, and by great variations in the thickness of the Mascot dolomite over short distances. If it is assumed that the rate of deposition of the Mascot sediments was nearly uniform over the Rose Hill district, which seems reasonable in view of the fact that the Mascot is composed largely of even-bedded carbonate and in view of the small size of the district, then the variations in thickness of the Mascot are a measure of the relief on the pre-Murfreesboro erosion surface. In places this amounts to at least 400 feet. Near the mouth of Martin Creek (Pl. 17), a hill on the old erosion surface was either not submerged till well along in Murfreesboro time or else early deposits on this hill were swept by wave or current action into lower areas near by. The result is a complete absence of the lower or dolomite member of the Murfreesboro in this region. Other unusually thin sections of the dolomite member are explained in the same manner (Fig. 6).

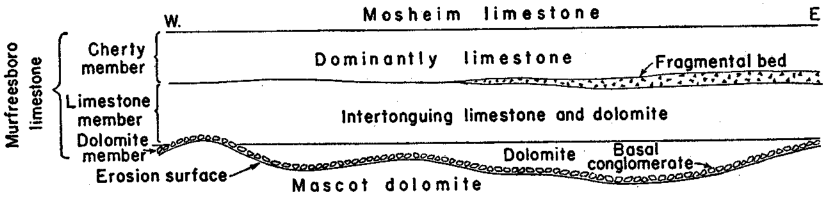

FIGURE 6.—Relation of the dolomite and limestone members of the Murfreesboro limestone to the erosion surface at the top of the Mascot dolomite.

A very interesting Mascot-Murfreesboro contact which is exposed along the road at Blue Hollow (Pl. 1) is illustrated in Plate 16A. A geologic section across the contact at this point is given below:

Section across the Mascot-Murfreesboro contact along the Blue Hollow road.

	Thickness	
	Ft.	In.
Murfreesboro limestone		
9. Limestone, fine grained, slightly argillaceous, with a few chert nodules	3	0
8. Dolomite, argillaceous, with dendrites; contains a few chert pebbles less than 1 inch in length; weathers buff with rounded surfaces	1	1
7. Conglomerate; closely packed pebbles of light-gray dolomite and white to black chalcedonic chert; pebbles slightly rounded; largest dolomite pebbles 6 inches long; largest chert pebbles 5 inches long	1	6
Mascot dolomite		
6. Conglomerate, intraformational, consisting of jumbled light-gray dolomite blocks with a maximum length of 6 inches and chalcedonic chert nodules up to 17 inches long; some chert nodules stand on edge	3	1
5. Dolomite of Mascot type containing thin nodules of white chert	1	6
4. Chert, white, chalcedonic, brecciated; in one gnarled bed		10
3. Conglomerate, intraformational; consists of dolomite pebbles up to 3 inches long, silicified dolomite with dolomolds, and irregular masses of coarse dolomite crystals	3	9

	Thickness	
	Ft.	In.
2. Dolomite, laminated, similar to unit 1 but with a little intraformational conglomerate	1	8
1. Dolomite, in layers, ¼ to 1 inch thick, but forms one massive bed; contains thin chert nodules	2	2

Units 6 and 7 of the above section appear in the photograph (Pl. 16A), in which the Mascot-Murfreesboro contact is about 6 inches above the hammer head. The contact was drawn here because Unit 7 is the first zone containing conglomeratic pebbles which clearly have been transported. Slumping, with accompanying tilting of the enclosed chert nodules, is, however, visible in Unit 6, and this unit, as well as Units 2 and 3, contains partly rounded dolomite pebbles, most and perhaps all of which are of intraformational type.

Thickness.—The thickness of the Murfreesboro limestone, as measured in six sections, ranges from 136 feet to 297 feet. The thinner sections are in the southeastern belt and the thicker in the northwestern belt. Where the Mascot dolomite is less than the average thickness, the Murfreesboro limestone is thickest, indicating that the oldest beds of the Murfreesboro were deposited only in the low areas of the old erosion surface.

Paleontology.—The limestones and argillaceous limestones of the Murfreesboro contain some fossils, many of which, however, are too fragmentary to be identified. *Tetradium* cf. *T. cellulosum,* formerly believed to be confined to the Lowville limestone, is abundant at places in the limestones of the Murfreesboro. A loose slab of unusually well preserved *Tetradium* (Pl. 16B) was collected at Rob Camp Church. The slab was unquestionably derived from the Murfreesboro and probably came from Unit 18 of the measured section at that locality (Geologic Section 6). Fossils identified for this report and those collected and identified by Butts from the Yellow Branch section are shown in Table 2.

Age and correlation.—The Murfreesboro limestone of the Rose Hill area is of Lower Ordovician age. It is known to extend northeastward 25 miles to Pennington Gap, Virginia, and southwestward 15 miles to Gap Creek in Claiborne County, Tennessee, without any radical change in character (Pl. 13). Fifteen miles south of the Rose Hill district along Copper Ridge the Murfreesboro limestone seems to be

TABLE 2.—*Fossils from the Murfreesboro limestone identified for this report, and also fossils from this limestone previously identified from the section at Yellow Branch by Charles Butts*

Rose Hill District (Identified for this report)	Section at Yellow Branch (Identified by Butts)
Cherty Member	
Bolboporites aff. *B. americanus* Billings Cystid plates Bryozoa, ramose *Glyptorthis* sp. *Strophomena* n. sp. Gastropods, unidentifiable *Homotelus?* sp. *Calliops* sp. *Leperditella* sp. Smooth ostracodes	*Tetradium syringoporoides* Ulrich *Hemicistites eckeli* Cullison and Prouty *Helicotoma tennesseensis* Ulrich and Scofield *Oxydiscus catilloides* (Raymond) *Polylopia (Salterella) billingsi* (Safford)? *Oncoceras* aff. *O. constrictum* Hall *Pterygometopus* sp.? *Pterygometopus troosti* (Safford)? *Isochilina*, two species *Leperditella* cf. *L. inflata* Ulrich *Leperditella mundula* Ulrich
Limestone Member	
Tetradium syringoporoides Ulrich Gastropods, unidentifiable	
Dolomite Member	
Tetradium cf. *T. cellulosum* Ostracodes, unidentifiable	*Isochilina* sp. *Primitia* sp.?

present, but it has been described and mapped as "lenses of chert conglomerate" and possibly in part as "basal compact limestone and dolomite," which have there been designated as the lowermost beds of the Chickamauga limestone.[69] The name Chickamauga limestone was used by Rodgers in the Maynardville region for beds between the Mascot dolomite, below, and the Lowville and Moccasin limestones, above.

Long range correlation of the beds assigned to the Murfreesboro limestone in the Rose Hill district is precarious because of insufficient regional stratigraphic information and insufficient knowledge of the faunas in this part of the geologic column. Some new information and

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[69] Rodgers, John, Copper Ridge zinc district (east part), Hawkins, Hancock, and Grainger counties, Tennessee: U. S. Geol. Survey, Strat. Min. Invest., Prelim. Map, 1944.

concepts which may assist in the eventual solution of the correlation problems are presented.

A comparison of a detailed section of the Murfreesboro limestone measured at Murfreesboro, Tennessee, where only the upper 90 feet of the formation are exposed, with the Murfreesboro of the Rose Hill district shows only slight insignificant lithologic resemblances. In both areas dark chert nodules are numerous near the top of the limestone and the beds are only moderately fossiliferous. In contrast with the Murfreesboro of the Rose Hill area, however, the type Murfreesboro has only a few thin beds of birdseye limestone and no argillaceous dolomites or dolomitic limestones. In addition, the type Murfreesboro contains *Camarocladia* which occurs in the Lowville limestone in the Rose Hill district.

Butts[70] correlated the beds between his Beekmantown and Mosheim in southwest Virginia with the type Murfreesboro limestone on the basis of faunal similarity. In northeastern Lee County, Bates[71] did not recognize the Murfreesboro but included the dolomitic part of the formation with the underlying Beekmantown and the limestone part with the Mosheim.

In Butts' report on the Appalachian Valley of Virginia, he introduced the terms St. Clair and Blackford for different facies of the Murfreesboro limestone. The St. Clair facies, which is named from St. Clair railroad station near Bluefield, Tazewell County, Virginia, consists of pure limestone. The Blackford facies, with its type region 4½ miles northwest of Gate City, Scott County, Virginia, is composed of red and gray shale, argillaceous limestone and argillaceous dolomite in the lower 70 feet, and of thin-bedded chert-bearing limestones in the upper 100 to 300 feet. Butts states that, in general, the Blackford facies lies in a belt southeast of the St. Clair facies,[72] which implies that the differences between the facies are due to lithologic gradation from southeast to northwest. There seem, however, to be numerous exceptions to this parallel linear arrangement of the two facies.

In most of the Rose Hill district, the Murfreesboro limestone resembles Butts' description of the Blackford facies more closely than the St. Clair facies because it contains dolomites in the lower part and chert-bearing limestones in the upper part. However, our dolomite member of the Murfreesboro ranges from 0 feet at the mouth of

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[70] Butts, Charles, op. cit., pp. 133-135.

[71] Bates, R. L., Geology of Powell Valley in northeastern Lee County, Virginia: Virginia Geol. Survey Bull. 51-B, pp. 31-94, 1939.

[72] Butts, Charles, op. cit., p. 126.

Martin Creek to about 120 feet at Hagan (Pl. 17). At Yellow Branch, the dolomite member is poorly exposed, and at this locality Butts described all beds in the lower part of the formation as argillaceous limestone. He cites this section as one of the best exhibits of the St. Clair facies,[73] despite the presence of abundant chert nodules in limestones in the upper part of the formation.

We found numerous interbeds of dolomite and argillaceous dolomitic limestone in the lower part of the section at Yellow Branch, but the dolomite member contains somewhat more limestone here than at Hagan and numerous other places in our area. At the mouth of Martin Creek, where the dolomite member is absent, the Murfreesboro limestone would have to be assigned to the St. Clair facies, but at Hagan, where the dolomite member is thick and perfectly exposed, the Murfreesboro would have to be assigned to the Blackford facies.

Within our area we believe the changes in character of the Murfreesboro can be explained best by differences in deposition due to the irregularities of the Mascot erosion surface. The earliest Murfreesboro sediments were dolomitic and argillaceous and were deposited in the low areas of the erosion surface. As these were filled, the character of deposition changed and became less dolomitic, so that the earliest material deposited on the high areas of the old erosion surface is mainly limestone (Pl. 17). Thus no concept of facies changes of equivalent beds is involved.

In Tazewell County Cooper and Prouty[74] have noted similar changes within short distances in the thickness of basal clastics, dolomites, and argillaceous dolomites directly overlying the Beekmantown (Longview, Kingsport and Mascot) dolomite. They likewise attribute these changes to deposition of the basal clastics and dolomites, principally in the low areas of the Beekmantown erosion surface. We suspect that this same explanation may also apply to other supposedly anomalous relations in the distribution of Butts' Blackford and St. Clair facies, such as the situation at the Klotz quarry, north of Ripplemead, Giles County, Virginia, where Butts[75] described a section of the Blackford facies in the midst of a belt of St. Clair facies.

Cooper and Prouty in the publication cited above argue with reason for a new classification of the "lower Middle Ordovician" rocks of the Appalachian Valley. Unfortunately their proposed classi-

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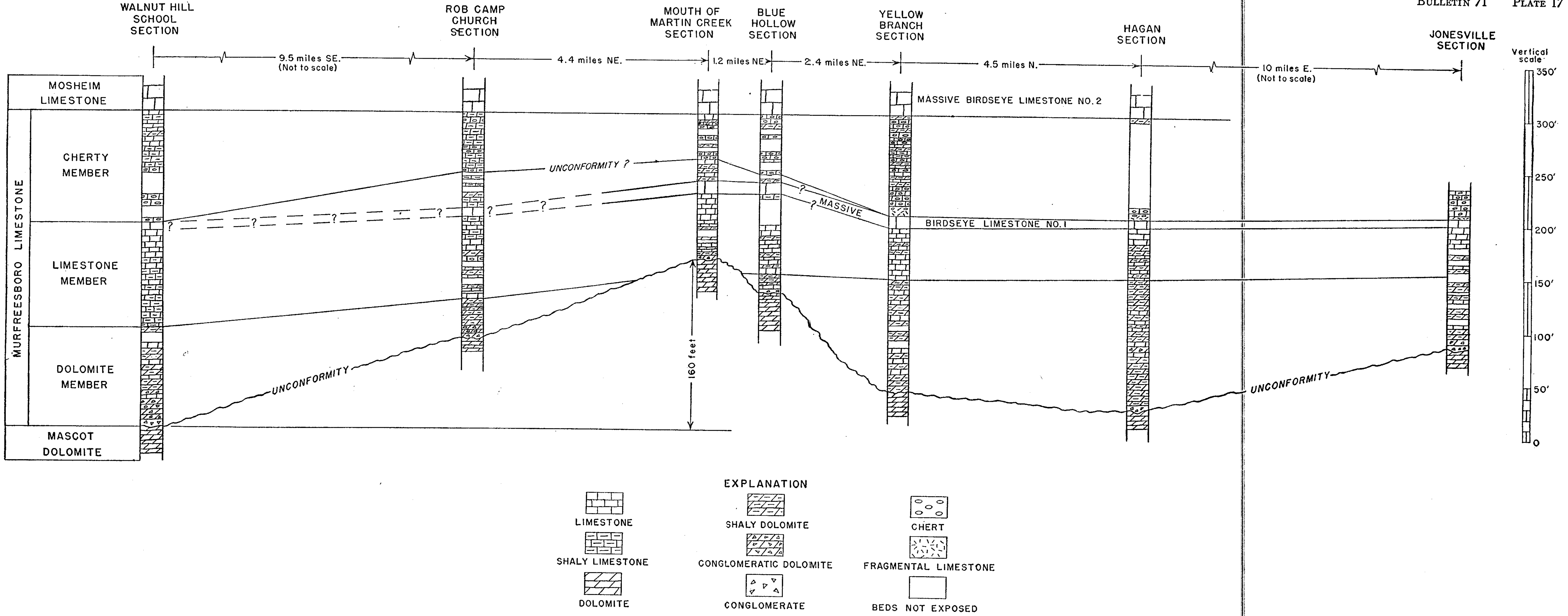
[73] Butts, Charles, op. cit., p. 133.

[74] Cooper, B. N., and Prouty, C. E., Stratigraphy of the lower Middle Ordovician of Tazewell County, Virginia: Geol. Soc. America Bull., vol. 54, no. 6, pp. 823-825, 1943.

[75] Butts, Charles, op. cit., pp. 126, 130-132.



Correlation of sections of the Murfreesboro limestone in and near the Rose Hill district.

fication is not immediately applicable in the Rose Hill region owing to the distances between the areas, to lithologic changes in the sediments, and to unconformities recognized or suspected in the Rose Hill district, which may be of regional scope and influence.

In his analysis of the Murfreesboro fossils collected by us from the Rose Hill district, G. A. Cooper[76] says "My studies elsewhere in the Appalachians indicate that the basal portion of the Murfreesboro formation is actually a correlate of the Lenoir limestone of the type area * * * I am unable to place in any named sequence most of the localities recorded here except F18 to F20 which contains fossils that occur in the 'blocky chert' horizon of Cooper and Prouty." The "blocky chert" horizon of Cooper and Prouty is the top of the Blackford member of their Cliffield formation (Fig. 10). The collections F18 to F20 came from our cherty member of the Murfreesboro.

The Murfreesboro limestone of the Rose Hill region, therefore, is the same as Butts' Murfreesboro limestone of the Appalachian Valley and appears to correlate with the Blackford member of the Cliffield formation of Cooper and Prouty. Our interpretation of these relations is shown in Figure 7.

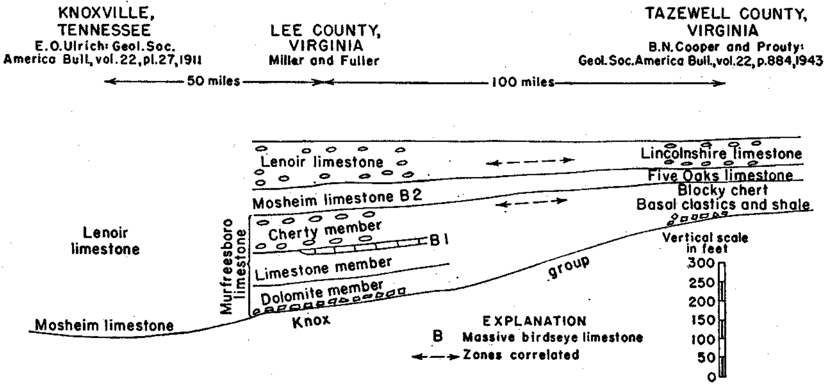


FIGURE 7.—Suggested correlation of the Murfreesboro, Mosheim, and Lenoir limestones of Lee County, Virginia, based on analysis of the faunas by G. A. Cooper.

MOSHEIM LIMESTONE

Name and distribution.—The Mosheim limestone was named by Ulrich[77] from outcrops in a railroad cut 0.8 mile east of Mosheim

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[76] Cooper, G. A., personal communication.

[77] Ulrich, E. O., Revision of the Paleozoic systems: Geol. Soc. America Bull., vol. 22, pp. 413, 414, 538, 543, 544, 557, 636, Pl. 27, 1911.

station on the Southern Railway and 7 miles northwest of Greenville, Greene County, Tennessee. The Mosheim of the Rose Hill district occurs in narrow continuous belts on both limbs of the Powell Valley anticline. In addition, it forms part of a fault slice on the northeast side of the Dean fenster and is exposed in the southern part of the Sugarcamp fensters.

Character.—The Mosheim limestone tends to form either sinkholes or prominent ledges whether in fields or in woods. Both the sinkholes and the ledges owe their existence to the massiveness of the beds, the relative absence of joints and bedding planes, and the purity of the limestone. When it is considered that the main belts of Mosheim lie in broad nearly flat lowlands, the number of outcrops is surprising.

The Mosheim is composed of the type of limestone called massive birdseye limestone. This was described in the section on the Murfreesboro limestone, which contains a zone of massive birdseye limestone designated No. 1 zone. The Mosheim limestone is the thickest and most prominent zone of massive birdseye limestone in the Rose Hill district, and is here designated No. 2 zone. Outcrops of the Mosheim consist of a series of rounded nubbins or massive ledges, most of which show well-developed flutings on weathered surfaces. These flutings converge groundward and normally form a fanlike pattern. The flutings are best developed on inclined surfaces and are formed largely by solution of the limestone by rain water flowing down the bare rock surfaces, although some minor channeling may be caused by solution by vadose water seeping downward through the soil. Except in regions of nearly flat dip, a belt, more than 40 feet wide, of these ghostlike gray nubbins is almost certain to be the Mosheim limestone, because most of the zones of massive birdseye limestone in the Murfreesboro and Lowville limestones are much thinner. Commonly the limestones of the chert-bearing Lenoir limestone and of the cherty member of the Murfreesboro limestone have been dissolved near the surface, so that a belt of nubbins of Mosheim limestone is bounded by two broad belts of chert-bearing soil with no outcrops.

Numerous complete sections of the Mosheim limestone are revealed on the outer meander curves of Powell River. In some of these exposures the Mosheim, surmounted by a cap of basal Lenoir limestone, forms sheer cliffs of massive limestone in which only one or two bedding planes are visible from the base to the top. More prolonged weathering of the same rocks, however, reveals the presence of more closely spaced beds.

The Mosheim is composed of massive cryptocrystalline limestone, which breaks with a typical conchoidal fracture. A hammer blow produces a ringing sound, and the resulting fresh surface has a soft light-brown color. White calcite veinlets and white calcite patches, which have been called "eyes" or "birdseyes," are scattered through the otherwise homogeneous rock. The calcite "birdseyes" average 1/16 to ¼ inch in diameter, but a few attain a diameter of 1¼ inches. The calcite may be yellowish or brown, owing to a coating of limonite formed on cleavage faces during weathering. A photomicrograph showing discoloration of similar calcite birdseye in a massive birdseye limestone of the Lowville limestone is shown in Plate 24A. Some of the calcite patches fill cavities of fossils, especially the body-cavities of medium-spired gastropods. The coarse-crystalline calcite patches are less soluble than the cryptocrystalline limestone, so that they stand in relief on weathered surfaces and give the rock a studded appearance.

In most sections the massive birdseye limestone described above constitutes the entire Mosheim, but locally a few beds of other rock types are included. An argillaceous dolomitic limestone of lower Murfreesboro type occurs as a 17-inch bed in the middle of the Mosheim limestone, in a small area on the south flank of the Powell Valley anticline (Geologic Section 7, Unit 24). Other minor variations from the typical Mosheim lithology include a reddish phase of the birdseye limestone, mottled limestone, dolomitic limestone, and coarse crystalline limestone containing large masses of white calcite.

Stratigraphic relations.—The Mosheim limestone conformably overlies the Murfreesboro limestone. The contact has been drawn at the base of the massive beds of pure limestone and above the thinner bedded and usually less pure limestone of the Murfreesboro. In the eastern part of the area a bed of smooth buff-weathering argillaceous dolomitic limestone is persistent in the upper few feet of the Murfreesboro and helps to place the contact. The Lenoir limestone overlies the Mosheim unconformably. Variations in thickness of the Mosheim are due to erosion along this unconformity, and the unconformable relations are clearly shown in exposures at Walnut Hill School (Fig. 8). Along the contact the pure light-colored Mosheim limestone abuts against a darker-colored less pure limestone typical of the lower Lenoir. The contact is always sharp, and never gradational. In some places it lies within a single ledge and is sealed, so that hand specimens spanning it can be obtained (Pls. 18A and 19A).

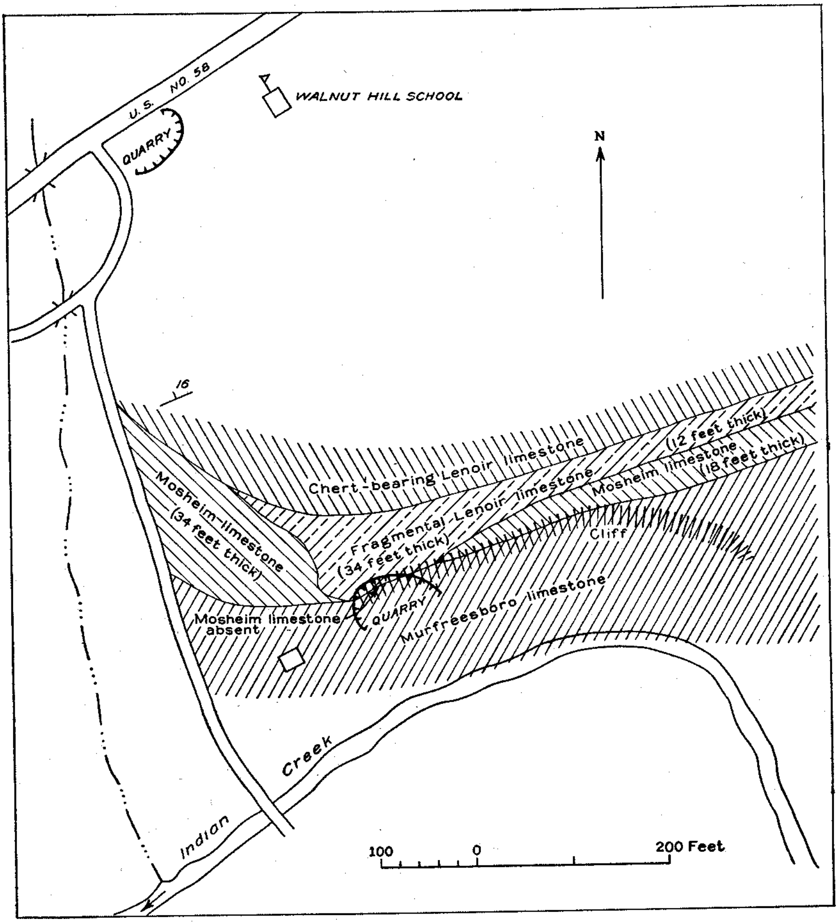

FIGURE 8.—Sketch map of the unconformity at the base of the Lenoir limestone at Walnut Hill School, Lee County, Virginia.

Thickness.—The Mosheim limestone ranges in thickness in measured sections from a thin layer to 136 feet. The thickest sections are found in the southwestern part of the area. The measured thicknesses of the Mosheim at several localities in and near the Rose Hill district (see Pl. 1 and Pl. 13) are listed in Table 3 in order from east to west.

Paleontology.—Fossils are scarce in the Mosheim limestone, but pockets found at some places may be quite fossiliferous, with one or two species of large gastropods the most abundant forms. The fossils weather in relief but do not break free of the compact limestone, so

TABLE 3.—*Measured thicknesses of the Mosheim limestone in and near the Rose Hill district*

NORTHWESTERN BELT		SOUTHEASTERN BELT	
Hagan	72 feet	Yellow Branch	29 feet
Beatty Store	60 feet	Bacon Ford footbridge	47 feet
Walnut Hill School	0 to 34 feet	Martin Creek mouth	83 feet
		Rob Camp Church	136 feet
		Buchanan Ford	60+ feet

that it is difficult to collect identifiable material. Good displays of Mosheim fossils are present 4½ miles northeast of Rose Hill on U. S. Route 58 opposite a small cedar furniture factory. A collection of large gastropods, stem bryozoa, a straight cephalopod, and ostracodes was made in this region, but none of the fossils proved identifiable. *Stromatocerium?* occurs in the Mosheim just below the Mosheim-Lenoir contact, near the mouth of Martin Creek (Pl. 19A). The gastropods *Trochonemella trochonemoides* (Ulrich) and *Lophospira* sp. have been identified by Butts from the Mosheim of the Rose Hill district.

Age and correlation.—The age of the Mosheim is Lower Ordovician, but its correlation is as controversial as the correlation of the Murfreesboro. Solution of the problem requires additional work over a broad area of southwest Virginia and east Tennessee, but some facts may be added to the record as a result of the field work in the Rose Hill area. The correlation problem is composed of two different questions, namely: (1) Shall any other beds besides massive birdseye limestone (vaughanite of Butts, calcilutyte of Cooper and Prouty) be included in the Mosheim, and, if so, what determines the base and top of the formation? (2) In a region containing more than one zone of massive birdseye limestone, which one shall be called the Mosheim? Thus there is a question of the stratigraphic limits and of the stratigraphic position of the Mosheim. Characteristically, the Mosheim in the Appalachian Valley of Virginia is composed of pure, thick-bedded limestone of the type that we have mapped in the Rose Hill district and have called massive birdseye limestone No. 2. This rock type is distinctive, but in some places in southwest Virginia thinner-bedded birdseye limestone has also been included in the Mosheim. When this is done the problem of choosing the limits of the formation becomes difficult because thin beds of limestone of this type are abundant, extending from a position low in the Murfreesboro limestone upward through the Lowville limestone. An example of the problem of placing the Mosheim contacts is seen in Butts' section, at South Fork of Buffalo Creek, Rockbridge County, Virginia, part of which is given below.[78]

Murfreesboro, Mosheim and Lenoir limestones at the South Fork of Buffalo Creek, Rockbridge County, Virginia

(Measured by Charles Butts)

	Thickness Ft.	Thickness In.
Lenoir limestone		
15. Slope covered with chert debris		
Mosheim limestone (102+ feet)		
14. Limestone, compact, vaughanitic, with much chert	30	
13. Limestone, thick bedded, compact, vaughanitic, bluish gray	60	
12. Limestone, thin bedded, curly limestone partings	6	
11. Limestone, thick bedded, argillaceous; a layer 2 inches thick, 2 feet above the bottom crowded with gastropods; scattered angular fragments of chert in basal bed	6	
Murfreesboro (?) limestone (28+ feet)		
10. Limestone, blue	2	6
9. Limestone, argillaceous	1	8
8. Limestone, blue	3	
7. Limestone, argillaceous, many angular chert fragments in basal bed	9	
6. Limestone, argillaceous	8	
5. Shale	4	
Beekmantown formation		

Concerning the difficulty of drawing a Mosheim-Murfreesboro contact in this section, Butts states: "It could be reasonably thought that beds 5 to 12 represent the thinned Murfreesboro . . . . The occurrence of the beds with angular fragments of chert, like those at the base of the Murfreesboro, and necessarily derived from the underlying Beekmantown, strongly suggests this conclusion."[79]

Usually the Mosheim-Lenoir contact is less difficult to recognize because, in places, a good unconformity may be noted and commonly a

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[78] Butts, Charles, op. cit., p. 137

[79] Butts, Charles, op. cit., p. 138.

sharp change takes place from light-tan or gray birdseye limestone of the Mosheim to dark-gray cryptocrystalline or fine- to coarse-crystalline limestone of the Lenoir. Furthermore, in the Rose Hill district, the Lenoir limestone is abundantly chert-bearing, whereas the Mosheim limestone in most places contains no chert whatever. Our experience thus supplies no clue as to why Butts included Unit 14 in his Buffalo Creek section with the beds assigned to the Mosheim rather than with the overlying chert-bearing beds assigned to the Lenoir.

In northeastern Lee County Bates[80] also encountered difficulty in finding clear-cut limits to the Mosheim. He described a section at Deep Creek School, which is quoted below.

Mosheim limestone south of Deep Spring School, northeastern Lee County, Virginia

(Measured by Robert L. Bates)

	Thickness Feet
Lenoir limestone	
Limestone, dark colored, granular, slabby	
Mosheim limestone (72 feet)	
6. Limestone, light to medium gray, vaughanitic, pure, in beds 8 to 10 inches thick	20
5. Limestone, dense, argillaceous, in thin beds with clay partings	4
4. Limestone, light gray, vaughanitic, pure, in massive beds	12
3. Limestone, medium to dark gray, vaughanitic to dense granular, with a little chert	8
2. Limestone, dark, fine grained, with much black chert in beds and flattened nodules	10
1. Limestone, light to medium gray, vaughanitic, pure, in massive beds from 1 to 4 feet thick; weathers light blue gray with a rough surface	18
Covered (top of Beekmantown)	

We have studied the section at this locality and feel that Bates' Units 1 to 3 represent our cherty member of the Murfreesboro limestone. Bates does not map the Murfreesboro limestone but has included in his Beekmantown dolomite (Longview, Kingsport, and Mas-

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[80] Bates, R. L., Geology of Powell Valley in northeastern Lee County, Virginia: Virginia Geol. Survey Bull. 51-B, p. 46, 1939.

cot dolomites of this report) the beds that we would place in the dolomite member of the Murfreesboro, and he has included in his Mosheim, beds that we would place in the limestone and cherty members of the Murfreesboro. He states, however, that several species of *Pterygometopus* were collected from beds close above the Beekmantown and that it "is a characteristic fossil of the Murfreesboro formation, which at some localities in Virginia and Tennessee intervenes between the Beekmantown and the Mosheim."[81]

In order to determine the lithology of the type Mosheim we visited the exposure near Mosheim, Greene County, Tennessee and measured the section here given:

Mosheim limestone along Southern Railroad 1.0 mile west of Mosheim Station, Greene County, Tennessee

	Thickness	
	Ft.	In.
Athens shale		
10. Shale, gray to brown, chippy, with some fine-grained, gray, platy limestone	125±	
Lenoir limestone (39 feet)		
9. Limestone, coarse crystalline, fragmental, dark brownish gray, laminated	11	2
8. Limestone, largely covered, dark gray fine to coarse crystalline, nodular, with shaly partings	28	0
Mosheim limestone (78 feet)		
7. Covered	8	0
6. Limestone, massive, light bluish gray, birdseye type, with calcite eyes, and stringers; abundant gastropods	13	2
5. Covered zone across railroad tracks; one bed of mottled ribbon to nodular limestone at base	49	7
4. Limestone, conglomeratic; limestone pebbles, one half inch or less in length, in matrix of impure laminated fine-grained limestone	3	8
3. Covered	3	0
2. Limestone, conglomeratic; small angular pebbles of limestone in light brownish-gray dense fine-grained limestone	1	1
Knox group		
1. Limestone, fine grained, bluish gray, laminated, dolomitic	2±	

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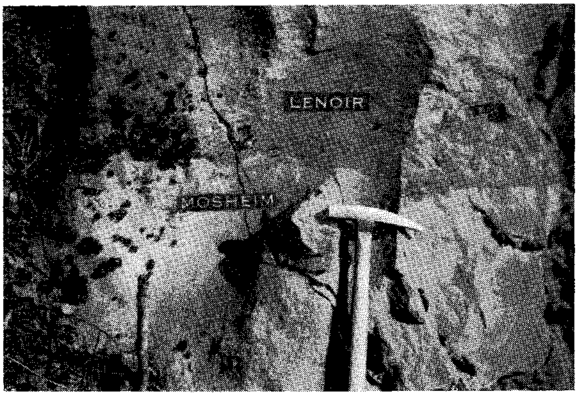
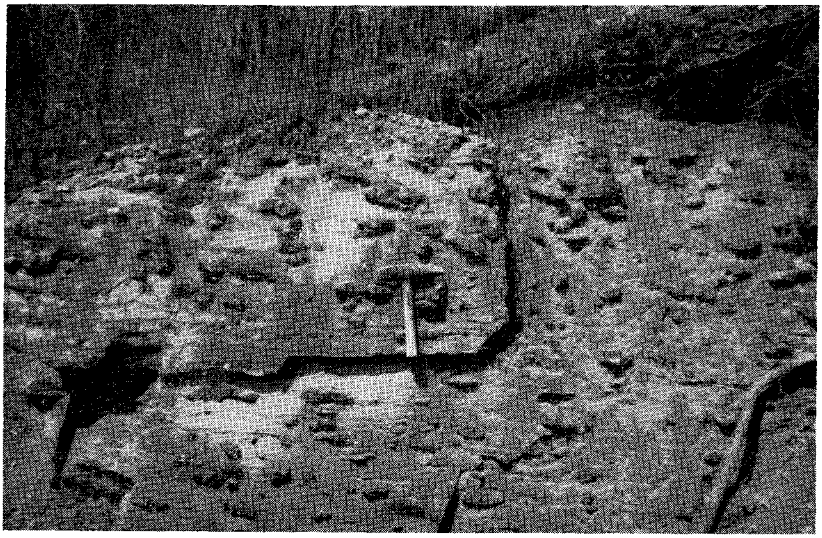
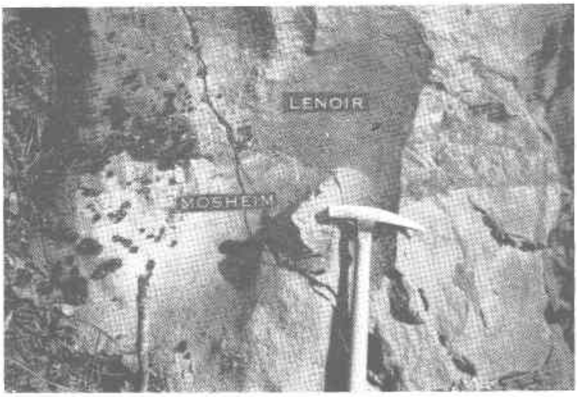
[81] Bates, R. L., op. cit., p. 47.



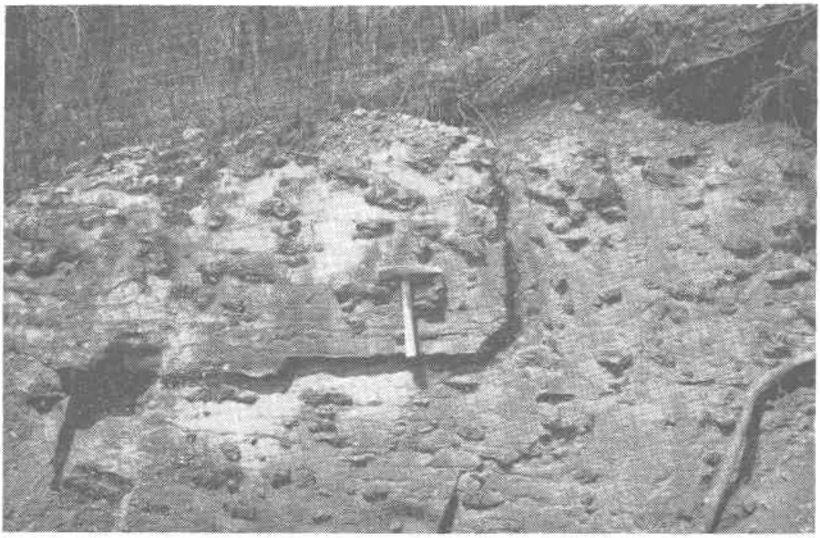
A, Sealed and wavy Mosheim-Lenoir contact just above hammer in the section at Yellow Branch.



B, Chert nodules in the dark-colored limestones of the lower part of the Lenoir limestone along the Powell River road northeast of the Yellow Branch crossing.



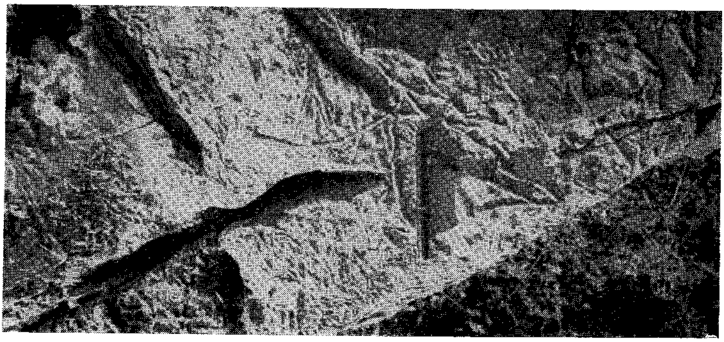
A, Sealed and wavy Mosheim-Lenoir contact just above hammer in the section at Yellow Branch.



B, Chert nodules in the dark-colored limestones of the lower part of the Lenoir limestone along the Powell River road northeast of the Yellow Branch crossing.

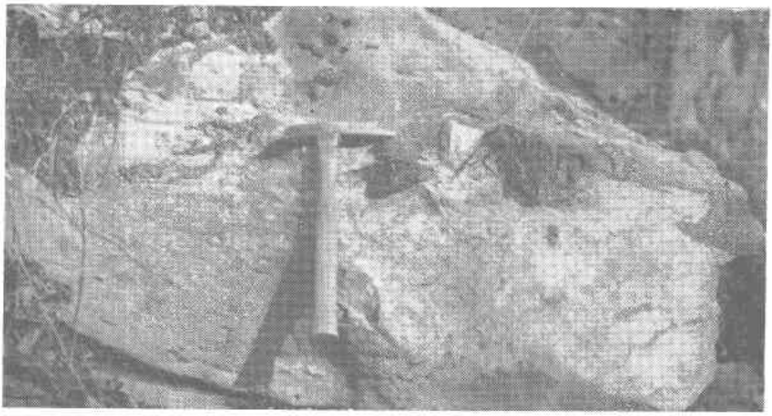
A

B



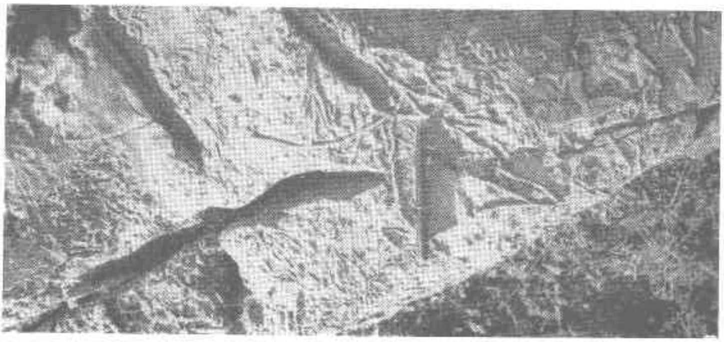
C

A, Irregular, sealed contact of Mosheim limestone, below hammerhead, and Lenoir limestone, above hammerhead, along road north-northeast of the mouth of Martin Creek. B, Contact of Lenoir limestone (below) and Lowville limestone (above) along the L. & N. R. R. 2 miles west of Ewing. Hammer (indicated by arrow) marks the contact. C, *Camarocladia* beds in the platy member of the Lowville limestone in a small quarry at Chattels Station Church.



A

B



C

A, Irregular, sealed contact of Mosheim limestone, below hammerhead, and Lenoir limestone, above hammerhead, along road north-northeast of the mouth of Martin Creek. B, Contact of Lenoir limestone (below) and Lowville limestone (above) along the L. & N. R. R. 2 miles west of Ewing. Hammer (indicated by arrow) marks the contact. C, *Camarocladia* beds in the platy member of the Lowville limestone in a small quarry at Chattels Station Church.

The type Mosheim thus includes impure and nodular limestones at the base and has a zone of massive birdseye limestone at the top. Only 13 feet of massive birdseye limestone is exposed, but probably part of the 57 feet of covered zone represents this type of rock. Large gastropods are present in the birdseye limestone, but most of them are different from those found in the Mosheim limestone of the Rose Hill district. The sequence at Mosheim is different from that in our district, because the Mosheim there lies directly on the Knox. Throughout a considerable part of southwestern Virginia, Butts' Mosheim lies on chert-bearing beds called by him Murfreesboro, and is overlain by chert-bearing beds which he calls Lenoir. The Mosheim between the two would thus seem to be the same as our Mosheim in the Powell Valley.

Cooper and Prouty[82] are of the opinion, however, that Butts has applied the name Mosheim to zones of birdseye limestone at different stratigraphic positions. Prouty studied the section at Yellow Branch and noted "two zones of Mosheim-looking calcilutyte (vaughanite), one below the *Polylopia billingsi* fauna and directly above the blocky chert zone. The other is that identified by Butts and Ulrich as the Mosheim."[83] The only bed of birdseye limestone below the *Polylopia* (*Salterella*) *billingsi* fauna identified by Butts and above the chert-bearing beds is unit 27 of Butts' section;[84] it is only 3 feet 6 inches thick (Fig. 9). Numerous other beds of dense fine-grained limestones with equal or greater thicknesses are present throughout the Murfreesboro limestone and this bed would hardly be called "Mosheim-looking." It seems more likely that the zone Cooper and Prouty intended to refer to is that covered by units 11 to 13 in Butts' section, although these units lie below the chert-bearing beds. These units include 26 feet of dense, fine-grained limestone. In either case, however, the beds underlie *Polylopia billingsi,* which is supposed to be a guide fossil for the type Murfreesboro. Cooper and Prouty describe two Mosheim-like "calcilutytes" in Tazewell County, Virginia, which are separated by beds with *Polylopia billingsi,* and they conclude: "From the striking similarity in stratigraphic succession of zones at Yellow Branch in Lee County and in Tazewell County, one may infer that the lowest calcilutyte zone at Yellow Branch corresponds to the first calcilutyte zone

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[82] Cooper, B. N., and Prouty, C. E., Stratigraphy of the lower Middle Ordovician of Tazewell County, Virginia: Geol. Soc. America Bull., vol. 54, p. 850, 1943.

[83] Cooper, B. N., and Prouty, C. E., op. cit., p. 852.

[84] Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. I, Geologic text and illustrations, p. 121, 1940.

in Tazewell County and that the second calcilutyte of Tazewell County is the same as that identified by Ulrich and Butts at Yellow Branch as Mosheim . . . . . . That two zones exist, both at Yellow Branch and in Tazewell County, reveals a possible error by Ulrich and Butts in their identification of the Mosheim at Yellow Branch . . . . . ."[85] This view has been restated by Cooper[86] in a recent paper.

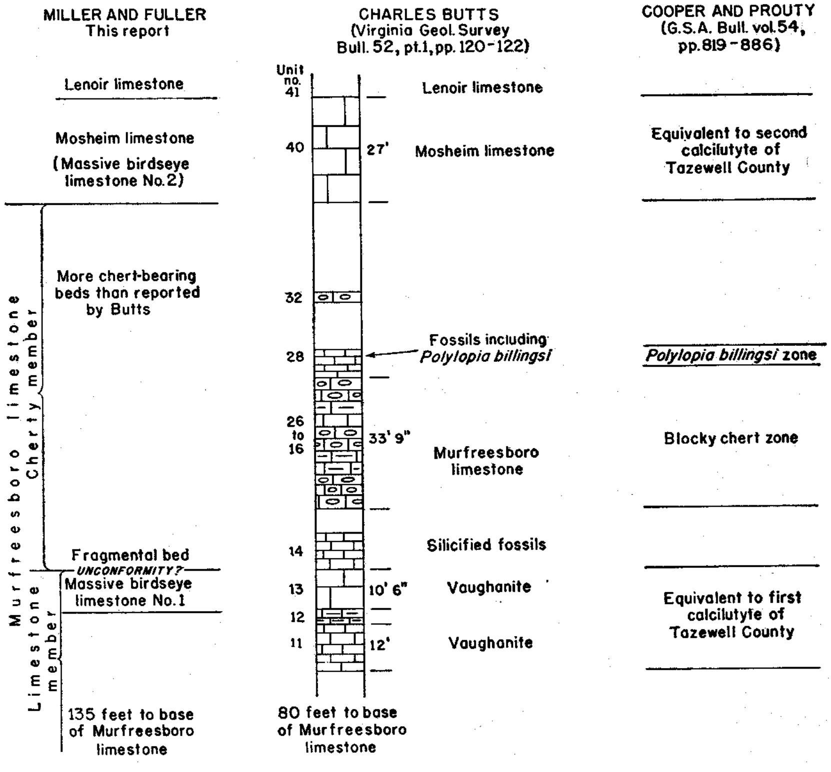

FIGURE 9.—Interpretations of the middle part of the section of Murfreesboro limestone at Yellow Branch, Lee County, Virginia.

We do not agree with these conclusions. Units 11 and 12 in Butts' section of the Murfreesboro limestone at Yellow Branch are composed of fine-grained limestone in beds less than 2 feet thick and they contain some argillaceous limestone. Neither of these types of limestone is particularly "Mosheim-like" and beds of both types are common throughout the limestone member of the Murfreesboro. Unit

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[85] Cooper, B. N., and Prouty, C. E., op. cit., pp. 852, 853.

[86] Cooper, B. N., Stones River equivalents in the Appalachian region: Jour. Geology, vol. 53, no. 4, p. 270, 1945.

13 of Butts,[87] which he lists as 10 feet 6 inches thick, contains 9 feet of rock which has been designated by us massive birdseye limestone No. 1. Plate 15B shows the field relation of massive birdseye limestone No. 1 to the overlying massive birdseye limestone No. 2, the Mosheim limestone of this report. Units 11 and 12 are not distinctive throughout the area. Unit 13 is persistent as an easily recognized unit over only part of our area; it loses its identity westward and could not be found in the section at Rob Camp Church (Geologic Section 6), 8 miles southwest of Yellow Branch. It has a maximum thickness of 11 feet 6 inches at the mouth of Martin Creek, and thins in an eastward direction to 9 feet at Yellow Branch and 7 feet at Jonesville, 11 miles east of Yellow Branch. A rock unit, which is not persistent enough to be recognizable everywhere within an area as small as the Rose Hill district and which thins both to the east and west, cannot, with safety, be correlated on the basis of lithology with another unit several times as thick 100 miles away.

G. A. Cooper, who studied our Ordovician faunas, states that fossils collected by us from beds between our massive birdseye limestone No. 1, near the top of the limestone member of the Murfreesboro, and massive birdseye limestone No. 2 (Mosheim) "occur in the 'blocky chert' horizon of B. N. Cooper and Prouty" (Fig. 10), and that it is possible to recognize the Lincolnshire limestone of Cooper and Prouty in 11 faunules from various parts of our Lenoir limestone. Thus, beds below and above our Mosheim appear to correlate with beds below and above the first calcilutyte (Five Oaks limestone of Cooper and

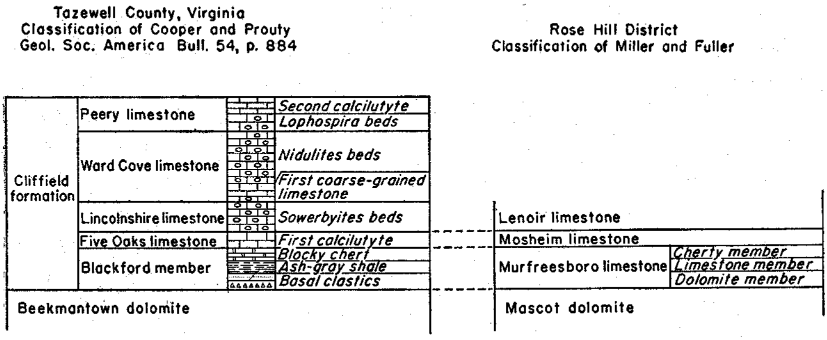

FIGURE 10.—Classification of oldest post-Knox beds in Tazewell County, Virginia, by B. N. Cooper and C. E. Prouty compared with classification used in this report. The dashed lines connecting the sections represent the authors' interpretation of the correlation between the two areas.

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[87] Butts, Charles, op. cit., p. 122.

Prouty) in Tazewell County, and Butts' identification of the Mosheim in the two localities appears to have been correct.

Our conclusions may be summarized as follows:

1. Six prominent zones of massive birdseye limestone occur in the Lower and Middle Ordovician sequence in the Rose Hill district.
2. Butts was correct in his identification of the second massive birdseye limestone of the section at Yellow Branch as the Mosheim of Virginia.
3. The Mosheim of Butts at Yellow Branch correlates with the Five Oaks limestone of the Cliffield formation of Cooper and Prouty in Tazewell County.
4. Butts was correct in stating that the Mosheim of Virginia overlies the Murfreesboro of Virginia.

LENOIR LIMESTONE

Name and distribution.—The Lenoir limestone receives its name from Lenoir City, Tennessee, 75 miles southwest of Rose Hill.[88] In the Rose Hill district the Lenoir forms continuous belts on both flanks of the Powell Valley anticline, and short narrow belts of the Lenoir are also found in fault slices in the Dean fenster and the southern Sugarcamp fensters.

Character.—The Lenoir limestone is the least resistant of the formations that make up the lowland belts of the Rose Hill district. On the northwestern flank in the Indian Creek lowland good outcrops are rare, but on the southeastern flank dissection of the Powell River lowland by Powell River and its tributaries has exposed numerous ledges and some sheer cliffs of Lenoir. In spite of the scarcity of outcrops, the Lenoir limestone is readily mapped because of the extremely abundant blocks of chert in the soil derived from it.

In the southeastern belt, the Lenoir commonly underlies broad chert-covered fields bounded on the northwestern side by big nubbins of Mosheim limestone and on the southeastern side by small ledges of the Lowville limestone. In many places, the ledgy outcrop areas of the Lowville limestone have been left in woodland, and the northwest sides of these wood lots follow the Lenoir-Lowville contact with remarkable consistency. The outcrop belt of the Mosheim limestone

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[88] Safford, J. M., and Killebrew, J. B., The elementary geology of Tennessee, pp. 108, 123, 130-131, 137, Nashville, Tennessee, 1876.

may also have been left in woodland, especially where it is broad. On the northwestern flank of the Powell Valley anticline, the belt of the Lenoir limestone is not so conspicuous because the adjacent Mosheim and Lowville limestones have few outcrops and because the full width of the limestone lowland is cultivated.

The basal beds of the Lenoir are characteristically dark gray in color. Those basal beds that were deposited in low areas of the pre-Lenoir erosion surface are fragmental and have a few dark fine-grained chert-bearing beds overlying them. Above the dark beds, there is a sequence of interbedded chert-bearing and chert-free light-colored limestones, which make up the remainder of the formation.

The basal beds commonly contain abundant small and medium-sized fragments of bryozoans, crinoids and brachiopods. These form a coquina-like rock composed of numerous small chips of crystalline calcite. Normally the rock is cross-bedded and locally it has small limestone pebbles at the base. We refer to this rock-type as fragmental limestone to differentiate it from the coquinal limestone of the Trenton limestone. Fragmental limestone was also described at the base of the cherty member of the Murfreesboro limestone, but that zone of fragmental limestone is thinner and less widespread than is the fragmental limestone in the basal Lenoir. On both fresh and weathered surfaces the rock is usually dark-colored, but coarse-crystalline light-brown material is present locally. Normally the fragmental beds are chert-free, but in some localities a few dark-gray chert nodules may contain non-fragmentary silicified fossils. Weathering causes some fragments to stand in relief and gives the rock a fine-textured rough surface. The fragmental limestone is apparently a channel-filling formed when the first invasion of the Lenoir sea swept a mass of shells into the depressions of the pre-Lenoir erosion surface. This interpretation is supported by the fact that the fragmental beds seem to be very thin or absent at localities where the Mosheim is unusually thick (Fig. 8) and thus stood as high areas. At places a second fragmental bed lies above the basal bed and is separated from it by fine-crystalline dark-gray limestone. In the Rose Hill district the fragmental beds, where present, range in thickness from a thin film to 34 feet.

Above the fragmental limestone, or directly overlying the Mosheim where the fragmental beds are absent, are dark limestones that carry abundant chert nodules and lenses (Pl. 18B). The dark limestones are commonly fine-crystalline to dense with conchoidal fracture, but some beds are coarse-crystalline. They may contain "birdseyes" of calcite. The dark color of the limestone is apparently due to organic matter of various types, for some carbon streaks are visible and normally the rock has a petroliferous odor after fresh fracture. One specimen found at Hagan had a black sticky oily film on a fresh surface. The chert occurs in oval nodules which lie in parallel layers and which range from 2 to 4 inches in length. Along some beds the chert is so abundant that nodules have coalesced to form hummocky beds of chert which may be solid or may contain numerous oval holes. The chert on fresh surfaces is dark-gray to black, and well-shaped nodules commonly show concentric color-banding. After weathering the chert is dark-gray to white, but may be tinged with orange on the outer surfaces. Numerous joints nearly at right angles to one another cut the chert beds and nodules, so that the pieces of chert in the soil of the Lenoir limestone are very blocky, with several smooth flat faces and one or more rounded surfaces which represent the outside of the original nodule or bed. Although numerous undulatory partings are visible in weathered ledges, the dark-colored limestones commonly form massive units several feet thick between major bedding planes. The zone of dark-colored limestones in the Lenoir varies from 20 to 40 feet thick.

The upper part of the Lenoir limestone is composed of interbedded light-colored chert-free and chert-bearing compact limestones which have a conchoidal fracture. These rocks, when relatively pure, are light brownish-gray on fresh surfaces, and weather light blue-gray. Argillaceous beds are, however, quite common especially near the top of the limestone. They weather to a buff color, and may show mud cracks. The purer beds contain abundant chert nodules and lenses that are similar in every respect to those in the underlying zone of dark-colored limestone. Near the top of the Lenoir limestone a bed, 1 to 1½ feet thick, is commonly present, whose lithologic character is much more typical of the Murfreesboro than of the Lenoir. It is a greenish-tan argillaceous dolomitic limestone which weathers to a buff color and has characteristic well-rounded surfaces. Also near the top of the Lenoir there are commonly several beds of pure compact conchoidally-fracturing limestone 1 to 2 feet thick, which stand out from the argillaceous beds because of their purity and thickness. The zone of light-colored limestones is about 70 feet thick.

Stratigraphic relations.—The Lenoir limestone lies unconformably on the Mosheim limestone in the Rose Hill district. Variations in thickness of the Mosheim indicate maximum relief on the pre-Lenoir erosion surface of about 140 feet. The character of the unconformity and its relation to the overlying fragmental and dark-colored limestones are best seen near Walnut Hill school on U. S. Route 58, 4½ miles west of the western limit of the mapped area. In the sketch map of this area (Fig. 8) it will be noted that at the southern quarry the Mosheim limestone has been eroded completely and fragmental Lenoir limestone lies on the Murfreesboro limestone. To the west of the quarry the Mosheim thickens rapidly to a maximum of 34 feet at which point there are no fragmental beds between the Mosheim and the dark chert-bearing Lenoir. To the east of the quarry the Mosheim thickens more slowly and at the east edge of the map 18 feet of Mosheim is overlain by 12 feet of fragmental beds (Lenoir) which are in turn overlain by dark fine-crystalline chert-bearing limestone (Lenoir). At this locality it is apparent that over a distance of several hundred feet horizontally the pre-Lenoir erosion surface had a relief of 34 feet, and the first deposits of Lenoir were of the fragmental type and were confined to the lower area of the erosion surface.

Wherever the exact contact between the Mosheim and Lenoir has been seen, it lies within a single ledge and is so tightly sealed that it is possible to collect a hand-specimen that spans the contact (Pl. 18A). The contact is very irregular and the dark fine- to coarse-crystalline Lenoir limestone lies on the light-colored Mosheim. A thin section across the contact showed the presence of a stylolite along the contact, thus indicating some solution and recrystallization, which probably partly explains the sealed character of the contact. Plate 11F is a photomicrograph of a thin section across the contact. In grinding the thin section, the stylolitic material along the contact tore out leaving a gap in the slide. To the right of the gap in the section is fragmental limestone (Lenoir) made of fossil fragments of medium crystalline calcite, whereas to the left is the typical very fine-crystalline birdseye limestone of the Mosheim with scattered eyes and veinlets of coarse-crystalline calcite.

A similar, irregularly sealed Mosheim-Lenoir contact is illustrated by Butts[89] from a quarry one mile east of Staunton, Augusta County, Virginia. In his description of the plate he states "This kind of contact of the two formations has been observed at several places in the Valley through a distance of several hundred miles."[90] Butts suggests that the extreme irregularities of the contact may be due to "subaerial

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[89] Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. I, Geologic text and illustrations, Pl. 33-B, 1940.

[90] Butts, Charles, op. cit., p. 168.

rill marks or channels caused by rainwater trickling over a rounded surface of limestone."[91]

One unusual Mosheim-Lenoir contact is exposed along the road 1250 feet north-northeast of the mouth of Martin Creek (Pl. 19A). The dense birdseye limestone of the Mosheim is slightly pinkish and contains several *Stromatocerium*-like fossils, the best of which is a foot to the right of the hammer point just below the contact. Above the very irregular contact the Lenoir is dark-colored and fragmental. Along the right edge of the ledge the dark-colored Lenoir limestone projects downward into the Mosheim limestone and actually underlies a small projection of the Mosheim. It would appear that the Lenoir here had filled an irregular solution opening on the weathered surface of the Mosheim. Along Hardy Creek near Hagan the Lenoir near the contact with the Mosheim has a few mottled very fine sandy stringers, which show best on weathered surfaces. The Lenoir is conformably overlain by the Lowville limestone.

Thickness.—The Lenoir limestone ranges in thickness from 97 to 128 feet. Much of this variation is believed to be due to the presence in some places and absence elsewhere of beds at the base of the formation that represent the fillings of the channels on the pre-Lenoir erosion surface. Some of it is apparently due to westward thinning of the whole formation.

Paleontology.—The Lenoir limestone has a fairly abundant and varied fauna but the fossils are firmly embedded in the rock so that it is difficult to collect good specimens. In the fragmental bed and the overlying dark fine-grained limestone, bryozoa, crinoid stems, and brachiopods are especially abundant and unidentified straight cephalopods are common. Fossils identified from the Lenoir for this report and by Butts from the Yellow Branch section are listed in Table 4. The presence of *Tetradium cellulosum,* formerly considered one of the guide fossils of the Lowville limestone, is of special interest.

Age and correlation.—The Lenoir limestone of the Rose Hill area is of Lower Ordovician age. It is believed to be largely and perhaps entirely identical with the Lenoir described by Butts for the Appalachian Valley of Virginia. Butts' Lenoir is lithologically and faunally similar to ours and in most regions rests on the Mosheim limestone with the same type of sealed contact as noted in our area. His Lenoir is overlain, however, by different formations in different

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[91] Butts, Charles, op. cit., pp. 139-140.

TABLE 4.—*Fossils identified from the Lenoir limestone of the Rose Hill district*

ROSE HILL DISTRICT (Identified for this report)	SECTION AT YELLOW BRANCH (Identified by Butts)
Girvanella sp.	*Batostoma* sp.
Tetradium cellulosum (Hall)	*Crepipora* cf. *C. perampla* Ulrich
Tetradium cf. *T. cellulosum* (Hall)	*Mesotrypa* sp.
Silicified trepostome bryozoan	*Nicholsonella pulchra* Ulrich
Camarella aff. *C. varians* Billings	*Nicholsonella* sp.
Multicostella cf. *M. saffordi* (Hall and Clarke)	*Pachydictya* cf. *P. robusta* Ulrich
Schizambon sp.	*Rhinidictya trentonensis* (Ulrich)
Strophomena tenuitesta Willard	*Camarella varians* Billings
Strophomena sp.	*Mimella* sp.
Illaenus sp.	*Rafinesquina champlainensis* Raymond
Isochilina aff. *I. armata* (Walcott)	
Leperditia fabulites (Conrad)	
Leperditia sp.	

regions. Southeast of Clinch Mountain the overlying formation is the Athens shale or Whitesburg limestone and westward toward the Rose Hill district the successive overlying formations are the Holston limestone, the Ottosee limestone and the Lowville limestone. If, as Butts suggests, a hiatus exists between the Lenoir and the next overlying formation, then the greatest break in southwest Virginia would be in our area where the Holston, Whitesburg, Athens, and Ottosee (or Sevier), are absent and the Lenoir is overlain by the Lowville.[92] In the Rose Hill district, however, the Lenoir and Lowville seem to be conformable and near the contact the only lithologic distinction between the two is the absence of chert in the Lowville. The restricting of the Lenoir to the abundantly chert-bearing limestones is in accordance with Butts' usage of the term, but in view of the absence of any visible hiatus above the chert-bearing beds and the presence of several beds containing numerous chert nodules in the lower part of the Lowville, doubt exists whether the top of the abundantly cherty beds represents a constant horizon over broad areas. G. A. Cooper[93] who studied our Lenoir fauna states: "It is possible to recognize the Lincolnshire limestone of B. N. Cooper and Prouty in localities H 1 to 8, 11, 12, 14. This limestone is the Lenoir of Butts * * * ." Inasmuch as *Sowerbyites* and several other fossils common in B. N. Cooper's and Prouty's Lincolnshire have not been found in the Lenoir of the Rose

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[92] Butts, Charles, personal communication.
[93] Cooper, G. A., personal communication.

Hill district, G. A. Cooper does not, however, consider the paleontologic evidence for this correlation completely unequivocal. In summary, the Lenoir of the Rose Hill area is approximately the same as the Lenoir of Butts in southwest Virginia, and probably correlates with the Lincolnshire of B. N. Cooper and Prouty in Tazewell County, Virginia.

At Lenoir City, Tennessee, the Lenoir limestone lies directly on the Knox dolomite. Several feet of coarse fragmental beds overlie the contact, above which are about 300 feet of massive beds of dark-gray fine-crystalline noncherty characteristically nodular limestone. Another diagnostic feature of type Lenoir is an abundance of *Maclurites magnus*. In the Rose Hill district a very few beds in the Lenoir limestone have a nodular appearance, but this feature is here not characteristic of the Lenoir. *Maclurites* was not found by us, although Huffman[94] reports a few specimens from Lee County.

LOWVILLE LIMESTONE

Name.—The name Lowville has been used by writers in various ways since its original definition in New York State.[95] In Lee County, Virginia, it has been applied by Butts to all beds overlying the Lenoir limestone and underlying the Eggleston limestone, but to the east in Scott County, Butts recognizes that the red Moccasin limestone is the equivalent of the upper part of his Lowville of Lee County. The Moccasin equivalents are here treated as a separate formation under that name, and the term Lowville is restricted to the pre-Moccasin beds, whose thickness amounts to about two-thirds of the Moccasin-Lowville sequence.

Two members of the Lowville limestone (restricted) have been mapped in the Rose Hill district, but the sequence is capable of still further subdivision. In Tazewell County, several new formation names have been proposed[96] for beds at least partly equivalent to those described here under the Lowville but correlations between the two areas are not established, and the Tazewell County names are, therefore, not applied in the Rose Hill district.

Distribution.—Two belts on opposite flanks of the Powell Valley anticline form the outcrop areas of the Lowville limestone in the

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[94] Huffman, G. G., Middle Ordovician limestones from Lee County, Virginia to central Kentucky: Jour. Geology, vol. 53, no. 3, p. 150, 1945.

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

[96] Cooper, B. N., and Prouty, C. E., op. cit.

Rose Hill district. Each is about 9 miles long, and extends from the southwest to the northeast edges of the district. The northern belt averages about 0.2 mile in width, whereas the southern belt, because of gentler dips, is from 0.4 mile to more than a mile in width.

In addition the Lowville limestone crops out prominently in the Sugarcamp fensters, where the beds are folded and faulted so that the normal stratigraphic sequence is lost. Two small slivers of Lowville rocks have been dragged along major fault planes and are now exposed near the southeast corner of the Fourmile fenster.

Topographic character.—The Lowville limestone has abundant outcrops in the southern belt especially along and near the Powell River. Zones of massive birdseye limestone (see p. 65), in particular, form steplike ledges in the flat areas and along the crests of the meander spurs, but the thinner-bedded limestones are also widely exposed. This characteristic of the Lowville contrasts very sharply with the underlying Lenoir limestone, which has almost no outcrops. Cedars flourish on the ledgy areas of Lowville limestone and the north edge of the cedar woods in many places follows almost exactly the Lenoir-Lowville contact. At places along the river the Lowville limestone forms steep to vertical cliffs.

On the north flank of the Powell Valley anticline the Lowville has few outcrops, largely because of less active erosion and consequent deeper weathering. Even the zones of massive birdseye limestone are poorly exposed. Here almost all the outcrop area of the Lowville is nearly flat or gently rolling and is cultivated. However, near the northeast corner of the Rose Hill district, the lowland belt is dissected by the headwaters of Hardy Creek, where the Lowville has ledgy outcrops similar to those on the south flank of the Powell anticline.

REDBED MEMBER

Name.—The Lowville limestone in the Rose Hill district has been divided into two members of approximately equal thickness, the redbed member below and the platy member above. These members were mapped separately throughout the district. The lower member is referred to as the redbed member because of the presence within it of several argillaceous zones, which are red at many places. Quantitatively the argillaceous beds make up only a small part of the member, but they are especially distinctive and most of the argillaceous zones are readily mappable units.

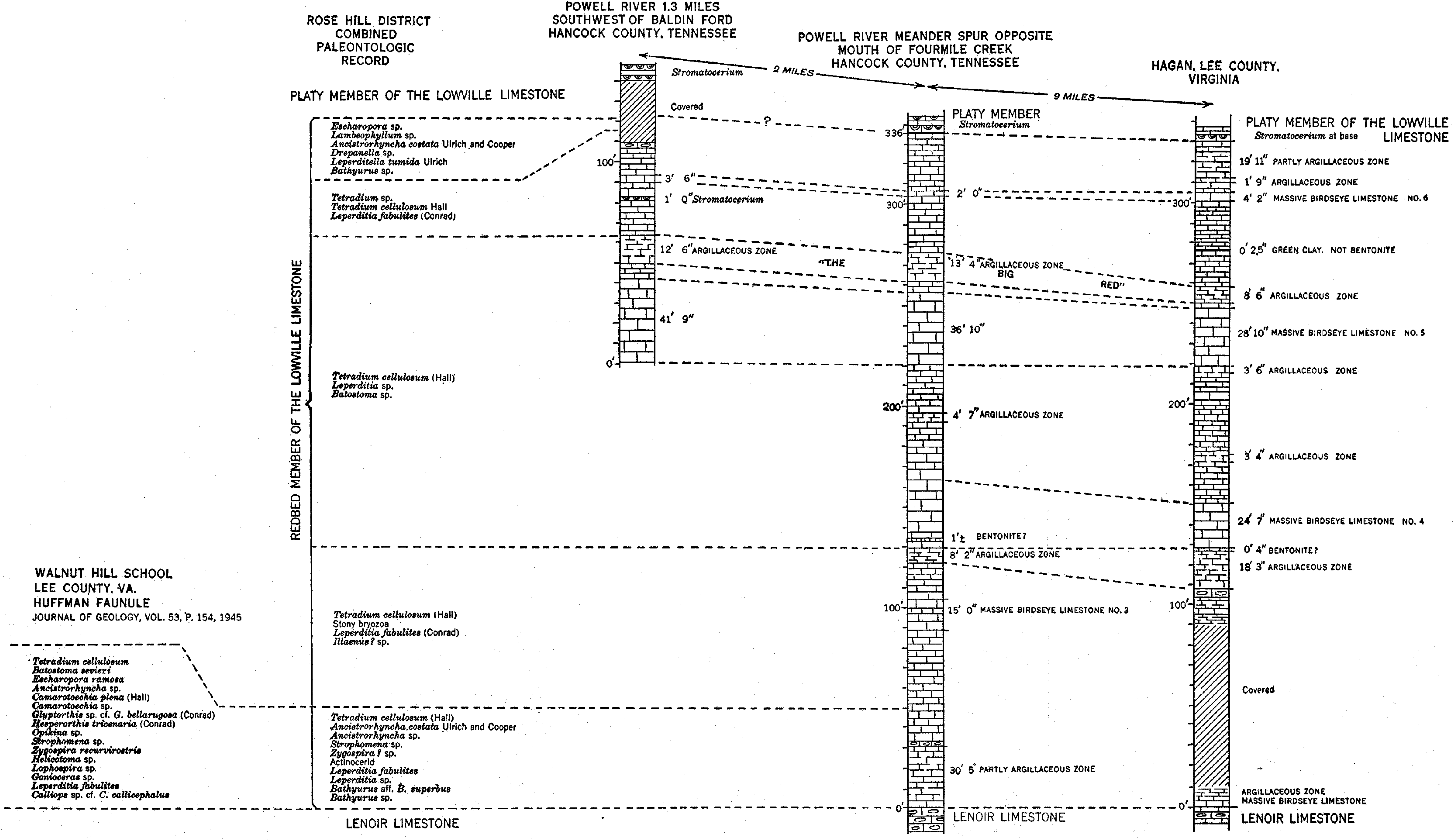
Character.—The redbed member is well exposed in many places along Powell River, but is very poorly exposed in most of the northern belt. It consists predominantly of fine-grained, thin-bedded, conchoidally fracturing limestone, but it contains prominent zones of much more massive-bedded birdseye limestone, and also prominent zones of argillaceous limestone, which weather buff or red.

The argillaceous limestone is almost never seen in its fresh state at the surface. It is characteristically a buff, reddish-brown or greenish-gray in color and is thin-bedded to shaly. The most argillaceous beds in these zones are quite earthy, and might even be called calcareous shales. There are all gradations from argillaceous limestone to fine-grained limestone that is only slightly argillaceous but may discolor on weathering to a buff or faint red color. Mud cracks are common in the argillaceous limestone, but they are well preserved or well exposed in few places.

The argillaceous zones are normally from a few feet up to 15 feet thick. They are most conspicuous where red, but the red color is subordinate in quantity to buff and greenish-gray, and is not persistent. An argillaceous zone which has prominent red beds at one locality may be entirely buff a few hundred feet away along the strike. For this reason it is unsafe to map or correlate "redbeds" in the Rose Hill district, but the argillaceous nature of the zones persists over broader areas, and such zones have been mapped successfully. The color of the argillaceous limestone is largely, if not entirely, due to surface weathering. In the cuttings of the Lemons well which penetrated the entire Lowville, no red or green limestone was seen. Chips of very light brown limestone in one sample were thought possibly to represent one of the argillaceous limestone zones, but the strong contrast visible at the surface between argillaceous zones and pure limestone zones is much fainter or is nonexistent in the fresh rock at depth.

In thin sections of the argillaceous limestone, small clear calcite crystals, which are apt to pass unnoticed in hand specimens, are seen to be scattered abundantly through a fine-textured matrix, which may be gray, brown, or red. Angular veinlets of clear calcite are also abundant and, in general, they parallel the shaly bedding. In one thin section small ostracodes are very abundant in the rock, though only an occasional ostracode is recognizable in the hand specimen from which the section was cut. Apparently the rock commonly fractures and weathers across the shells so that the fossils are not readily seen.

Several argillaceous zones are present in every section of the Lowville limestone but their position and spacing in the limestone



Faunal zones and correlation of measured sections of the Redbed member of the Lowville limestone.

varies. In much of the Powell River area there are three prominent argillaceous zones. Parts of each zone are normally but not invariably red. One of the argillaceous zones in the upper part of the redbed member was recognized over the whole district and was named "the big red." Another prominent argillaceous zone, immediately underlying the No. 4 massive birdseye limestone (see below), was found over most of the Rose Hill district. A third argillaceous zone, which is very persistent and which forms a valuable horizon marker, lies from 10 to 15 feet above the base of the Lowville limestone. This zone does not contain redbeds anywhere in the district, but weathers to a buff earthy shaly limestone, which contrasts strongly with the thin-bedded, tan and gray, high-calcium limestone around it. Other argillaceous zones are conspicuous at one locality and poorly exposed or absent near by. They seem to grade laterally into purer limestone indistinguishable from the enclosing limestones. The position and thickness of the most prominent argillaceous zones in measured sections are shown in Plate 20.

Zones of massive-bedded birdseye limestone are prominent in the redbed member, and are even more useful horizon markers than the argillaceous zones. Most of the birdseye limestone has a smoky-gray color, but some is tan. Small white or colorless calcite crystals are scattered indiscriminately through the rock and larger calcite "eyes" and small veinlets of white calcite are common. One of the large calcite "eyes" surrounded by very fine-textured limestone is shown in photomicrograph in Plate 24A. The beds of the massive birdseye zones are all more than 1 foot thick and characteristically they are from 3 to 6 feet thick. They thus contrast strongly with the enclosing thin-bedded limestones which are in layers only a few inches thick. The massive beds weather to a light blue-gray color, always with rough, irregular surfaces, which in many places have solution channels or grooves converging downward (Pl. 15A). Weathered surfaces of this type are called fluted. Bedding planes between layers of massive birdseye limestone are poorly defined in the fresh rock, and in the weathered ledges solution has so modified the original beds that accurate dip and strike measurements are normally impossible. In the major zones of massive birdseye limestone no other type of limestone is present, and none of these zones in the Lowville limestone contains any chert.

The thick zones of massive birdseye limestone in the redbed member of the Lowville may be traced for many miles with only minor changes in thickness, and each maintains almost exactly the same position above the base of the formation. They thus form valuable horizon markers, which are completely reliable at least within the Rose Hill district. Unfortunately in well cuttings the zones of massive birdseye limestone cannot be distinguished from the enclosing thin-bedded limestone. The prominent massive birdseye limestone zones are numbered in order upward from 3 to 6, zones 1 and 2 previously having been described in the sections on the Murfreesboro and Mosheim limestones. Zone No. 3 was not recognized in the northwestern belt of Lowville. It lies in a part of the Lowville that is very poorly exposed in that belt, which probably accounts for the failure to find it. In the southeastern belt of Lowville it is consistently present, about 90 feet above the base of the formation (Pl. 20). It is not quite as massively bedded, and hence not as distinctive as the higher zones of massive birdseye limestone. In the section near the mouth of Fourmile Creek (Geologic Section 8, Unit 5) it is 15 feet thick. Zones Nos. 4 and 5 are the most prominent zones of massive birdseye limestone in the Lowville. They average about 30 feet in thickness, but both are thicker in the southern belt of the Lowville than in the northern belt. They are readily recognizable wherever the lower member of the Lowville is reasonably well exposed. The No. 6 zone is everywhere less than 5 feet thick, yet it was consistently recognized over the entire district.

The position and thickness of the numbered zones of massive birdseye limestone in different parts of the Rose Hill district are shown in Plate 20. The lines connecting units in the different sections are not strictly time lines. This is shown clearly by massive birdseye limestone zone No. 4. At Hagan this zone has a probable bentonite at its base, but on Powell River the same bentonite lies 3 feet above the base. Furthermore this massive limestone zone is thicker in the Powell River section and the underlying argillaceous zone thinner than the corresponding units at Hagan. The massive birdseye limestone at the Powell River locality thus includes 3 feet of beds, which at Hagan are argillaceous and were placed in the underlying argillaceous zone. Lateral gradations of a few feet of beds from one kind of rock to another are believed to account for most of the differences in thickness of the lithologic zones shown in the sections on Plate 20.

Besides the numbered zones of massive birdseye limestone described above, individual beds of massive birdseye limestone are present in some sections, but most are not prominent and were not recognized over any considerable areas. One bed, which is quite persistent, however, is about 4 feet thick and lies about 3 feet above the base of the Lowville. It forms a useful horizon marker, because of its tendency to crop out and because of its position near the contact with the Lenoir limestone.

More than half of the redbed member of the Lowville is composed of fine-textured, gray or tan, conchoidally-fracturing limestone in even beds from 1 inch to 1 foot thick but averaging 2 or 3 inches. Patches of white calcite ("birdseyes") and veinlets of calcite are common in many beds but other beds are dense throughout. The beds weather to a blue-white color, with smooth surfaces.

Beds containing abundant chert nodules are locally prominent in the redbed member, but attempts to correlate chert-bearing zones from one part of the district to another were unsuccessful. There is a tendency, however, for one or two chert-bearing beds to be present in the lower part of the member, a chert-free zone in the middle of the member and several chert-bearing beds near the top. The chert in the lower part, like that in the Lenoir limestone (Pl. 18B), consists of nodular masses that coalesce and branch so that they cover more than half of a bedding surface. The chert in the upper part of the member occurs in oval nodules, which are one or two inches in length and are separated from one another by much greater distances of chert-free limestone. Chert-bearing zones of both types are normally only 1 or 2 feet thick, and in some cases the chert nodules or masses are scattered along only one bedding plane. Most of the chert is smoky or gray, but some is nearly black. The nodules are not conspicuously banded or zoned.

Intraformational conglomerate was found in a few places but is rare in the member. At one locality a zone of intraformational conglomerate consists of pebbles of unfossiliferous limestone in a matrix of fossil fragments. A probable bentonite, 4 inches thick, lies at the base of the No. 4 zone of massive birdseye limestone in the Hagan section and the same bentonite was also found in the section along Powell River at the mouth of Fourmile Creek. For further discussion of this bentonite, see the section on Ordovician bentonites.

A complete section of the redbed member was measured opposite the mouth of Fourmile Creek on the south side of Powell River (Geologic Section 8).

Stratigraphic relations.—The contact between the Lenoir limestone and the redbed member of the Lowville limestone has been placed at the top of the limestone zone containing abundant Lenoir-type chert. Despite the fact that the Lenoir has very few outcrops this makes a readily mappable contact, because the change from abundant chert nodules and fragments in the Lenoir soil to little or no chert in the Lowville soil is very striking. Except on steep slopes, the line of change is sharp and marks the position of the contact within a few feet. The top of the chert-bearing beds is nearly if not exactly at the same horizon in all parts of the district, as shown by the fact that a bed of buff-weathering argillaceous dolomite is consistently found a few feet below the top of the Lenoir. Furthermore an argillaceous zone is consistently present and a bed of massive birdseye limestone is locally present in the lower Lowville a few feet above the Lenoir-Lowville contact. Chert like that in the Lenoir does occur sporadically in the lower part of the Lowville, but these chert-bearing zones are so few and so thin that little possibility exists for confusion. The exact contact of the two limestones is commonly covered, but it shows in a cut of the Louisville and Nashville Railroad south of Chattles Station Church, 2 miles west of Ewing (Pl. 19B). Chert nodules are visible in the beds at the lower right of the picture and lenses and beds of chert appear near the center of the picture in the beds beneath the hammer, which is at the contact. The lowest Lowville limestone is entirely chert-free and is somewhat more dense and pure than the uppermost Lenoir limestone. The two formations seem conformable.

The top of the redbed member is drawn at the base of a very persistent zone of *Stromatocerium rugosum*. This contact is described in more detail in the section on the platy member of the Lowville.

Thickness.—At Hagan (Pl. 13) on the north flank of the Powell Valley anticline the redbed member of the Lowville is 331 feet thick, and in the Powell River section (Geologic Section 8) it is 336 feet thick. This close agreement in sections 9 miles apart diagonally across the regional strike confirms the impression gained while mapping that there is little variation in thickness of the member in the district.

Paleontology.—Fossils are sparingly present in the redbed member. Most of them are found in the thin-bedded limestones but the massive birdseye limestones and argillaceous limestones have yielded some specimens. *Tetradium cellulosum* and *Leperditia fabulites* were found from the base to the top of the member. In addition, the brachiopod *Ancistrorhynca costata* and the trilobite *Bathyurus* were found at both the base and the top. Huffman[97] reports *Batostoma sevieri, Escharopora ramosa, Hesperorthis tricenaria, Öpikina* sp., *Glyptorthis* sp., *Lophospira* sp., and other fossils from beds near the

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[97] Huffman, G. G., Middle Ordovician limestones from Lee County, Virginia, to central Kentucky: Jour. Geology, vol. 53, no. 3, p. 154, 1945.

base of the Lowville at Walnut Hill School (see Pl. 13). The complete list of fossils collected by the writers and by Huffman from the redbed member in and near the Rose Hill district is shown in Plate 20. The collections are not sufficiently large to justify a rigorous analysis of the paleontology of the redbed member, but it is clear from the faunules collected that this member shows little faunal variation from its base to its top. The apparent absence of distinctive "Ottosee" fossils such as *Receptaculites* and *Maclurites* is very conspicuous. *Tetradium cellulosum* has commonly been considered a guide fossil to the Lowville limestone, but it was also found in the Murfreesboro limestone in the Rose Hill district, and Huffman[98] also reports it from the Eggleston limestone.

Age and correlation.—Huffman[99] has called all except the top 65 feet of our redbed member "Ottosee," correlating it with the Ottosee of Rye Cove in Scott County, Virginia. Its stratigraphic position above the cherty Lenoir limestone and below abundant *Stromatocerium* supports this correlation, although the absence of many characteristic fossils found in the Ottosee of Rye Cove has already been noted. Butts, on the other hand, believes that a major hiatus exists between the Lenoir and Lowville limestones in Lee County, which farther east and southeast is occupied by the Blount group, consisting of the Holston, Whitesburg, Athens, Tellico and Ottosee formations. The apparent conformable nature of the contact between the Lenoir and the Lowville limestones in the Rose Hill district and the consistent thickness of the upper part of the Lenoir does not favor the thesis of a major hiatus at the base of the Lowville.

The redbed member of the Lowville is believed to be of lower Black River age as determined from its fossils. Huffman[100] favors a Chazyan age for these beds, however, because he believes that *Cryptophragmus* beds in the platy member of the Lowville correlate with lowest Black River of New York State.

PLATY MEMBER

Name.—The platy member includes roughly the upper half of the Lowville limestone, being the part of the formation that lies between the base of the *Stromatocerium* beds and the base of the Moccasin

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[98] Huffman, G. G., op. cit., p. 160.
[99] Huffman, G. G., op. cit., pp. 152-154.
[100] Huffman, G. G., op. cit., p. 173.

limestone. The name is used because of the thin and even bedding that distinguishes the limestone of the member.

Character.—The platy member is abundantly and well exposed in the southern belt of the Lowville limestone, where it crops out in bluffs of Powell River and also in numerous small ledges on the meander spurs of the river. The left and central parts of the panoramic photograph (Pl. 36A) show a typical display of the platy member. The member is extremely poorly exposed in most of the northern outcrop belt of the Lowville, but good sections may be seen at Hagan 2 miles east of the Rose Hill district and in the Wheeler quarry 3 miles west of the district.

The member consists of interbedded cryptocrystalline, fine-crystalline, and coarse-crystalline, tan and gray, dense limestone. Almost all beds are less than a foot thick and most of the member is made up of even platy beds only a few inches thick. Several of the thickest beds have fluted weathering and somewhat resemble massive birdseye limestone, but they are somewhat thinner bedded than the massive birdseye limestone previously described in the redbed member, and individual beds of this type are separated by much greater thicknesses of normal platy limestone. No argillaceous limestones or redbeds are present in the platy member.

Cryptocrystalline and crystalline beds are present in the platy member in about equal proportions, the former being more abundant in the lower part of the member and the latter in the upper. Many beds contain intergrown areas of both the crystalline and cryptocrystalline types. Some of the coarsest crystalline beds resemble marble and a few contain abundant pink calcite giving the rock a salmon color. Fragmental fossils are abundant in some crystalline beds and in part account for the crystallinity. In no place are there zones of any distinctive lithologic character, which would make readily recognizable lithologic units. Chert is uncommon in most of the platy member of the Lowville, but a few chert-bearing beds are consistently present near the top of the member. The chert is in the form of small oval nodules scattered along bedding planes at definite horizons. In the Powell River section (Geologic Section 8) the chert is most abundant in the top 16 feet of the member.

The upper half of the member contains abundant remains of the sponge *Camarocladia.* In some beds the Camarocladias weather in relief and have a buff slightly sandy-looking surface, with the enclosing limestone having a blue-white smooth surface. They appear as branching pencil-like markings, which are very distinctive. In other beds the Camarocladias dissolve away completely leaving small tubular holes, which give the rock a wormy appearance. Plate 19C shows a particularly good but somewhat unusual exhibit of *Camarocladia* which has weathered out in relief. Some of the *Camarocladia* beds are dark gray and have a faint petroliferous odor.

Stratigraphic relations.—The contact at the base of the platy member is taken as the base of the persistent zone of abundant *Stromatocerium rugosum.* This contact lies about 30 feet above the No. 6 massive birdseye limestone in the upper part of the redbed member. Locally *Stromatocerium* may occur below the zone, which has been mapped as the contact. For example southeast of Baldin Ford on Powell River, a zone of *Stromatocerium,* 1 foot thick, approximately 30 feet below the base of the platy member, is persistent for nearly a mile along the strike. *Stromatocerium* has also been found in the Mosheim limestone (see p. 77), hence it cannot be considered a guide fossil of any one formation or member. It is, however, far more abundant at the base of the platy member than anywhere else in the Rose Hill district, and is therefore an excellent marker zone. The contact between Huffman's[101] Ottosee, which corresponds approximately with the redbed member of our Lowville and his "Lower Moccasin" (quotes are Huffman's) which corresponds approximately with the platy member of our Lowville, was placed by him at the top of the argillaceous zone labeled "the big red" on Plate 20. We prefer to subdivide the Lowville at the base of the *Stromatocerium* zone 60 to 65 feet higher, because these 60 to 65 feet of beds include an ubiquitous zone of massive birdseye limestone and a local zone of argillaceous limestone, both of which are characteristic of the redbed member, and they do not include any beds of crystalline limestone, which forms a considerable part of the platy member. Furthermore we find no important differences in the faunules collected from these 60 to 65 feet of beds and those collected from the underlying part of the redbed member.

The contact between the platy member of the Lowville and the overlying Moccasin limestone is conformable, and lies at the base of a thick zone of buff-weathering argillaceous limestone. The contact is discussed more completely in the section on the Moccasin limestone.

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[101] Huffman, G. G., Middle Ordovician limestones from Lee County, Virginia, to central Kentucky: Jour. Geology, vol. 53, no. 3, pp. 152-153, 1945.

Thickness.—In the Powell River section at the mouth of Fourmile Creek (Geologic Section 8) the platy member is 244 feet thick and at Hagan it is 256 feet thick. Although no other sections of the member have been measured, thicknesses calculated elsewhere from the known dip and the width of the outcrop correspond approximately with those above, indicating that there is no important variation in thickness of the member in the district.

Paleontology.—The platy member of the Lowville is moderately fossiliferous throughout. Brachiopods and bryozoans predominate but other types are abundant at places. At and near the base of the member, one or more zones contain numerous specimens of *Stromatocerium rugosum. Stromatocerium* was found at every locality where the exposures of this part of the Lowville were good. The heads of this form may be scattered through a basal layer, 2 to 5 feet thick, but in some places they are confined to one bed less than a foot thick. They are best seen on weathered bedding surfaces. In rare instances heads nearly touch one another, but more commonly individual heads are several feet or tens of feet apart. An example of closely spaced *Stromatocerium* heads is shown in Plate 21A. In most parts of the area only one zone of *Stromatocerium* is present, but in places a second zone lies from 10 to 51 feet above the base of the member, and at one locality 3 separate zones were found. One lone *Stromatocerium* in the Powell River section was 131 feet above the base of the member.

In exposures showing *Stromatocerium,* an unnamed species of *Tetradium* is common, which is made up of septae that radiate from a center and bind together the enclosing rock into a bun-shaped mass normally about 6 inches in diameter. A typical *Tetradium* of this type is shown in Plate 21B, and Butts[102] has illustrated similar ones from his Ottosee of Rye Cove.

A zone of abundant *Öpikina* is almost everywhere found from 7 to 15 feet above the basal zone of *Stromatocerium.* The form has been identified by G. A. Cooper as *Öpikina* aff. *Ö. transitionalis. Hesperorthis* aff. *H. tricenaria* is also locally abundant in or near the *Öpikina* zone (Pl. 21C). *Cryptophragmus antiquatus* first appears about 60 feet above the base of the platy member and ranges through 50 to 75 feet of beds. Although it is common at some localities it was not found everywhere. Plate 21D is a photograph of the largest

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[102] Butts, Charles, Geology of the Appalachian Valley in Virginia Virginia Geol. Survey Bull. 52, pt. II, Fossil plates and explanations, Pl. 88, 1941.

Cryptophragmus seen in the area. *Camarocladia* is extremely abundant throughout the upper half of the platy member. Generally the base of the *Camarocladia* zone overlaps only the upper part of the *Cryptophragmus* zone, but in some places good specimens of *Camarocladia* were found below the lowest *Cryptophragmus.*

The upper 50 feet of beds of the platy member are extremely fossiliferous. Among the most abundant genera are *Zygospira, Öpikina, Doleroides, Rhynidictya, Helopora, Escharopora,* and *Drepanella. Doleroides gibbosus* and *Pionodema minuscula,* which were not found in the redbed member of the Lowville limestone, occur throughout the platy member.

The fauna and the faunal zones of the platy member of the Lowville are shown graphically in Table 5. The best collecting from the upper part of the platy member is along the rim of Wheeler quarry (Pl. 13), and the *Stromatocerium* and *Hesperorthis* zones are excellently developed at a quarry on the Shawanee road almost exactly on the State line 2½ miles east of Cumberland Gap (Pl. 13). For a complete well-exposed sequence of the faunules from base to top of the member one must go to one of the meander spurs on the south side of Powell River east of Parkey Bridge, such as the one opposite the mouth of Fourmile Creek.

Age and correlation.—The platy member of the Lowville is of Black River age. *Cryptophragmus antiquatus,* which occurs in the middle of the member, is considered an excellent guide to the Lowville of New York. Huffman[103] has referred to the beds included in our platy member as "Lower Moccasin", but does not thereby imply correlation with the type Moccasin. In Tazewell County, Virginia, Cooper and Prouty[104] have divided the interval between the base of the *Stromatocerium* zone and the base of the Moccasin limestone into the Wardell, Bowen and Witten formations. The Bowen is a tongue of redbeds which probably grades laterally in a westward direction toward Lee County into non-red beds similar to the overlying and underlying beds. The exact equivalence of the Lowville limestone of the Rose Hill district to the Wardell, Bowen and Witten has not been established, but it is clear that the *Stromatocerium* zone of our platy member correlates with part of Cooper and Prouty's Wardell and that the *Cryptophragmus-Camarocladia* beds of our platy member correlate with their Witten. The upper part of the platy member correlates

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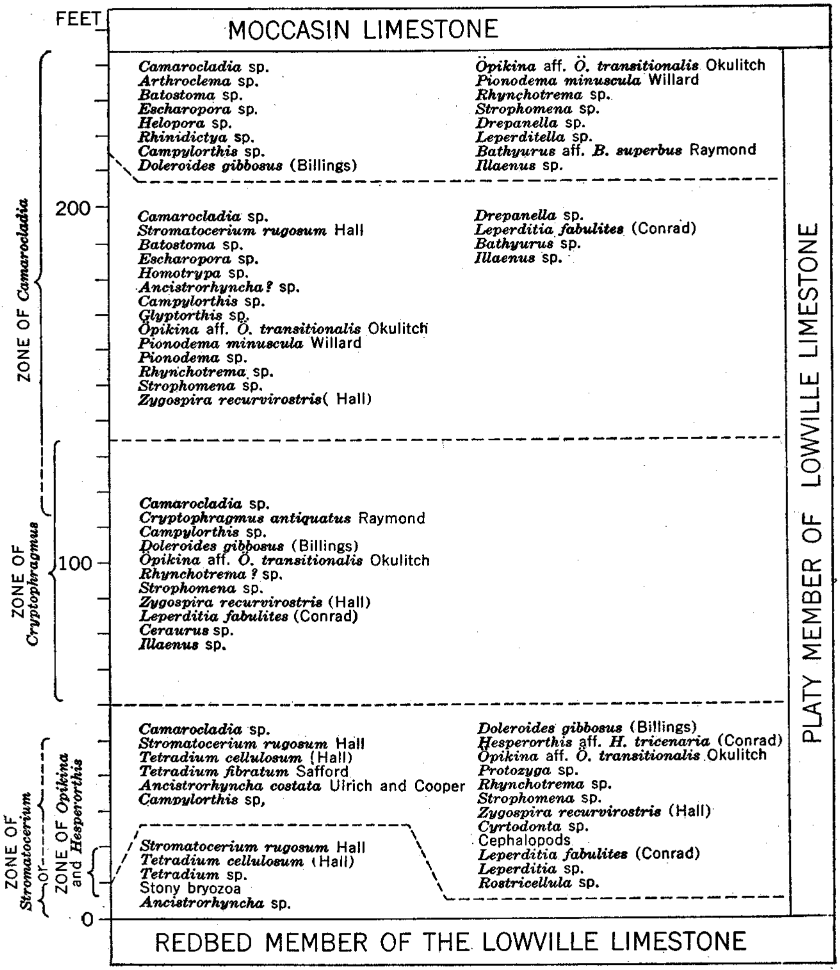
[103] Huffman, G. G., op. cit., p. 151, 1945.

[104] Cooper, B. N., and Prouty, C. E., op. cit.

TABLE 5.—*Faunal zones of the platy member of the Lowville limestone*



Camarocladia sp.
Arthroclema sp.
Batostoma sp.
Escharopora sp.
Helopora sp.
Rhinidictya sp.
Campylorthis sp.
Doleroides gibbosus (Billings)
Öpikina aff. ***Ö. transitionalis*** Okulitch
Pionodema minuscula Willard
Rhynchotrema sp.
Strophomena sp.
Drepanella sp.
Leperditella sp.
Bathyurus aff. ***B. superbus*** Raymond
Illaenus sp.

Camarocladia sp.
Stromatocerium rugosum Hall
Batostoma sp.
Escharopora sp.
Homotrypa sp.
Ancistrorhyncha? sp.
Campylorthis sp.
Glyptorthis sp.
Öpikina aff. ***Ö. transitionalis*** Okulitch
Pionodema minuscula Willard
Pionodema sp.
Rhynchotrema sp.
Strophomena sp.
Zygospira recurvirostris (Hall)
Drepanella sp.
Leperditia fabulites (Conrad)
Bathyurus sp.
Illaenus sp.

Camarocladia sp.
Cryptophragmus antiquatus Raymond
Campylorthis sp.
Doleroides gibbosus (Billings)
Öpikina aff. ***Ö. transitionalis*** Okulitch
Rhynchotrema ? sp.
Strophomena sp.
Zygospira recurvirostris (Hall)
Leperditia fabulites (Conrad)
Ceraurus sp.
Illaenus sp.

Camarocladia sp.
Stromatocerium rugosum Hall
Tetradium cellulosum (Hall)
Tetradium fibratum Safford
Ancistrorhyncha costata Ulrich and Cooper
Campylorthis sp,

Stromatocerium rugosum Hall
Tetradium cellulosum (Hall)
Tetradium sp.
Stony bryozoa
Ancistrorhyncha sp.

Doleroides gibbosus (Billings)
Hesperorthis aff. ***H. tricenaria*** (Conrad)
Öpikina aff. ***Ö. transitionalis*** Okulitch
Protozyga sp.
Rhynchotrema sp.
Strophomena sp.
Zygospira recurvirostris (Hall)
Cyrtodonta sp.
Cephalopods
Leperditia fabulites (Conrad)
Leperditia sp.
Rostricellula sp.

Additional forms collected and identified by Huffman mainly from platy member, but including beds overlying "The Big Red" of the redbed member. Collections from quarries near Shawanee and Harrogate, Tennessee, 8 and 10 miles west of the Rose Hill District. Journal of Geology, vol. 53, p. 156, 1945.

Batostoma magnapora Ulrich
"***Chasmatopora***" ***(Subretopora)*** sp. cf. ***C. sublaxa*** (Ulrich)
Escharopora confluens Ulrich
Escharopora subrecta (Ulrich)
Rhinidictya nicholsoni Ulrich
Camarotoechia plena Hall
Fascifera sp.

Öpikina sp. cf. ***Ö. minnesotensis*** (Winchell)
Pionodema subaequata (Conrad)
Liospira sp.
Lophospira oweni Ulrich and Scofield
Trochonema sp.
Cycloceras sp.
Orthoceras multicameratum Emmons

with the Lebanon limestone of the Central Basin of Tennessee and the lower part may be the equivalent of the Ridley limestone of that area.

MOCCASIN LIMESTONE

Name.—The Moccasin limestone has its type locality at Gate City, Virginia, 40 miles east of the Rose Hill district.[105] It was originally described as consisting of the red argillaceous limestone lying between the Chickamauga limestone below and the Sevier shale above. Cooper and Prouty[106] and Cooper[107] place the base of the type Moccasin at the base of the thick sequence of argillaceous limestone that overlies Lowville-type beds with abundant *Camarocladia* and they exclude a red mudrock tongue 100 feet lower in the section. The lower limit of the Moccasin limestone, as used in the Rose Hill district, conforms with the usage of Cooper and Prouty, although the Moccasin limestone in the Rose Hill area is buff rather than red.

The Moccasin limestone of the Rose Hill district is divided into two parts, a lower member which is an argillaceous, mudcracked limestone, and an upper member, here named the Hardy Creek member, which consists of chert-bearing, even-bedded limestone.

Distribution.—Parallel belts of Moccasin limestone lie in normal stratigraphic position in the lowland areas on opposite sides of the Rose Hill district. The northern belt averages about 500 feet wide and the southern belt about 700 feet wide. The Moccasin is also present in the northern part of the Sugarcamp fensters, where it is almost everywhere in fault contact with the exposed contiguous formations.

Lower member.—The lower member of the Moccasin limestone forms smooth grassy slopes, which have no prominent outcrops and which contrast strongly with the abundant small ledges in the belts of the underlying Lowville limestone (Pl. 36A), and of the overlying Hardy Creek member of the Moccasin limestone. Most of the southern outcrop belt of the Moccasin has been left in woodland but the soil-covered northern belt is largely in pasture or is cultivated.

The lower member of the Moccasin is a buff-weathering, argillaceous limestone, which occurs in thin, platy to shaly beds. In some beds mottled red patches are conspicuous, but nowhere is there any appreciable thickness of red beds. Zones, a few feet thick, of platy

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[105] Campbell, M. R., U. S. Geol. Survey Geol. Atlas, Estillville, Virginia, folio (No. 12), 1894.

[106] Cooper, B. N., and Prouty, C. E., Stratigraphy of the lower Middle Ordovician of Tazewell County, Virginia: Geol. Soc. America Bull., vol. 54, no. 6, p. 879, 1943.

[107] Cooper, B. N., Geology and mineral resources of the Burkes Garden quadrangle, Virginia: Virginia Geol. Survey Bull. 60, Pl. 9, 1944.

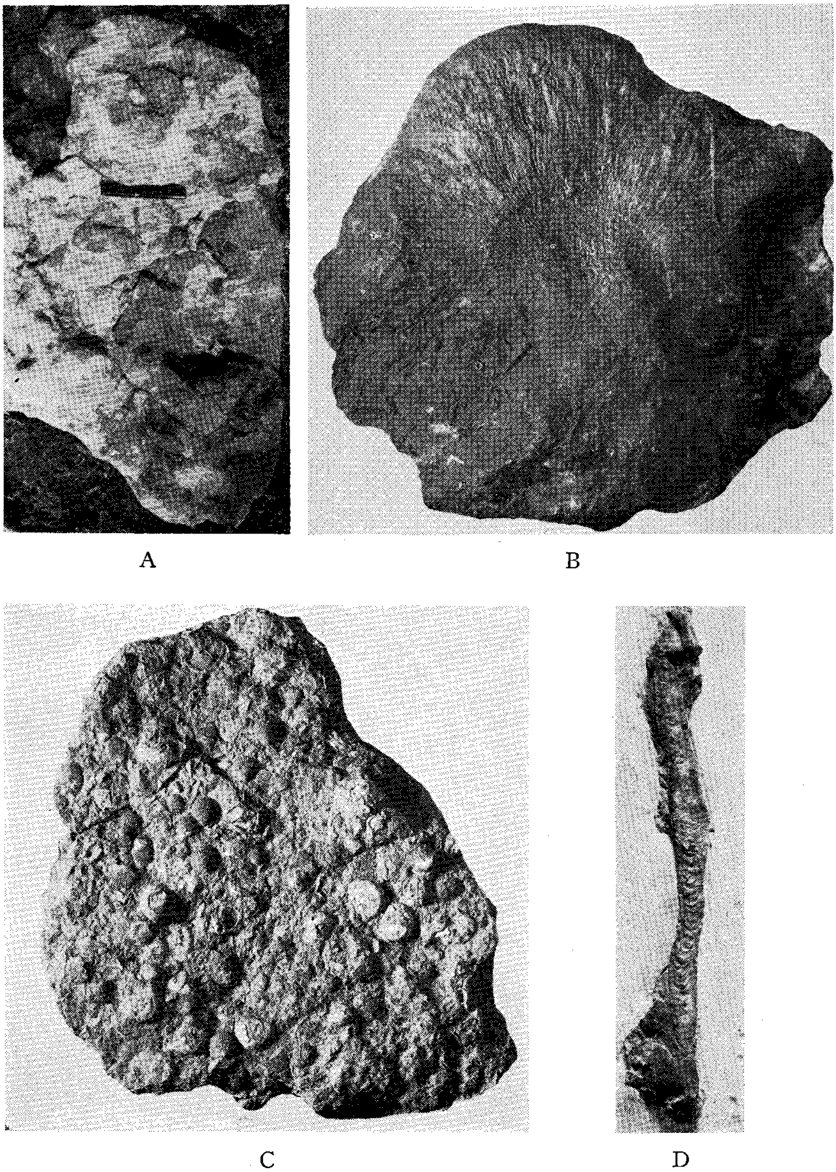
limestones similar to those in the underlying Lowville limestone may be interbedded near the base and top of the lower member of the Moccasin. In cliffs and in quarries the argillaceous and shaly character of the limestone is not readily apparent, and the fresh rock appears to be a brown or gray limestone in relatively massive units with well-developed bedding planes from 2 to 10 feet apart. Some of the limestone beds are cryptocrystalline, others fine- to coarse-crystalline, and still others have microcrystalline and macrocrystalline types of limestone in the same bed either as layers or as intergrown areas. Much if not all of the crystalline limestone is abundantly fossiliferous. Mud cracks are abundant and intraformational conglomerate is present in places, but chert is entirely absent.

Hardy Creek member.—The Hardy Creek member of the Moccasin consists of even-bedded, pure or siliceous limestone, which is believed to be equivalent to the upper part of the type Moccasin because of its stratigraphic position. The name of the member is taken from a locality 2 miles northeast of the Rose Hill district where a complete section, designated the type section of the member (Geologic Section 9), is exposed in a cut of the Louisville and Nashville Railroad at the Hagan switchback, which parallels Hardy Creek.

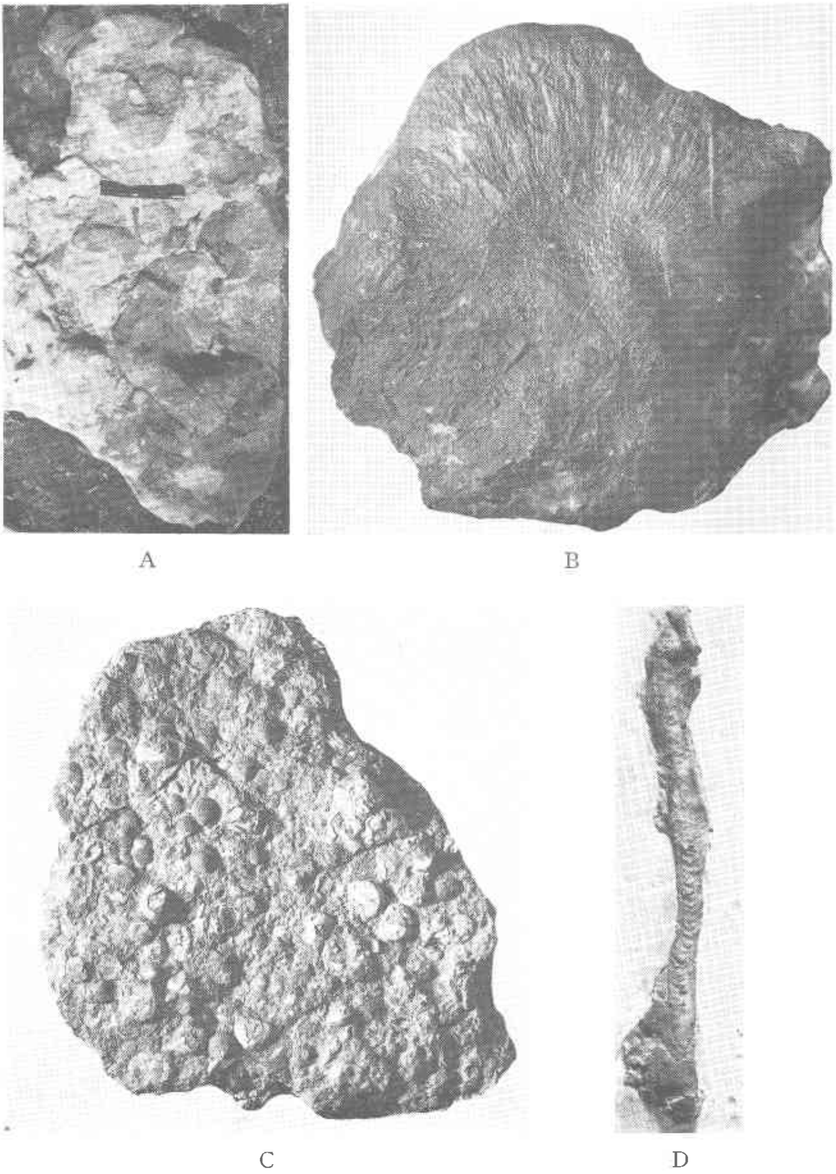
The limestone of the Hardy Creek member weathers slowly in contrast with the shaly beds in the lower member of the Moccasin and the silty beds of the lower part of the Eggleston limestone. The Hardy Creek member thus forms a conspicuous belt of numerous ledgy outcrops between two belts whose smooth slopes have no prominent outcrops. Because of its resistance to erosion this member is a more consistent cliff-maker in the bluffs of Powell River than is the lower member of the Moccasin.

The Hardy Creek member is composed of tan and gray, cryptocrystalline and fine-crystalline limestone with a few beds of medium-crystalline limestone near the top. Most beds are from 1 to 6 inches thick though thicker beds are present locally. Much of the limestone is siliceous and some appears very slightly dolomitic. Although the fresh rock seems to be of uniform texture throughout, siliceous or silty laminations appear on weathered surfaces in some beds, and in a few places these laminae cause markings on bedding surfaces which superficially resemble *Camarocladia*.

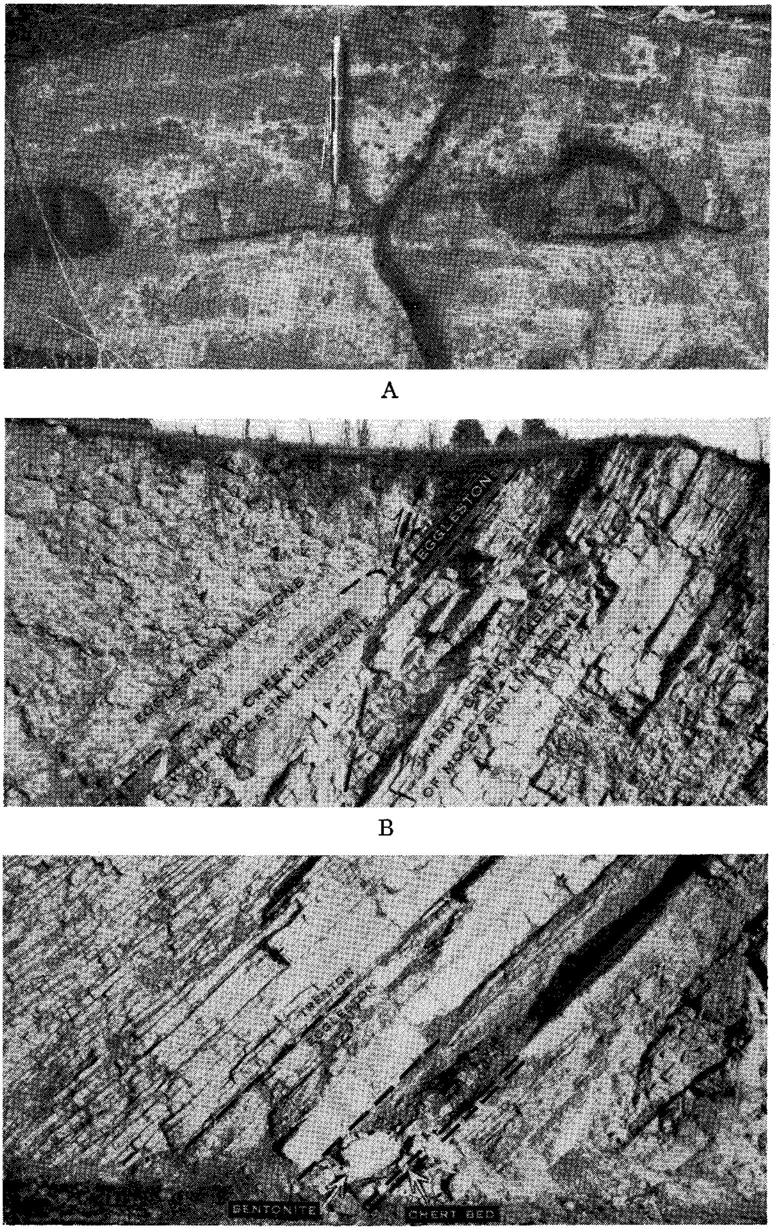
In thin section typical specimens of the Hardy Creek member show scattered rhombs of clear calcite in a very fine calcite matrix. The lamination of the limestone appears to be due to a rough aline-



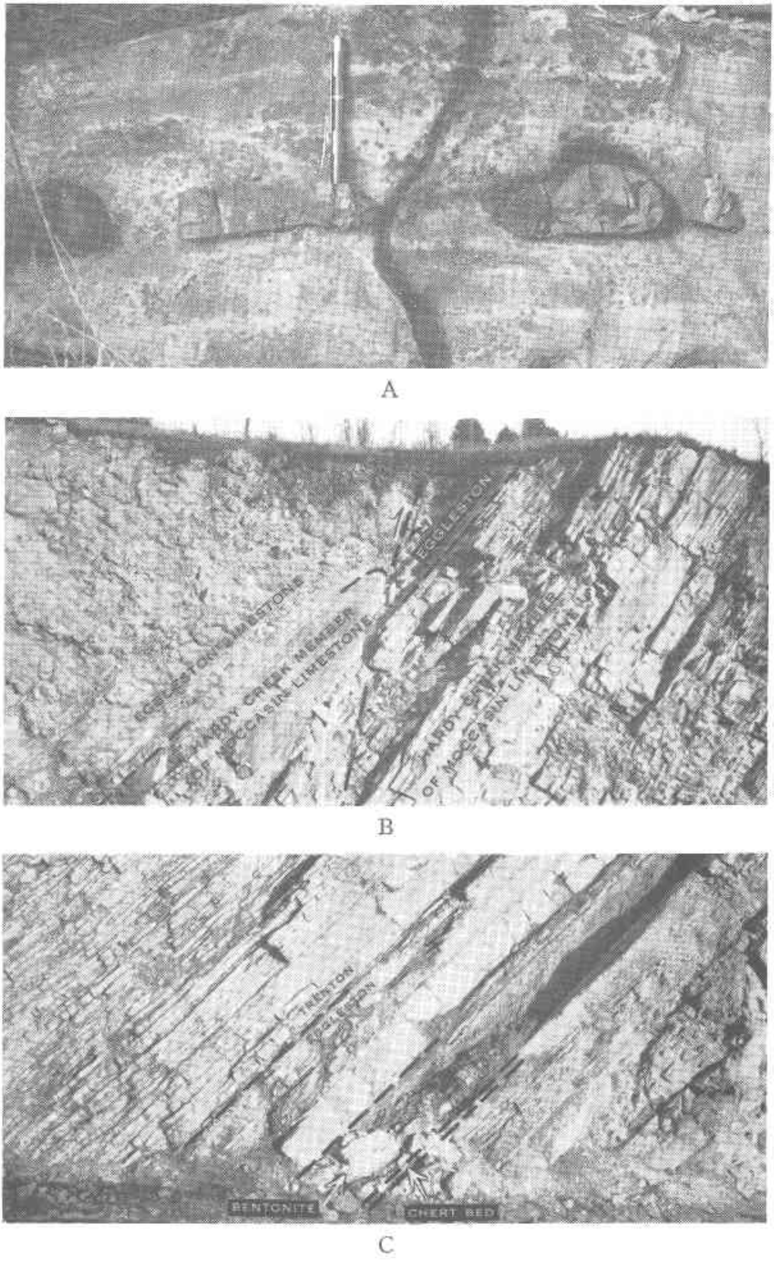
A, Closely packed heads of *Stromatocerium rugosum* from the base of the platy member of the Lowville limestone. Shawanee Road Quarry. B, Radial colony of *Tetradium* sp. in the Lowville limestone. Common near the *Stromatocerium* zone. From Baldin Ford on the Powell River. x½. C, *Hesperorthis tricenaria* and *Öpikina* aff. *O. transitionalis* from part of the platy member of the Lowville limestone. Shawanee Road Quarry. x½. D, Unusually large specimen of *Cryptophragmus antiquatus* from the middle part of the platy member of the Lowville limestone near Hagan. x½.



A, Closely packed heads of *Stromatocerium rugosum* from the base of the platy member of the Lowville limestone. Shawanee Road Quarry. B, Radial colony of *Tetradium* sp. in the Lowville limestone. Common near the *Stromatocerium* zone. From Baldin Ford on the Powell River. x½. C, *Hesperorthis tricenaria* and *Öpikina* aff. *O. transitionalis* from part of the platy member of the Lowville limestone. Shawanee Road Quarry. x½. D, Unusually large specimen of *Cryptophragmus antiquatus* from the middle part of the platy member of the Lowville limestone near Hagan. x½.



A, Chert nodules in the Hardy Creek member of the Moccasin limestone at Hagan. B, Contact of the Eggleston and Moccasin limestones at Hagan. C, Big bentonite near top of Eggleston limestone, and near Eggleston-Trenton contact at Hagan.



A, Chert nodules in the Hardy Creek member of the Moccasin limestone at Hagan. B, Contact of the Eggleston and Moccasin limestones at Hagan. C, Big bentonite near top of Eggleston limestone, and near Eggleston-Trenton contact at Hagan.

ment of these rhombs. The brown color of the limestone is partly due to disseminated specks of limonite but very finely disseminated carbonaceous material may account for some of the colors.

Among the most striking features of the Hardy Creek member is the presence of very perfectly formed oval or flattened nodules of zoned chalcedonic chert, many of which are 5 or 6 inches long. Although they occur in only a few beds, the nodules are very prominent both in the bedrock and the soil. Individual beds with chert are apparently not persistent over the whole area, for the positions of chert-bearing beds are not the same in measured sections. The nodules differ from those in all other Ordovician formations in being larger than any other well-shaped oval nodules, and more perfectly oval than any other large nodules. They thus form a valuable guide to this member, especially in complexly faulted areas, such as the Sugarcamp fensters. Good exposures of the nodules are found in the Hagan railroad cut, where those shown in Plate 22A were photographed.

The only persistent key bed we found in the Hardy Creek member is a bed of massive birdseye limestone, 2 to 3 feet thick, which lies from 5 to 15 feet below the top of the member. It is so much more massive than the enclosing beds that it forms a conspicuous, though small, ledge on the lower slopes of Wallen Ridge; it was also found in several places in the northern belt of the Moccasin limestone and in the Sugarcamp fensters. It differs from all other beds of massive birdseye limestone in the Rose Hill district in that it consistently contains a few, widely spaced, small, oval chert nodules. It does, however, possess the characteristic fluted weathering, conchoidal fracture, and chemical purity of the massive beds of birdseye limestone in the Lowville and older limestones.

In well cuttings recognition of the Hardy Creek member of the Moccasin is extremely difficult and uncertain. An occasional chip of chert is sufficient evidence to distinguish this member from the lower member, but the drill may penetrate the entire Hardy Creek member without encountering one of the chert nodules. Other distinctions between the lower and upper members, which are conspicuous in the weathered beds at the surface, are vague or wanting in the cuttings. We were thus not able to delimit the Hardy Creek member with assurance in the Lemons No. 1 well.

The Hardy Creek member is sparingly fossiliferous except in the top 10 feet where good collections were obtained at several localities.

These fossiliferous beds have been placed in the Eggleston by Huffman.[108]

Stratigraphic relations.—The base of the Moccasin is drawn at the base of the buff-weathering argillaceous limestone. The base of the upper member of the formation, the Hardy Creek member, is drawn at the base of the zone of even-bedded nonargillaceous limestone. In general this contact is sharp, but at Hagan the lowest 15 feet of limestone of the Hardy Creek member contains thin interbeds and partings of yellow-weathering shaly limestone, forming a transition zone between it and the lower member.

The base of the Hardy Creek member is unquestionably a transgressing boundary rather than a time boundary. The nonargillaceous limestones grade eastward into the argillaceous facies and the member then disappears. Northwest from Rose Hill the next exposures of Middle Ordovician rocks are along the Kentucky River on the edge of the Blue Grass district, 110 miles away. Here the limestone of the Highbridge group, which includes beds equivalent to the Moccasin limestone, contains no argillaceous limestone.

Thickness.—The lower member of the Moccasin is 143 feet thick in the section at the mouth of Fourmile Creek (Geologic Section 8) and 138 feet at Hagan (Geologic Section 9). At the Wheeler quarry west of the Rose Hill district (Pl. 13) it appears to be 114 feet thick but at this place the top contact is not exposed and its estimated position may have been in error. In the section at Hagan the Hardy Creek member is 141 feet thick, and in the section at the mouth of Fourmile Creek it is 154 feet thick. The total thickness of the Moccasin limestone is thus 279 feet at Hagan and 297 feet at the mouth of Fourmile Creek.

Paleontology.—The lower member of the Moccasin limestone is moderately to richly fossiliferous, but the overlying Hardy Creek member has relatively few fossils except in the topmost beds. Fossils may be collected from the lower member wherever it is exposed, but the most abundant and best-preserved fossils from this member were found along the rim of the abandoned Wheeler quarry 3 miles west of the Rose Hill district. At this quarry the top 82 feet of beds in the north wall belong to the lower member and 20 feet of additional beds are exposed in the stripped area at the back of the quarry. The basal beds of the member are characterized by abundant bryozoans, especially

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[108] Huffman, G. G., op. cit., p. 161.

Rhinidictya, Helopora and *Escharopora.* This richly fossiliferous zone was found at the base of the Moccasin throughout the Rose Hill district, and is well exemplified by the slab from the Wheeler quarry shown in Plate 23A. *Zygospira* is also locally abundant in beds near the base of the Moccasin, and *Camarocladia* may be present but is not as abundant as it is in the underlying Lowville limestone.

In the middle part of the lower member of the Moccasin bryozoans are numerous in some beds, brachiopods of the genera *Strophomena, Pionodema* and *Rhynchotrema* are common, and trilobites, pelecypods, and ostracodes are fairly common. *Drepanella* sp. is found throughout the lower Moccasin, but a zone of profuse *Drepanella* lies 98 feet above the base. Well-preserved specimens from the Wheeler quarry are illustrated in Plate 23C. Our specimens were identified as *Drepanella* sp., but Butts has collected *Drepanella* from the same locality, which he identified as *Drepanella* aff. *D. crassinoda* Ulrich and illustrated in Figure 1 of Plate 94 of Virginia Geological Survey Bulletin 52.[109]

The best fossil collections, from the Hardy Creek member, come from the top few feet. Most of the genera are the same as those found in the lower member of the Moccasin limestone or in the underlying Lowville limestone but genera not identified from older beds include *Lichenocrinus, Dermatostroma, Subulites, Cyrtodonta,* and *Eurychilina. Tetradium cellulosum* was found 5 feet below the top of the Hardy Creek member. The complete record of identified fossils from the Moccasin of the Rose Hill district is shown in Table 6.

Age and correlation.—The Moccasin has generally been considered Black River in age. Cooper and Prouty[110] have suggested, however, that it may be lower Trenton, and Huffman[111] correlates the Moccasin and Eggleston of southwest Virginia with Kay's Nealmont limestone of central Pennsylvania, which has been dated by Kay[112] as lower Trenton. Huffman believes that there may be a regional unconformity at the base of the Moccasin of Virginia. The Moccasin in the Rose Hill district contains many fossils common to the Lowville, including *Tetradium cellulosum,* usually considered a guide to the Lowville. In Tazewell County the base of the Moccasin is placed by Cooper and Prouty at

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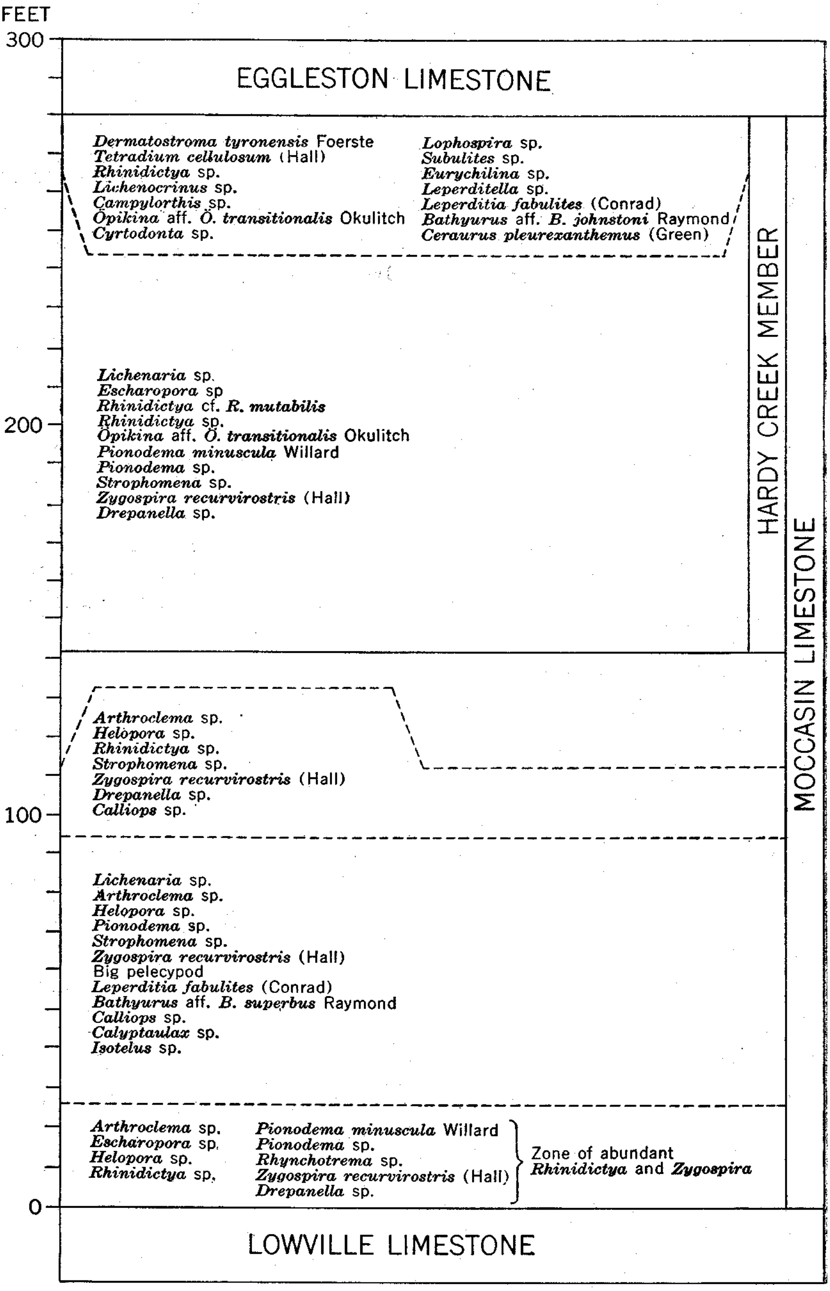
[109] Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. II, Fossil plates and explanations, Pl. 94, 1941.

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

[111] Huffman, G. G., op. cit., p. 174.

[112] Kay, G. M., Middle Ordovician of central Pennsylvania: Jour. Geology, vol. 52, no. 1, pp. 1-23; no. 2, pp. 97-116, 1944.

TABLE 6.—*Faunal zones of the Moccasin limestone*



the base of a thick zone of redbeds. The color line, however, is very irregular and transgresses beds which, except for their color, are lithologically identical above and below. In Tazewell County a tongue of redbeds, the Bowen of Cooper and Prouty, also lies below the Moccasin. There thus seem to be objections to Huffman's suggestion of an unconformity between the Moccasin and Lowville limestones and to the assignment of a Trenton age to the Moccasin and a Black River age to the Lowville.

EGGLESTON LIMESTONE

Name.—The Eggleston limestone receives its name from an exposure at Narrows on the New River in Giles County, Virginia. Mathews[113] defined the formation as including beds of upper Black River age, younger than the upper red Moccasin limestone and older than the Trenton limestone. Rosenkrans[114] and Butts[115] have published measured sections of the Eggleston at Narrows.

Distribution.—The Eggleston limestone forms narrow belts of outcrop lying in normal position between the Moccasin and Trenton limestones on both the north and south flanks of the Powell Valley anticline. The northern belt averages about 250 feet wide, and the southern belt is slightly wider. A short belt of Eggleston is poorly exposed along the northeast edge of the Sugarcamp fensters, and two slivers of Eggleston occur at the northeast and southeast corners of the Dean fenster.

Character.—Although essentially a weak formation, the Eggleston is slightly more resistant to erosion than the enclosing Moccasin and Trenton limestones. Less solubility of the Eggleston, which is most pronounced in the upper part of the formation, seems to account for this relative resistance. The Eggleston thus forms a series of low, gently rounded hills, on the valley floor in the northern belt, and it forms very low knobs on the spurs of Wallen Ridge in the southern belt. The main part of the formation is normally found on the slopes that face the older formations, and the contact with the Trenton limestone lies near or just over the crest of the hills and knobs. The Eggleston is partly exposed at many places in the Rose Hill district,

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

[114] Rosenkrans, R. R., Stratigraphy of Ordovician bentonite beds in southwestern Virginia: Virginia Geol. Survey Bull. 46-I, pp. 105-106, 1936.

[115] Butts, Charles, op. cit., p. 192, 1940.

but the only completely exposed section of the formation is in the railroad cut at Hagan 2 miles northeast of the Rose Hill district (Geologic Section 9). The formation is fairly well exposed on a very small knoll in the northeast edge of the town of Rose Hill. In the southern belt, the Eggleston crops out at many places on the south side of the Powell River. Among the more complete sections is one along a small gully one mile southwest of Baldin Ford and another in the valley of a small creek flowing northward into Powell River half a mile east of Rob Camp Church.

Lithologically the Eggleston limestone of the Rose Hill district is made up of two contrasting kinds of rock. One is a massive-bedded, soft, calcareous mudstone, the other a platy-bedded, hard limestone. The soft mudstone predominates in the lower and upper parts of the Eggleston and the hard platy limestone in the middle part. For convenience of description and discussion these parts will be referred to as the lower, middle and upper members of the Eggleston. The lower and upper members form smooth slopes with almost no outcrops, whereas the platy limestone of the middle member crops out as numerous small ledges. The members are relatively thin, and were not mapped separately, but are readily recognizable in all good exposures of the Eggleston in Lee County.

The lower member is made up entirely of gray, calcareous mudstone, which at Hagan forms a unit 36 feet thick (Geologic Section 9, Unit 11). Abundant small patches of white calcite in the mudstone resemble the birdseye of the Lowville limestone, but in this case the enclosing rock is quite different. The birdseyes of the lower member of the Eggleston serve to distinguish it from the argillaceous limestone of the lower member of the Moccasin which is otherwise somewhat similar. The rock is very poorly bedded, and crumpling and flowage of the mudstone are apparent in many places. At Hagan where the lower member of the Eggleston is perfectly exposed (Pl. 22B) the only sign of original bedding was one thin layer of platy limestone in the middle of the unit. It is not clear whether the argillaceous limestone was deposited so uniformly that no bedding planes or laminations were formed, or whether squeezing of the very incompetent rock has caused small scale flowage and crumpling that destroyed most traces of the original bedding. In thin section (Pl. 24C) the mudstone is seen to be composed dominantly of minute calcite crystals, with the impurities in such fine particles as not to be visible under ordinary magnification. The calcite "eyes" are more or less lenticular and are alined parallel to a structure, which may be either bedding or flowage structure. Numerous small flakes of limonite are scattered through the rock, and a little glauconite is also present. The mudstone of the lower member is everywhere deeply weathered and has not been seen in its fresh state at the surface. It weathers to a uniform buff or greenish-buff color and breaks into small blocky pieces with curving joint surfaces. It is very sparingly fossiliferous, and the fossils are apt to be badly distorted. Unless special precautions are taken, they break to pieces as soon as they are removed from the bedrock.

The middle member is composed almost entirely of gray and brown platy limestone in beds from 1 inch to 1 foot thick. Some of them are cryptocrystalline, others fine- to coarse-crystalline. The crystalline beds are normally fossiliferous, the cryptocrystalline beds unfossiliferous. In some beds crystalline and noncrystalline limestones are intergrown, and a few beds were found in which intraformational conglomerate pebbles of noncrystalline, unfossiliferous limestone were enclosed in a matrix of crystalline, fossiliferous limestone. Shale partings separate many of the beds. Chert was not seen in the middle member at Hagan, but is common at many other places. It consists of white or gray chert, and is usually in small oval or irregular-shaped nodules or in lenses a few inches long. None of the oval nodules approaches in size those in the Hardy Creek member of the Moccasin limestone. In several places individual beds of birdseye limestone more than a foot thick form prominent ledges, and approach but do not equal the thickness of the massive birdseye limestone of the Lowville limestone. On slopes, the middle member of the Eggleston has numerous small ledgy outcrops of limestone that weathers light-gray to blue-white. In the section at Hagan the member is 57 feet thick.

The upper member consists of zones of platy limestone similar to the limestone in the middle member interbedded with zones of calcareous mudstone similar to the mudstone in the lower member. At Hagan the thickest zone of mudstone in the upper member measures 20 feet. This zone is underlain by 16 feet, largely of platy limestone, and overlain by 19 feet, also largely of platy limestone. In Plate 25A the lower platy zone of the upper member appears to the left of and above the bentonite. Along Wallen Ridge the upper member seems to be almost entirely mudstone with only a few interbeds of platy limestone, but the member maintains almost exactly the same thickness as at Hagan. This change of facies of the platy beds in the upper member of the Eggleston in a distance of only 7 miles suggests that the middle member may also change to mudstone farther east and southeast.

Bentonites have been described from the Eggleston limestone at many localities in southwest Virginia. They range in thickness from fractions of an inch up to several feet. Thin bentonites and possible bentonites occur in formations from the Murfreesboro to the Trenton, but by far the most conspicuous bentonites in the Rose Hill district are two thick ones in the upper part of the Eggleston limestone. The older of them lies at the top of the middle member. In the Hagan railroad cut it is 2 feet 2 inches thick, and is underlain by a 2-inch bed of gray chert (Pl. 25A). The bentonite is exposed at only a few other places in the district, but float from the underlying chert bed is conspicuous at many places. This chert can be distinguished from chert not associated with a bentonite by its uniform gray color, and by the blocky nature of the loose pieces, which have two flat parallel faces and have joint surfaces at varying angles on the other sides.

The second prominent bentonite lies 9 feet below the top of the Eggleston limestone. At Hagan (Pl. 22C) this bentonite is greenish-white where unweathered near the bottom of the railroad cut, but is yellow near the natural surface of the ground. It is 3 feet 4 inches thick and is underlain by a 2-inch bed of brownish-black chert (Pl. 23B). This chert bed also forms a prominent marker, as pieces of the chert can usually be found as float where the Eggleston has no outcrops. The interval between the two bentonites is only 41 feet, so that in places where exposures are poor there may be difficulty in telling whether loose pieces of blocky chert come from beneath the lower or the upper of the two big beds of bentonite.

Throughout most of the Rose Hill district minor folds, which are not directly associated with nearby faults, are extremely rare. Along Wallen Ridge, however, the mudstones of the Eggleston limestone have yielded by flowage, and the more competent platy limestones of the middle member of the Eggleston and the limestones of the uppermost Moccasin or lowermost Trenton have been folded. Most of the folds are too small to show on the geologic map (Pl. 2).

Stratigraphic relations.—The Eggleston-Moccasin contact has been drawn at the base of the lowest mudstone that is characteristic of the Eggleston in Lee County. The contrast between this mudstone and the underlying limestone of the Hardy Creek member of the Moccasin is shown very clearly in the photograph (Pl. 22B). Huffman[116] has

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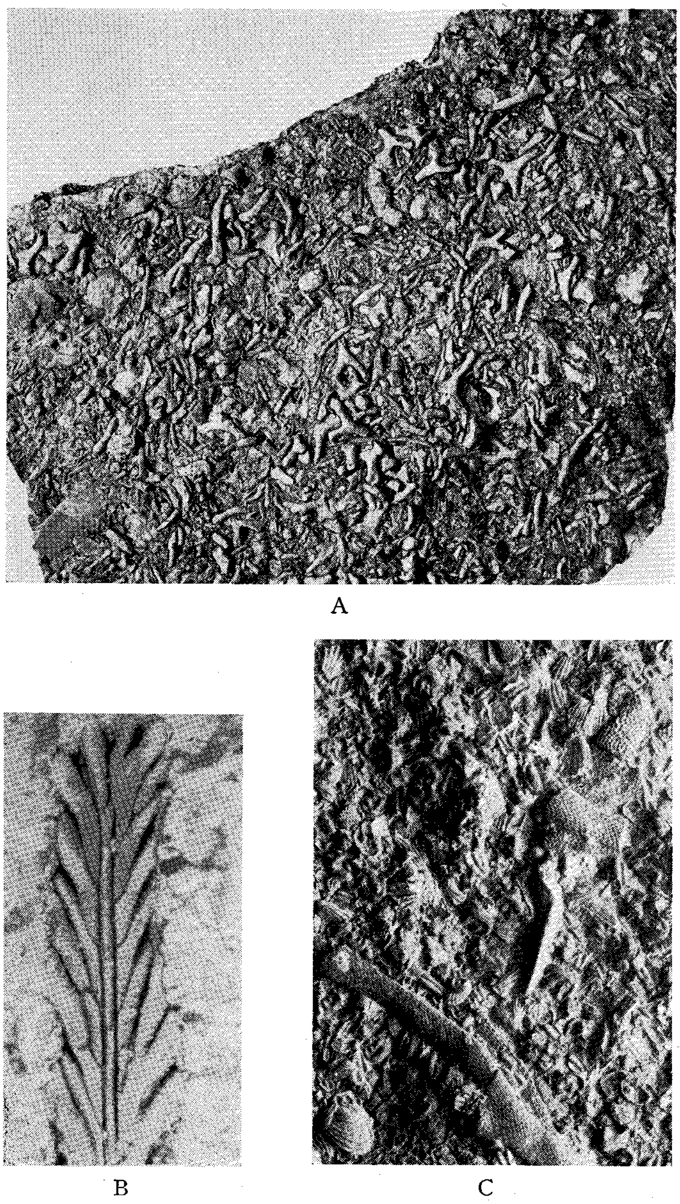
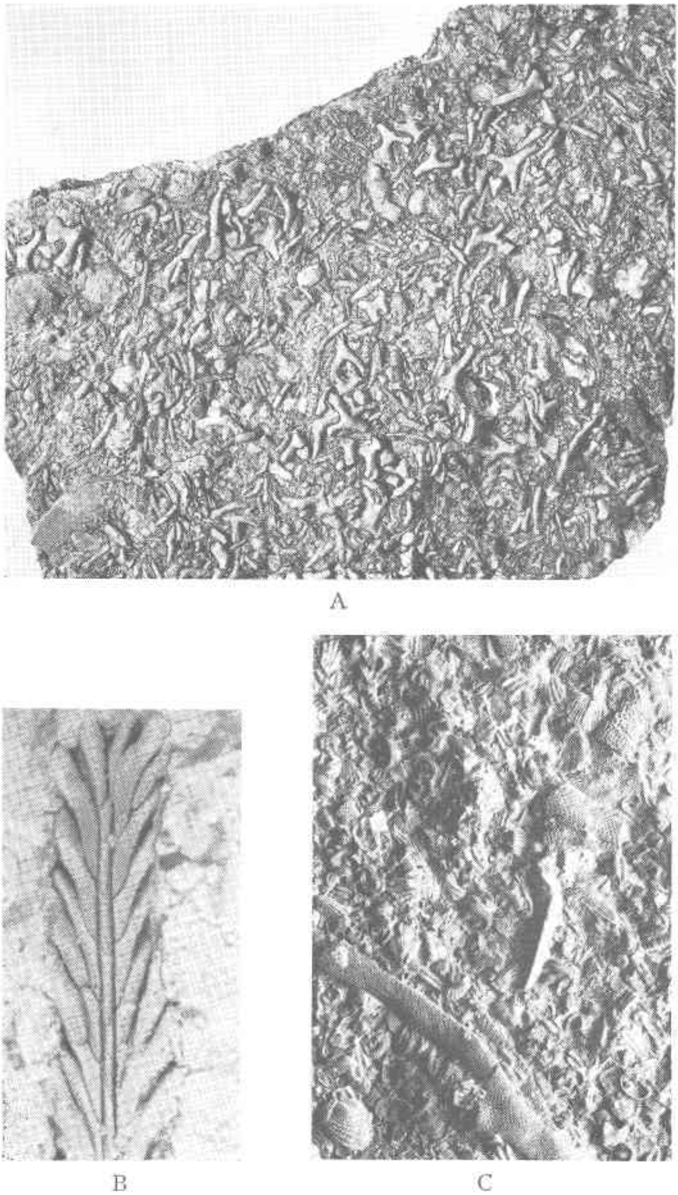
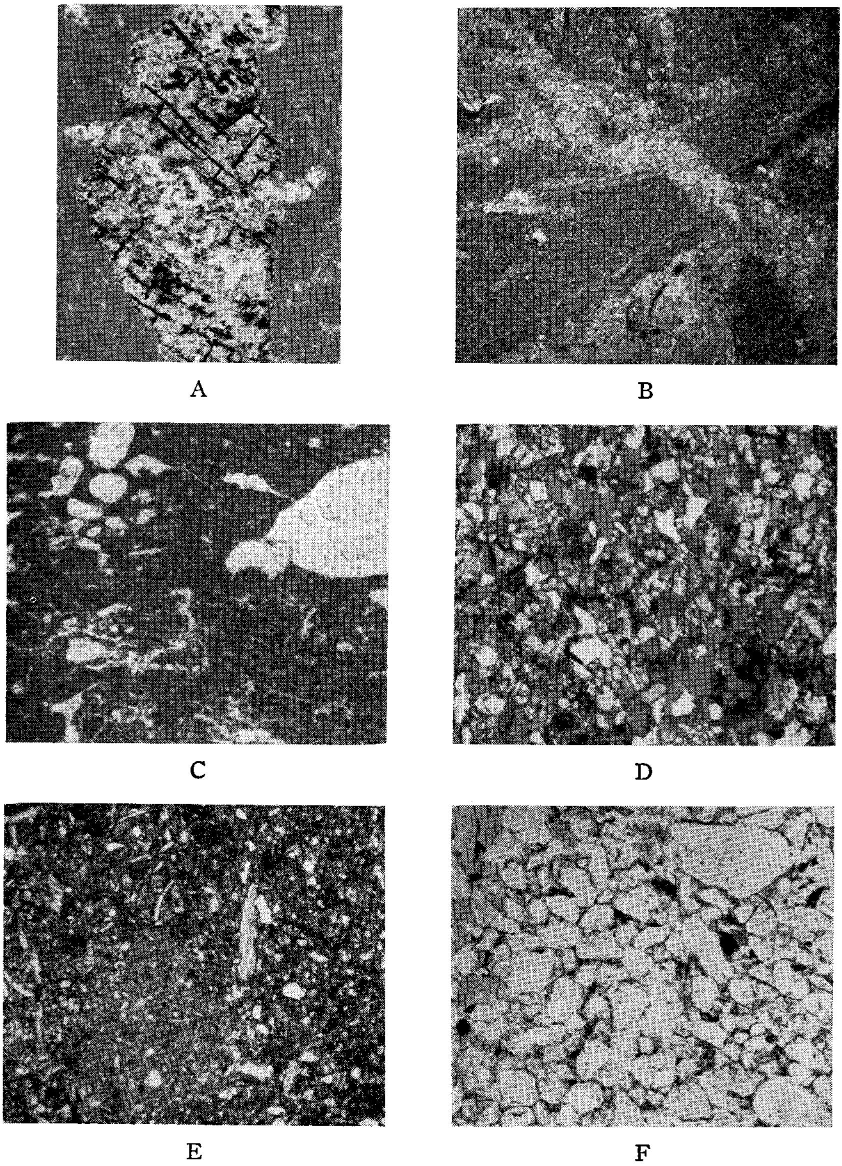
[116] Huffman, G. G., Middle Ordovician limestones from Lee County, Virginia, to central Kentucky: Jour. Geol., vol. 53, no. 3, p. 161, 1945.



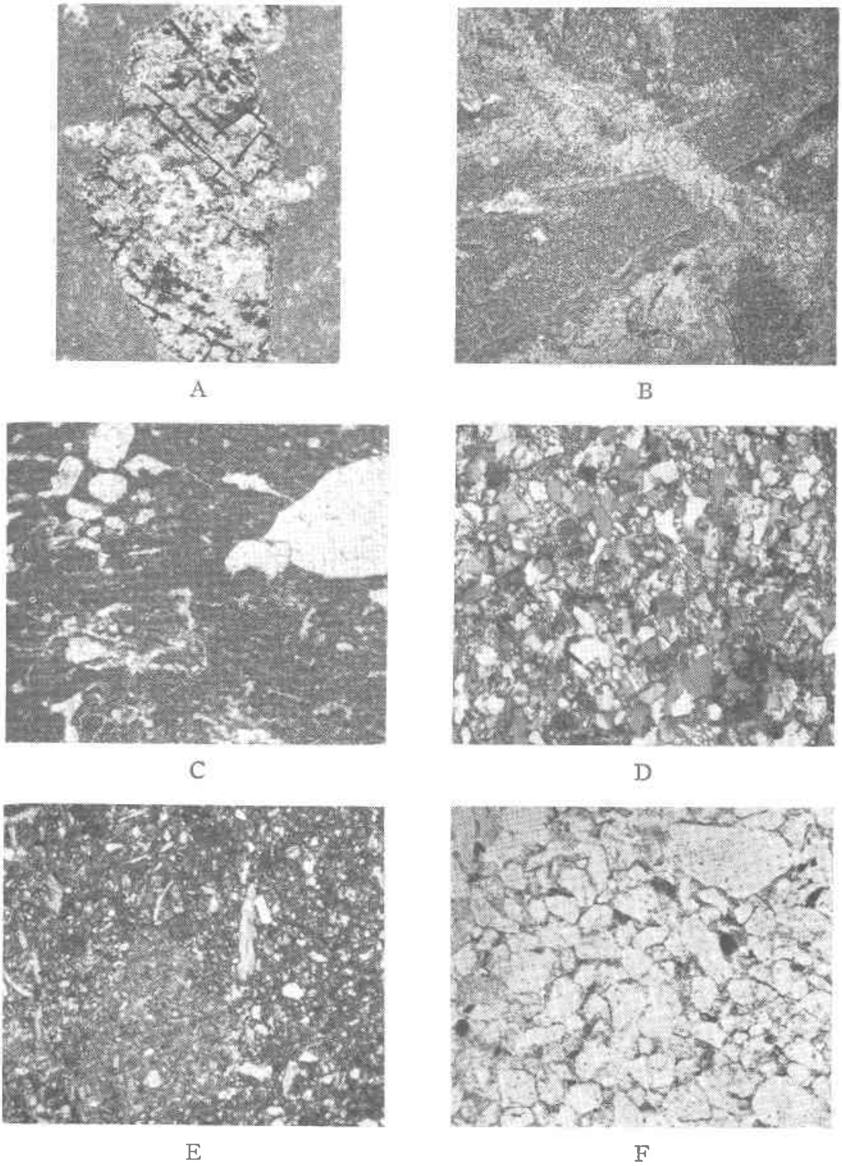
A, Typical slab from the rich bryozoan zone near the base of the Moccasin limestone. Wheeler Quarry. x½. B, *Helopora* sp. from massive sandstone of the Poor Valley Ridge member of the Clinch sandstone. Hagan section. x25. Photograph by Frank Swartz. C, Slab with abundant *Drepanella* sp. from 98 feet above the base of the Moccasin limestone at Wheeler Quarry. x½.



A, Typical slab from the rich bryozoan zone near the base of the Moccasin limestone. Wheeler Quarry. x½. B, *Helopora* sp. from massive sandstone of the Poor Valley Ridge member of the Clinch sandstone. Hagan section. x25. Photograph by Frank Swartz. C, Slab with abundant *Drepanella* sp. from 98 feet above the base of the Moccasin limestone at Wheeler Quarry. x½.



A, Birdseye of crystalline calcite surrounded by fine-textured limestone from a massive birdseye limestone of the Redbed member of the Lowville limestone. x50. B, Coquinal limestone of the lower part of the Trenton limestone. x15. C, Calcareous mudstone containing calcite birdseyes and veinlets. From the lower member of the Eggleston limestone. x20. D, Siliceous limestone in the Reedsville shale. Polarized light x70. E, Mudstone of the Sequatchie formation. x40. F, Sandstone from the Poor Valley Ridge member of the Clinch sandstone. x40.



A, Birdseye of crystalline calcite surrounded by fine-textured limestone from a massive birdseye limestone of the Redbed member of the Lowville limestone. x50. B, Coquinal limestone of the lower part of the Trenton limestone. x15. C, Calcareous mudstone containing calcite birdseyes and veinlets. From the lower member of the Eggleston limestone. x20. D, Siliceous limestone in the Reedsville shale. Polarized light x70. E, Mudstone of the Sequatchie formation. x40. F, Sandstone from the Poor Valley Ridge member of the Clinch sandstone. x40.

placed the contact at the base of a bentonite (?) 1½ inches thick, which is 9 feet lower in the section. He thus includes in the Eggleston, some beds that seem to us to belong with the Moccasin.

At the top of the Eggleston a 9-foot zone of interbedded cryptocrystalline and coarse-crystalline platy limestone overlies the big bentonite in the upper part of the Eggleston. Concerning this zone Huffman[117] says: "The 'cuneiform' beds are sparingly fossiliferous, but slabs with *Sowerbyella* and *Dalmanella* have been collected." He has, therefore, included this zone with the overlying Trenton. Nowhere have we seen *Sowerbyella* or *Dalmanella* in these beds, which lithologically belong with the Eggleston rather than with the Trenton. Furthermore we suspect that the "slabs" in which Huffman found *Sowerbyella* and *Dalmanella* came from the overlying beds which are coquinal and contain abundant specimens of these fossils. We have placed this 9-foot zone in the Eggleston limestone and have drawn the Eggleston-Trenton contact at the base of the lowest beds of typical Trenton lithology, which are also beds in which we found *Sowerbyella* and *Dalmanella.*

Thickness.—The Eggleston at Hagan is 146 feet thick. This section of the formation, which is perfectly exposed, is the thinnest in the area. The formation appears to be about 20 feet thicker at Chattels Station Church and about 30 feet thicker along Wallen Ridge. It is difficult to tell whether these greater thicknesses are due entirely to stratigraphic thickening of the formation or whether small faults such as are common in the Eggleston at Hagan may be present but unrecognized. The consistency of greater measured thickness for the Eggleston limestone along Wallen Ridge does, however, seem to indicate a thickening of the formation in a southeast direction. Huffman[118] reports that the Eggleston is 175 feet thick near Jonesville east of the Rose Hill area.

Paleontology.—Almost all the fossils of the Eggleston limestone are in the middle and upper members. Collections are made from these members at Hagan just east of the Rose Hill district, near Chattels Station Church in the northwest part of the district, and along U. S. Route 58, eight tenths of a mile west of Gibson Station and 7 miles west of the Rose Hill district (Pl. 13). The identified fossils are shown in Table 7, and additional forms collected in Lee County by Huffman[119] and identified by him are also listed.

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[117] Huffman, G. G., op. cit., p. 162.
[118] Huffman, G. G., op. cit., p. 158.
[119] Huffman, G. G., op. cit., p. 160.

TABLE 7.—*Fossils from Eggleston limestone, Lee County, Virginia*

	1	2	3	4
Sponge				
Camarocladia sp.	x			
Corals				
Lambeophyllum profundum (Conrad)				x
Lambeophyllum sp.			x	
Bryozoa				
Arthroclema sp.	x			
Batostoma sp.				x
Escharopora sp.	x			
Helopora sp.	x			
Rhinidictya cf. *R. mutabilis*	x			x
Rhinidictya sp.		x	x	
Ramose bryozoan, unidentifiable			x	
Brachiopods				
Doleroides gibbosus (Billings)				x
Doleroides sp.	x			x
Doleroides? sp.			x	
Glyptorthis sp.			x	
Öpikina aff. *Ö. transitionalis* Okulitch	x			x
Öpikina sp.			x	
Pionodema minuscula Willard?	x			
Pionodema sp.				x
Pionodema? sp.	x			
Rhynchotrema sp.	x	x		
Strophomena sp.	x	x	x	x
Zygospira recurvirostris (Hall)	x		x	x
Pelecypod				
Cyrtodonta sp.				x
Cephalopods unidentified	x	x	x	x
Gastropods				
Lophospira sp.			x	
Subulites sp.				x
Unidentifiable forms		x		x
Ostracodes				
Drepanella sp.			x	
Eurychilina sp.	x			
Leperditella sp.		x	x	
Leperditia fabulites (Conrad)			x	
Leperditia sp.			x	

1. Middle member of Eggleston at Hagan.
2. Upper member of Eggleston at Hagan.
3. Middle member of Eggleston on U. S. Route 58, three miles east of Cumberland Gap.
4. Middle member of Eggleston at Chattels Station Church, two miles west of Ewing.

Additional fauna reported by Huffman from the Eggleston of Lee County, Virginia

Coral
Tetradium cellulosum

Bryozoa
Escharopora sp. cf. *E. confluens* Ulrich
Escharopora subrecta Ulrich
Rhinidictya nicholsoni Ulrich

Brachiopods
Öpkina sp. cf. *Ö. minnesotensis* (Winchell)

Pelecypod
Cyrtodonta sp. cf. *C. huronensis* (Billings)

Gastropods
Helicotoma sp.
Lophospira oweni Ulrich and Scofield

Cephalopods
Cameroceras sp.
Cycloceras sp.
Endoceras sp.

Ostracodes
Aparchites sp.
Eurychilina subradiata Ulrich
Primitiella sp. (?)

Trilobites
Calliops sp. cf. *C. callicephalus* (Hall)
Eomonorachus sp.
Illaenus sp.

The fauna of the Eggleston limestone shows a strong similarity to the faunas of the underlying Moccasin and Lowville limestones. The only fossil we found abundantly in the Eggleston that is not also present in these two underlying formations is the horn coral *Lambeophyllum (Streptelasma) profundum*. In the Rose Hill district it is a reliable guide fossil for the middle and upper members of the Eggleston. *Lophospira* and *Eurychilina* were found, outside the Eggleston, only in the top beds of the Moccasin, but they have been reported elsewhere in southwest Virginia from lower beds by Cooper and Prouty[120] and by Butts.[121] *Tetradium cellulosum* is reported from the Eggleston by Huffman.

Age and correlation.—Matthews[122] assigned an upper Black River age to the Eggleston limestone and a lowermost Trenton age to the overlying beds. Rosenkrans[123] and Butts[124] in general accepted this view, but Cooper and Prouty[125] and Cooper[126] have suggested that the

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[120] Cooper, B. N., and Prouty, C. E., Stratigraphy of the lower Middle Ordovician of Tazewell County, Virginia: Geol. Soc. America Bull., vol. 54, no. 6, pp. 826, 829-833, 1943.

[121] Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. I, Geologic text and illustrations, p. 123, 1940.

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

[123] Rosenkrans, R. R., Stratigraphy of Ordovician bentonite beds in southwestern Virginia: Virginia Geol. Survey Bull. 46-I, p. 100, 1936.

[124] Butts, Charles, op. cit., p. 195.

[125] Cooper, B. N., and Prouty, C. E., op. cit., p. 881.

[126] Cooper, B. N., Geology and mineral resources of the Burkes Garden quadrangle, Virginia: Virginia Geol. Survey Bull. 60, p. 103, 1944.

Eggleston may be of Trenton age. Huffman[127] has recently correlated the Eggleston with Raymond's Rockland formation (basal Trenton) of New York. Huffman bases his belief in the Trenton age of the Eggleston of Lee County and the Tyrone of Kentucky on "their conformity with the Curdsville, which has been correlated with the Kirkfield (Hull) of Ontario and New York on the basis of its echinoderm fauna."[128]

Rosenkrans[129] questioned the propriety of designating the Eggleston as a separate formation, believing instead that it was a facies of beds that elsewhere in southwest Virginia have been assigned to the Moccasin limestone or Martinsburg shale. The first appearance of the fauna of the "Curdsville limestone" in Lee, Wise, Scott and Tazewell counties overlies rocks like the Eggleston. Beds that are equivalent to those in the Eggleston limestone in the western part of the Appalachian Valley probably do form the upper part of the Moccasin limestone to the east and southeast. For example, in Rosenkrans'[130] section of the Moccasin of Big Moccasin Gap, the upper 28 feet of beds which he assigns to the Moccasin seem to resemble the Eggleston calcareous mudstones much more closely than they do the usual type of Moccasin, and these beds also contain bentonite V3 of Rosenkrans which he includes in his Eggleston facies in Tazewell County.

Whereas the upper Moccasin, including probable Eggleston equivalents, is a mudstone east of Lee County, considerable thicknesses of platy nonargillaceous limestone are present in the middle and upper members of the Eggleston of the Rose Hill district. The mudstone facies thus appears to change to a limestone facies in a westward direction, and probably also in a northwestward direction. Huffman[131] correlates the Eggleston of Lee County with the upper part of the Tyrone limestone of central Kentucky, which is dominantly limestone but contains "beds of calcite-flecked mudrock * * * [which] resemble those in the Eggleston."

TRENTON LIMESTONE

Name.—The name Trenton limestone has been used by Butts,[132] in Lee and Wise counties, Virginia, to designate limestone over-

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[127] Huffman, G. G., op. cit., Fig. 9.
[128] Huffman, G. G., op. cit., p. 174.
[129] Rosenkrans, R. R., op. cit., p. 99.
[130] Rosenkrans, R. R., op. cit., pp. 108-110, 1936.
[131] Huffman, G. G., op. cit., pp. 169-170, 174.
[132] Butts, Charles, op. cit., pp. 213-216.

lying the Eggleston limestone of Black River age and underlying the Reedsville shale of Eden and Maysville age.

Distribution.—The Trenton limestone crops out in belts on opposite flanks of the Powell Valley anticline. In the northern belt the Trenton forms the northern part of the lowland of Ordovician limestone and the top of the Trenton lies a short distance above the base of Poor Valley Ridge. In the southern belt, where the relief between the floor of the lowland and the crest of the ridge of Clinch sandstone is greater, the Trenton lies almost entirely on the lower slopes of Wallen Ridge. The width of the northern belt averages 600 feet and the southern belt 1100 feet.

The Trenton limestone is also exposed in the Dean fenster, where the whole formation is present in Edds Hollow, and the upper part of the formation is exposed in Low Hollow. Also the Trenton limestone makes up all or part of six slivers that lie along overthrust fault planes in the Hamblin Branch, Dean, and Fourmile fensters.

Character.—The Trenton limestone of southwest Virginia is characteristically poorly exposed. In the Rose Hill district, although it forms gentle hills in its northern belt and lies on the slopes of Wallen Ridge in its southern belt, outcrops of the limestone are rare. In the northern belt, sinkholes are common and are concentrated especially in beds near the top of the lower third of the formation. Even where no sinkholes exist this part of the Trenton is commonly a little lower than the line of gentle hills along the Trenton-Eggleston contact,. The upper part of the Trenton in the northern belt lies along the lower slopes of Poor Valley Ridge below the line of knobs which are formed by the Reedsville shale. Hence outcrops of the upper part of the Trenton are more abundant than of the rest of the formation.

In the southern belt, where most or all of the Trenton lies on the lower slopes of Wallen Ridge, the lowest Trenton is normally exposed in small ledges. Commonly one or two zones of limestone higher in the Trenton also crop out, but outcrops of higher beds are not at consistent horizons and are due mainly to local conditions of drainage and erosion.

Although the Trenton limestone is essentially a lithologic unit, there are some variations in the type of limestone composing it. It can be divided roughly into three lithologic parts, which are not sharply distinguished from one another. No attempt was made to map these lithologic divisions.

The lower part, which is 200 feet thick, is composed of gray, or mottled gray-and-white, coarse-crystalline limestone with abundant fossils. Some beds are composed almost entirely of fossil shells, mainly brachiopods. The beds are even and platy, from 1 inch to 1 foot thick, but average from 3 to 6 inches in thickness. Partings of dark-gray shale are abundant, and a few beds of shale, up to 2 inches thick, are present. Chert lenses are common in some sections, rare in others. The chert in the Trenton differs from that in the Eggleston limestone and Lowville limestone. In the Trenton it is gray, granular and mealy, and occurs in beds or lenses from 1 to 2 inches thick, whereas it occurs as nodules in the Eggleston and Lowville. In thin section (Pl. 24B) the coquinal Trenton limestone appears as bladed, closely interlocking crystals with numerous sectioned fossils. The finer grained matrix in which the coarse-crystalline areas lie consists of argillaceous limestone.

The middle part of the Trenton is made up dominantly of gray fine- to medium-crystalline somewhat siliceous limestone in even beds which are in general thicker than those in the lower part of the Trenton. Some beds are nearly 2 feet thick although they average less than 1 foot thick. The limestone is sparingly fossiliferous and weathers with smoother surfaces than do the coquinal beds of the lower part of the Trenton. Beds of coarse-crystalline coquinal limestone are also present, but they account for only a small part of the total thickness. This part of the Trenton contains chert at some localities, but not at others. The chert is commonly gray or white, is of mealy texture, and may contain silicified fossils. A few lenses of dense flint are prominent in the upper beds near Chattels Station Church. This middle part of the Trenton is about 275 feet thick.

The upper part of the Trenton resembles the lower part in being dominantly a coarse-crystalline coquinal limestone. Much of the limestone, however, has a brown or brownish-gray color, which is especially prominent in well cuttings. This color helps to distinguish the upper Trenton from the middle Trenton and from limestones in the overlying Reedsville shale. Gray shale is interbedded with the limestone, mainly as partings, but in some zones shale accounts for nearly one-third of the rock. A few beds of fine- to medium-crystalline siliceous unfossiliferous limestone are interbedded with the coquina. The fossils are dominantly gastropods and bryozoa with occasional beds containing abundant brachiopods. Chert is sparingly present. This upper division of the Trenton is approximately 75 feet thick.

The Trenton is almost completely exposed in the cut of the Louisville and Nashville switchback at Hagan (Geologic Section 9). A fair section of the formation is also present along a small valley north of Chattels Station Church, and beds in the lower part of the Trenton are well exposed in a quarry along Powell River at Parkey Bridge.

Stratigraphic relations.—The Eggleston-Trenton contact is very distinct, but is apparently conformable. The highest beds of the Eggleston are composed almost entirely of tan cryptocrystalline or fine-crystalline limestone containing some fossils. The lowest Trenton is coarse-crystalline, gray limestone with abundant fossils including especially *Dalmanella fertilis, Sowerbyella curdsvillensis,* and *Rhynchotrema.* The contact lies about 9 feet above the top of the upper big bentonite in the Eggleston.

The contact of the Trenton limestone and Reedsville shale is drawn at the base of the beds composed dominantly of shale. This contact is easily recognizable even in poorly exposed areas because of the prominence of abundant shale chips in the soil derived from the lowest Reedsville and their comparative absence in the soil derived from the Trenton.

Thickness.—Only one reliable thickness measurement of the outcropping Trenton limestone was obtained in the Rose Hill district. This was at Hagan where the formation is 562 feet thick. At Chattels Station Church, where both the lower and upper contacts are concealed, the formation appears to be between 671 and 728 feet thick, but this section contains long covered intervals. It seems more likely that reverse faults, such as are visible at Hagan, have duplicated beds in this section rather than that the formation has thickened by 100 to 150 feet in the 12 miles between the two sections.

The only oil wells where nearly flat-lying Trenton beds were penetrated and where adequate records are available are the Brooks and Lemons No. 1 wells. In the former the Trenton is 549 feet thick and in the latter 560 feet thick. The Trenton thus appears to have an average thickness of about 560 feet in the Rose Hill district.

Paleontology.—The Trenton limestone is abundantly fossiliferous, especially in the lower and upper parts. Collections of fossils across the whole formation have been made at Hagan and Chattels Station Church but they were not exhaustive and much remains to be done in working out the faunal zones. The following statements on the Trenton fauna are of a tentative nature, and are based largely on the brachiopods. Few of the abundant bryozoa or gastropods have been identified.

The lower part of the Trenton is characterized by abundant *Dalmanella fertilis* and *Sowerbyella curdsvillensis. Rhynchotrema increbescens, Rafinesquina trentonensis* and *Dinorthis pectinella* are common in the lowest beds, and *Prasopora* sp. comes in a few feet above the base of the formation. This assemblage ranges through the lowest 150 feet of the Trenton and *Rafinesquina* and *Rhynchotrema* go even higher.

The middle part of the Trenton, which is much less fossiliferous, contains *Saccospongia* sp., *Rafinesquina trentonensis, Hebertella frankfortensis, Rhynchotrema increbescens, Zygospira recurvirostris, Byssonychia* sp., *Cyrtodonta* cf. *C. grandis,* and *Lophospira* cf. *L. ulrichi.*

The upper 75 feet, which is also abundantly fossiliferous, is composed in large part of unidentified bryozoans and gastropods, but also contains *Rafinesquina trentonensis, Hebertella* sp. and *Dinorthis pectinella.*

The complete fauna identified from the Trenton is given in Table 8.

Age and correlations.—No doubt exists regarding the Trenton age of the beds here included in the Trenton limestone. There is, however, some question whether the underlying Eggleston and Moccasin limestones may not also be Trenton (pp. 107, 116).

The Trenton limestone of Lee County represents a limy facies of beds that farther east and northeast are more shaly and are lithologically indistinguishable from the overlying shales of Eden and Maysville age.[133] Outside of Lee and Wise counties the name Martinsburg shale has therefore been used in southwest Virginia by Butts and others to include beds that are equivalent to the Trenton limestone and Reedsville shale of this report.

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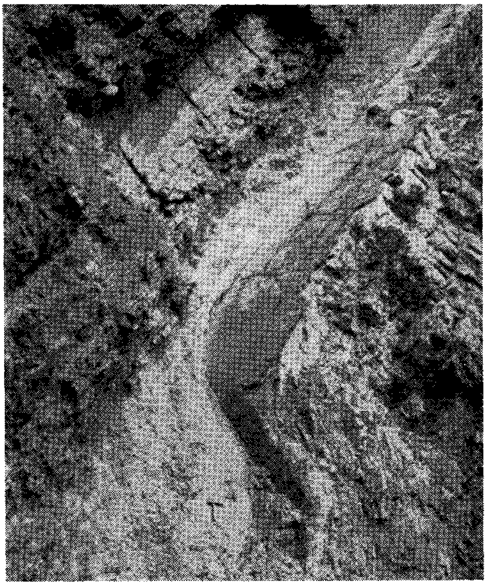
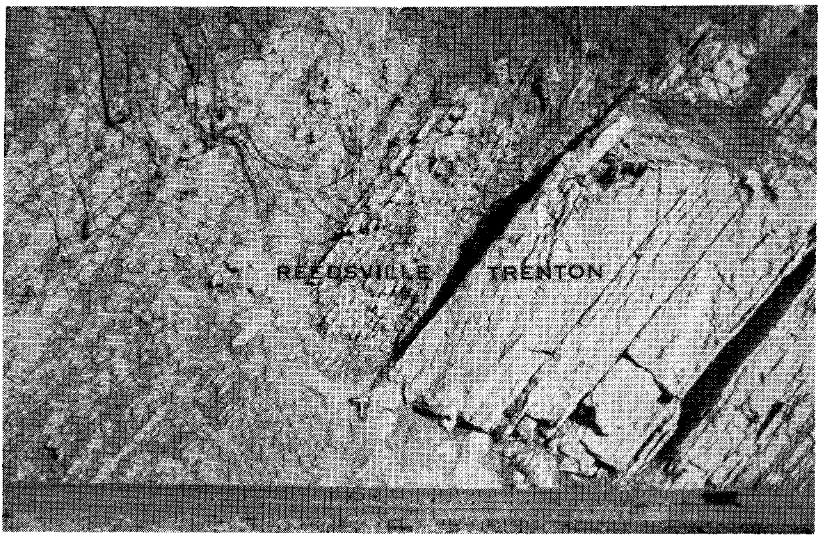
[133] Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. I, Geologic text and illustrations, pp. 202-203, 1940.



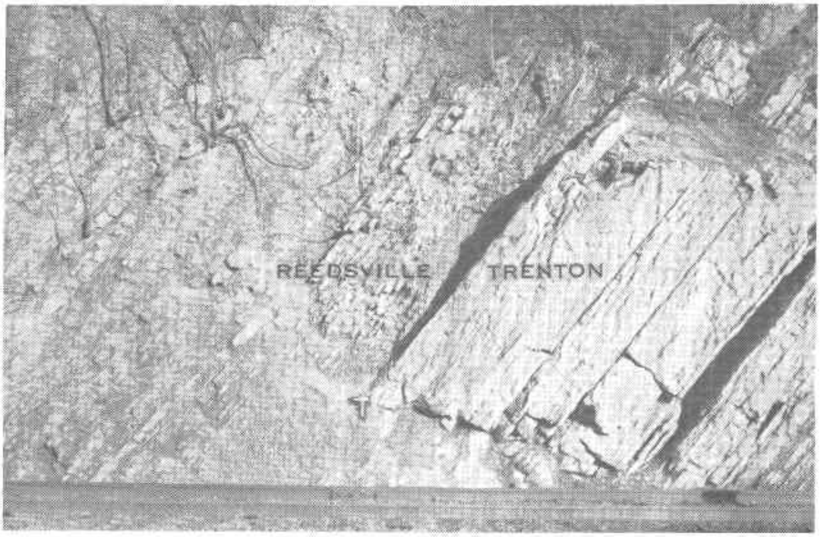
A



B

A, Lower big bentonite of the Eggleston limestone at Hagan. B, Trenton-Reedsville contact at Hagan, with massive-bedded upper part of Trenton limestone to right of hammer and Reedsville shale and platy limestone to the left.

A



B

A, Lower big bentonite of the Eggleston limestone at Hagan. B, Trenton-Reedsville contact at Hagan, with massive-bedded upper part of Trenton limestone to right of hammer and Reedsville shale and platy limestone to the left.

TABLE 8.—*Fauna of the Trenton limestone, Rose Hill district*

UPPER PART (75 feet)
- Bryozoa
- *Dinorthis pectinella* (Emmons)
- *Hebertella frankfortensis* (Foerste)
- *Hebertella* sp.
- *Hesperorthis tricenaria* (Conrad)
- *Platystrophia* sp.
- *Rafinesquina trentonensis* (Conrad)
- *Rhynchotrema increbescens* (Hall)
- *Rhynchotrema* sp.
- *Zygospira recurvirostris* (Hall)
- *Ctenodonta* sp.
- Cephalopods
- Gastropods

MIDDLE PART (275 feet)
- *Saccospongia* sp.
- Crinoid aff. *Glyptocrinus*
- Bryozoa
- *Hebertella frankfortensis* (Foerste)
- *Hebertella* sp.
- *Rafinesquina trentonensis* (Conrad)
- *Rhynchotrema* sp.
- *Sowerbyella curdsvillensis* (Foerste)
- *Zygospira recurvirostris* (Hall)
- *Byssonychia* sp.
- *Cyrtodonta* cf. *C. grandis* Ulrich
- *Cyrtodonta* sp.
- *Bellerophon* sp.
- *Lophospira* sp. cf. *L. ulrichi* Bassler
- *Lophospira* sp.
- *Sinuites sp.*
- *Ceraurus pleurexanthemus* (Green)

LOWER PART (200 feet)
- *Lambeophyllum* sp.
- *Prasopora* sp.
- Bryozoa
- *Dinorthis pectinella* (Emmons)
- *Hesperorthis tricenaria* (Conrad)
- *Rafinesquina trentonensis* (Conrad)
- *Resserella (Dalmanella) fertilis* (Bassler)
- *Rhynchotrema increbescens* (Hall)
- *Rhynchotrema* sp.
- *Sowerbyella curdsvillensis* (Foerste)
- *Strophomena* sp.
- *Ctenodonta* sp.
- *Liospira* sp.
- *Sinuites* sp.

Huffman[134] has recently subdivided the Trenton limestone of Lee County into Curdsville, Logana (Hermitage) and Catheys-Cannon. The top 9 feet of the Eggleston of this report and the lower 30 feet of the Trenton of this report are placed by him in the Curdsville limestone, whose type region is on the western side of the Blue Grass basin of Kentucky. Our reasons for including the lower 9 feet of Huffman's Curdsville in the Eggleston have previously been discussed (pp. 112-113). Both stratigraphic position and the association of *Sowerbyella curdsvillensis* and *Dinorthis pectinella* support his correlation of the overlying beds with the Curdsville of Kentucky, but the top of the zone of Curdsville age is very vague. Huffman draws the contact between his Curdsville and Logana (Hermitage) at the base of a bentonite, which at Hagan is 7 inches thick, and which is said to underlie a zone characterized by abundant *Sinuites cancellatus* and *Dalmanella fertilis*. *Sinuites cancellatus* is not a characteristic fossil of the Hermitage of either Kentucky or Tennessee and *Dalmanella (Resserella) fertilis* occurs abundantly below, as well as above, Huffman's contact between the Curdsville and Logana. Furthermore the beds above and

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[134] Huffman, G. G., Middle Ordovician limestones from Lee County, Virginia, to central Kentucky: Jour. Geology, vol. 53, no. 3, p. 160, 1945.

below the 7-inch bentonite are lithologically similar. The evidence thus seems inconclusive that the top of Huffman's Curdsville at Hagan is the same as the top of the Curdsville in Kentucky. Huffman includes 55 to 65 feet of beds in his Logana formation, which he correlates with the post-Curdsville part of the Hermitage of Tennessee. The separation of the Logana from the overlying Catheys-Cannon is also vague both lithologically and paleontologically. We feel that more paleontologic evidence is necessary before these correlations with the formations of Trenton age of Kentucky and Tennessee can be considered established.

BENTONITES OF THE ROSE HILL DISTRICT

GENERAL STATEMENT

The early hope that bentonites would be valuable tools for correlation over long distances has not materialized fully, owing partly to the large numbers of bentonites that have been found. Additional beds are still being discovered, as new highway cuts, quarries and excavations for foundations uncover beds not previously well exposed. Bentonites have now been reported in the Appalachian Valley in Ordovician formations ranging from the basal Murfreesboro limestone to the Sequatchie formation.[135] In a small area, however, bentonites provide an extremely valuable tool for mapping and local correlation, because the thickness, number, and spacing of the bentonites does not vary sufficiently from place to place to introduce serious difficulties in recognizing the identity of the bentonites.

Under ideal outcrop conditions, bentonites less than an inch thick can be recognized, but only the thicker bentonites are found at the surface in enough places to be real aids in mapping. In oil wells, thin bentonites are usually penetrated without being recognized by the driller or without showing in the cuttings. Bentonites 6 inches or more thick normally are noticed both by drillers and geologists. The tendency for bentonites to cave in uncased and untreated wells usually results, however, in much larger shows of bentonite fragments in some of the cuttings below the source bed than in the sample in which the bed was actually drilled.

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[135] Fox, P. P., and Grant, L. F., Ordovician bentonites in Tennessee and adjacent states: Jour. Geology, vol. 52, no. 5, pp. 319-332, 1944.

Laurence, R. A., An early Ordovician sinkhole deposit of volcanic ash and fossiliferous sediments in east Tennessee: Jour. Geology, vol. 52, no. 4, pp. 235-249, 1944.

Where several bentonites are closely spaced, as in the Eggleston limestone, it is almost impossible to recognize thinner bentonites underlying a thick one, because cavings from the thick bentonite contaminate the cuttings for some distance down the hole below the thick bed.

DESCRIPTION OF BENTONITES

Thirteen different bentonites or probable bentonites have been found in the Rose Hill district. They have been numbered R1 to R13 for convenience in referring to them, the R standing for Rose Hill district. There are numerous other clay beds in the Ordovician formations, some of which have been called bentonites by other workers. We have excluded them from the category of probable bentonites, because they failed to show any mica flakes, glass shards, or other characteristics that would confirm a bentonitic origin for them.

One of the bentonites is in the Murfreesboro limestone, one in the Lowville limestone, one in the upper part of the Trenton limestone and ten are in the 250 feet of beds extending from the upper part of the Moccasin limestone through the Eggleston limestone into the lower part of the Trenton limestone. A similar concentration of bentonites in and near the Eggleston limestone was found over a broad area in southwest Virginia by Rosenkrans,[136] and 12 of Fox and Grant's[137] 14 bentonites lie in the same part of the column.

Bentonite R1.—Six bentonites in the Rose Hill district are especially important as horizon markers. The lowest of them lies at the base of the Murfreesboro limestone (Pl. 26, R1). This bentonite does not appear to be everywhere present, for it was found only at Walnut Hill School (Pl. 13) and in the cuttings of the Lemons well. No doubt the agitated conditions of sedimentation in earliest Murfreesboro time, and the accumulation of the earliest Murfreesboro sediments only in low areas on the pre-Murfreesboro surface (p. 67) prevented the accumulation and preservation of an uncontaminated bed of volcanic ash over the whole region. However, exposures of this part of the Murfreesboro are poor, and the bentonite may be more widespread than is realized.

At Walnut Hill School the bentonite lies 11 feet above the base of the Murfreesboro. It was uncovered by digging on the west side of a barn 1500 feet due south of Walnut Hill School, and it was also found

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[136] Rosenkrans, R. R., op. cit.
[137] Fox, P. P., and Grant, L. F., op. cit.

in the meadow 100 yards east of the barn. The bentonite is a greenish-white slippery clay, which disintegrates but does not swell in water. Mica flakes, visible with the hand lens, are common but not abundant. They are both dark brown and light greenish-brown in color. A few rounded sand grains are scattered through the clay. The underlying bed of dolomite is poorly exposed at Walnut Hill School but does does not seem to be silicified. This bentonite is particularly useful for subsurface correlation, inasmuch as the criteria that make the mapping of the Murfreesboro-Mascot contact very simple at the surface are of little help in recognizing this contact in well cuttings. The horizon has been drilled only in the Lemons well where the bentonite was very prominent.

The bentonite (R1) in the basal part of the Murfreesboro limestone is the oldest Ordovician bentonite so far discovered. Fox and Grant[138] have recently reported a 3-foot bentonite directly overlying the basal conglomerate of the Murfreesboro in north Chattanooga and at Watts Bar dam in Rhea County, Tennessee (Pl. 26, B1). The identical stratigraphic position of their bentonite and the one in the Rose Hill district suggests that the Tennessee and Virginia occurrences represent the same ash fall.

Bentonite R2.—The second important bentonite of the Rose Hill district directly underlies the No. 2 zone of massive birdseye limestone in the redbed member of the Lowville limestone (Pl. 26, R2). It consists of a 4- to 12-inch bed of yellow and white clay, which is completely free from detrital material and is therefore believed by Ross[139] to be a bentonite. It contains practically no mica, and very little carbonate. The bed is exposed along the dirt road paralleling Hardy Creek at Hagan, where it is 4 inches thick. It is also exposed in a bluff overlooking the Powell River just west of the stratigraphic section measured opposite the mouth of Fourmile Creek (Geologic Section 8, Unit 8). At the latter locality it appears to average about 1 foot thick, but has been squeezed so that it varies greatly in thickness over short distances.

This bentonite bed (R2) was not observed in the Lemons well. It is probably too poorly consolidated to supply chips in the cuttings, and it is not thick enough to be noted by the driller unless considerable caving of the bentonite into the hole took place. It is of particular interest, however, as it lies in a part of the geologic column in which

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[138] Fox, P. P., and Grant, L. F., op. cit.
[139] Ross, C. S., personal communication.

bentonites have not previously been reported in Virginia, Kentucky or Tennessee.

Other possible bentonites in the Lowville limestone.—Another clay bed, 2½ inches thick, is exposed along the Hardy Creek road 149 feet above R2. It is reported by Ross,[140] however, to contain abundant detrital material, and is probably not a bentonite. A probable bentonite, which has not been seen at the surface, was found in cuttings of the Lemons well at a depth of 1953 feet. Its stratigraphic position is poorly known because of changes in dip of the beds and lack of horizon markers recognizable in well cuttings in this part of the section. It apparently lies somewhere near the *Stromatocerium* zone a little above the middle of the Lowville. It may be the same bed as the 2½-inch clay bed just described, which lies 55 feet below the *Stromatocerium* zone and was thought from its surface exposure not to be a bentonite. Because the information on this possible bentonite is so scanty, it has not been given a number and is not shown on Plate 26.

Bentonites R3-R6.—Four beds (R3 to R6) which are bentonites and probable bentonites, lie in the Hardy Creek member of the Moccasin limestone and in the lower and middle members of the Eggleston limestone (Pl. 26, R3-R6). Bentonites have also been reported from this part of the geologic column from other localities in Virginia and Tennessee. In the Rose Hill district these bentonites have been found only at Hagan, and were not noted in the Lemons well. Hence, they have been of little stratigraphic use. R4, which lies 25 feet below the top of the Moccasin, is 5 inches thick; the lower 2 inches of it is a grayish-white clay and the upper 3 inches a white bentonitic shale. The clay is powdery when dry, and disintegrates rapidly in water. It contains a small proportion of carbonate as shown by violent but brief effervescence in hydrochloric acid. Very small but abundant bronze mica flakes in the insoluble fragments are adequate proof of the bentonitic origin of this clay. R3 is a bed of probable bentonitic clay, a quarter of an inch thick, lying 2 feet below R4, and R5 is a 1½-inch bed of gray gritty clay of possible bentonitic origin 14½ feet above R4. R6 is a clay shale, 6 inches thick, which lies 52 feet above the base of the Eggleston limestone. It may be bentonitic, but has not been definitely identified as a bentonite.

Bentonites R7-R10.—By far the thickest and most conspicuous bentonites in the Rose Hill district are the two that lie in the upper

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[140] Ross, C. S., personal communication.

part of the Eggleston limestone. R7 is at the top of the middle member and R10 at the top of the upper member, 41 feet higher. Both are perfectly exposed in the Hagan railroad cut (Pls. 25A and 22C), where R7 is 2 feet 2 inches thick and R10 is 3 feet 4 inches thick. They have also been found in many other places in and near the district, and are undoubtedly much more widespread. Each bentonite is underlain by a prominent silicified zone consisting of an even bed of gray to black chert averaging 2 inches in thickness. The chert breaks into angular blocks with parallel bedding surfaces at the top and bottom. Even small chunks of this chert in the soil can be distinguished by color and shape from chert derived from nodules or beds not associated with a bentonite. The position of the two big bentonites in the Eggleston limestone can thus be spotted in many places by outcrops or by float from these distinctive chert beds. In some places one or both of the bentonites can even be uncovered in open fields by digging just above outcrops of the chert.

The lower (R7) of the big bentonites is not uniform throughout but contains layers of bentonitic shale, and a subsidiary bentonite, 1 to 2 inches thick, lies 6 inches above the top of the main bentonite zone. A section of the bentonite R7 and associated beds at Hagan follows:

Bentonite R7 at Hagan, Lee County, Virginia

		Thickness	
		Ft.	In.
	8. Limestone, gray, platy, with shaly partings 1 to 2 inches thick, some of which may be bentonitic	2+	
	7. Bentonite, dark greenish gray	0	1-2
	6. Limestone, light gray, cryptocrystalline and medium crystalline, fossiliferous; bottom surface undulatory	0	6
R7	5. Bentonite, green, soft, micaceous	0	6-9
	4. Bentonitic shale, light green, tough	0	10
	3. Bentonite, light green, soft, slightly gritty, micaceous	0	11
	2. Chert, gray, in even bed 2 inches thick, with sealed contact with underlying limestone	0	2
	1. Limestone, gray, even bedded	2+	
		7	2

At Hagan the R7 bentonite has been squeezed and faulted during the regional deformation so that at track level the bentonite funnels out and becomes nearly 10 feet wide.

Two relatively unimportant probable bentonites (R8 and R9) 1½ and 2 inches thick are exposed at Hagan in the interval between the big bentonites. They have not been observed elsewhere.

At Hagan the upper big bentonite (R10) of the Eggleston limestone is nearly uniform throughout its entire thickness of 3 feet 4 inches except for a 0 to 3-inch shaly zone near the middle. It is light gray, with abundant large flakes of bronze mica. It lies on a bed of gray chert, 2 inches thick, on the top surface of which excellent oscillation ripple marks are preserved. This bentonite, with its associated chert bed, is a valuable horizon marker both at the surface and in wells, because it is so readily recognized and because it lies only 9 feet below the base of the Trenton.

Bentonites R11 and R12.—Two bentonites were found in the lower part of the Trenton limestone. The lower one (R11), 31 feet above the base of the formation, is a 7-inch bed of greenish-gray clay, probably but not certainly of bentonitic origin. The upper one (R12), 69 feet above the base of the Trenton, is poorly exposed at Hagan, because it lies on the edge of a sinkhole through which the railroad cut has been driven. The sink is full of slumped residual clays, and the bentonite itself has mainly slumped into the depression. By extensive digging some of the bentonitic clay can still be uncovered on the edge of the sink or in the low cut on the opposite side of the railroad. The bentonite bed appears to be at least a foot thick. The only uncontaminated specimen that was obtained from the bed was of white clay, which disintegrates in water, and contains a few small dark bronze mica flakes and a very few greenish-white ones. A zone of silicified shale, 8 inches thick, directly underlying the bentonite still forms a prominent dip slope on the south side of the sink hole. The silicified shale breaks into very angular blocky pieces quite unlike the usual shale fragments. R12 was also identified in the Brooks well, where it lies the same distance above the base of the Trenton as at Hagan.

Bentonite R13.—At Hagan bentonite R13 is 482 feet above R12 and is 12 feet below the top of the Trenton limestone. It varies in thickness because of flowage but averages about 2 inches. It consists of yellow clay without the mica flakes or feldspar that would identify it definitely as a bentonite. In the Brooks and Fugate No. 3 wells, however, a bentonite with mica and associated chert was found at the identical horizon, and in the Fugate No. 2 well a flow of mud into the hole took place also at the same horizon. These four occurrences probably represent an authentic ash fall.

No bentonites were found in the Reedsville shale or the Sequatchie formation in the Rose Hill district. Fox and Grant[141] have, however, recently reported a bentonite, 3 to 4 inches thick, in the lower part of the Sequatchie formation near Chattanooga, Tennessee.

ORIGIN OF THE SILICIFIED BEDS UNDERLYING THICK BENTONITES

Many investigators of bentonites have mentioned the chert beds, which underlie some of the thicker bentonites, but have made little reference to their distinctiveness or to their significance. Young[142] first called attention to the constancy of chert zones beneath some of the thick bentonites. He attributed the chert to the deposition of silica from sea water, as the result of partial desilication of the tiny particles of volcanic glass, which were held in suspension or were very slowly sinking through the water. Later the clay particles, resulting from devitrification of the glass, coagulated and settled to the bottom to form the bentonite bed. This explanation seems to require a speed of devitrification of the volcanic glass difficult to credit even for material in very fine particles. Furthermore, as Young points out, it does not explain silicified zones overlying bentonites, such as have been reported by Young and by Cooper and Prouty.[143] Neither does it explain the fact that chert beds underlying bentonites in the Rose Hill district invariably have a sharp clear contact with the overlying bentonite, but a sealed and very indistinct contact with the underlying limestone.

Cooper and Prouty suggest that silicification of the rock adjacent to bentonites is the result of replacement of the original rock by silica set free during chemical alteration of the ash to bentonite. This explanation seems to accord with most observed facts. The alteration of ash to bentonite is accompanied by a decrease in the percentage of silica as shown by chemical analyses of bentonites and of the types of volcanic ash from which they are believed to have been derived. Inasmuch as there is no apparent addition of material during the alteration of volcanic ash to bentonite, some of the silica in the ash must go into solution and be removed. The replacement of adjacent

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[141] Fox, P. P., and Grant, L. F., op. cit., p. 329.

[142] Young, D. M., Bentonitic clay horizons and associated chert layers of central Kentucky: Univ. Kentucky Res. Club Bull. 6, pp. 27-31, 1940.

[143] Cooper, B. N., and Prouty, C. E., Stratigraphy of the lower Middle Ordovician of Tazewell County, Virginia: Geol. Soc. America Bull., vol. 54, no. 6, pp. 846-847, 1943.

rocks by this silica in solution is an expectable result. Apparently, however, a thick bed of volcanic ash is necessary to build up the concentration of silica in the water sufficiently to permit replacement. This is indicated by the fact that no bentonite less than a foot thick in the Rose Hill district has even an incipient silicified zone beneath the bentonite, whereas thicker bentonites have silicified zones from 1 to 8 inches thick. Apparently the formation of the silicified zones, and hence also the alteration of the volcanic ash to bentonite, was completed before the Appalachian revolution because the nature or thickness of the chert beds beneath the big bentonites in the Eggleston limestone in the Rose Hill district does not vary, whether the beds be flat, gently dipping, steeply dipping or overturned. Where the rock underlying the thick bentonites is limestone, the silicified zone is composed of chert. In the case of the thick bentonite (R12) in the Trenton limestone, however, 8 inches of shale underlying the bentonite has been altered to a splintery, silicified shale.

SOURCE OF THE BENTONITES

The volcanic origin of the Ordovician bentonites is well established and the evidence does not need to be repeated here. C. S. Ross[144] states that the original ash in the ash falls in southwest Virginia was probably of latitic rather than rhyolitic composition. The problems of location of the volcanoes, from which ash was distributed so plentifully over the Appalachian Valley and eastern interior has brought forth numerous diverse opinions. Nelson,[145] who first described Ordovician bentonites, thought the source lay in east-central Kentucky, close to the thick bed he found at High Bridge, Kentucky. Later he changed in favor of a volcanic source under the Cumberland Mountains near the junction of Kentucky, Virginia and Tennessee.[146] Many additional bentonite localities have since been found in the Appalachian Valley northeast, southwest and southeast of the tristate junction.

More recently Kay[147] has suggested western North Carolina as

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[144] Ross, C. S., personal communication.

[145] Nelson, W. A., Volcanic ash bed in the Ordovician of Tennessee, Kentucky, and Alabama: Geol. Soc. America Bull., vol. 33, no. 3, pp. 605-616, 1922.

[146] Nelson, W. A., Two new volcanic-ash horizons in the Stones River group of the Ordovician of Tennessee (abstract): Geol. Soc. America Bull., vol. 36, no. 1, p. 159, 1925.

———, Volcanic ash deposit in the Ordovician of Virginia (abstract): Geol. Soc. America Bull., vol. 37, no. 1, pp. 149-150, 1926.

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

the location of the Ordovician volcanoes and Grant and Fox[148] point to the presence of large areas of volcanic rocks of unknown but possibly of Ordovician age in central North Carolina as favoring the location of the volcanoes in that region.

It is quite possible that the Ordovician ash falls of southwest Virginia and eastern Tennessee came from volcanoes in central or western North Carolina. It seems obvious, however, that no one volcano or no one local volcanic region can be appealed to in accounting for bentonites distributed from New York to Alabama. At least several and probably many volcanoes must have been present along the land mass that lay to the east of the Appalachian seaway. A sequence of bentonites in one region probably represents a series of eruptions from a different volcano or from different volcanoes than do those in another region several hundred miles distant up or down the Appalachian Valley. The greatest of the ash falls may have blanketed large areas, but the identification of individual bentonite beds in widely separated regions is fraught with many uncertainties, particularly where numerous bentonites are present in the same sequence of rocks. Whitcomb[149] has expressed similar views with respect to the location of the volcanoes supplying the ash falls, and with respect to the limitations of bentonites for regional correlation.

CORRELATION OF BENTONITES OF THE ROSE HILL DISTRICT WITH THOSE IN OTHER REGIONS

Reference to Plate 26 will show both the possibilities for and the difficulties of correlation by means of bentonites between different regions. The great concentration of bentonites in a few hundred feet of beds in Tazewell County, in the Rose Hill district, and in eastern Tennessee, with only a few other bentonites reported in all the rest of the Ordovician, leaves little room for doubt that the parts of the section containing the abundant bentonites are approximate correlatives. The exact correlation of the bentonite-bearing beds is, however, much more difficult. In Plate 26, we have assumed that bentonite R7 in the Rose Hill district represents the same ash fall as do bentonites V4 in Tazewell County, Virginia, B3 in Tennessee, and the bentonite in the middle part

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[148] Fox, P. P., and Grant, L. F., Ordovician bentonites in Tennessee and adjacent states: Jour. Geology, vol. 52, no. 5, pp. 319-332, 1944.

[149] Whitcomb, Lawrence, Possible volcanic sources of Ordovicic bentonites: Pan-Am. Geologist, vol. 63, no. 4, pp. 265-270, 1935.

of the Tyrone limestone in Kentucky. This correlation seems probable but is not established. Doubt exists, however, whether the upper big bentonite (R10) of the Eggleston limestone is the same as Rosenkrans' V7, or whether it represents one of the thinner bentonites lying nearer the top of the Eggleston limestone. Cooper states, however, that the Eggleston in the Burkes Garden quadrangle of Tazewell County "where fully exposed * * * shows two thick zones of metabentonite, one about 10 feet above the siltstones at the top of the Moccasin and the other near the Eggleston-Martinsburg (Trenton) contact."[150] The upper of these zones seems, because of its stratigraphic position, to be the same as the big bentonite at the top of the Eggleston limestone in the Rose Hill district. The lower one lies much nearer the base of the Eggleston in Burkes Garden than does the lower big bentonite of the Rose Hill district. Available evidence lends support to the correlation of the lower big bentonite of the Eggleston of both the Burkes Garden quadrangle and the Rose Hill district despite their apparently dissimilar stratigraphic positions.

Our upper bentonite in the Eggleston would seem to correlate with similarly located bentonites in central Kentucky and in parts of central Tennessee. Fox and Grant believe that their B6 in eastern Tennessee is the same as the one at the top of the Carters limestone in central Tennessee. Thus the identity of our R10 with Fox and Grant's B6 is suggested. Our bentonite R1 near the base of the Murfreesboro is almost certainly the same as the similarly located bentonite (Fox and Grant's B1) in eastern Tennessee, which has been recognized in the Chattanooga region and in Rhea County.

The correlations suggested above need further checking. This can be done by studying the bentonites in intermediate localities at the outcrop and by getting data from deep wells to bridge over the long covered interval between the Ordovician of the Appalachian Valley and of central Kentucky and central Tennessee.

REEDSVILLE SHALE

Name and distribution.—The Reedsville shale was named from exposures at Reedsville, Mifflin County, Pennsylvania.[151] The

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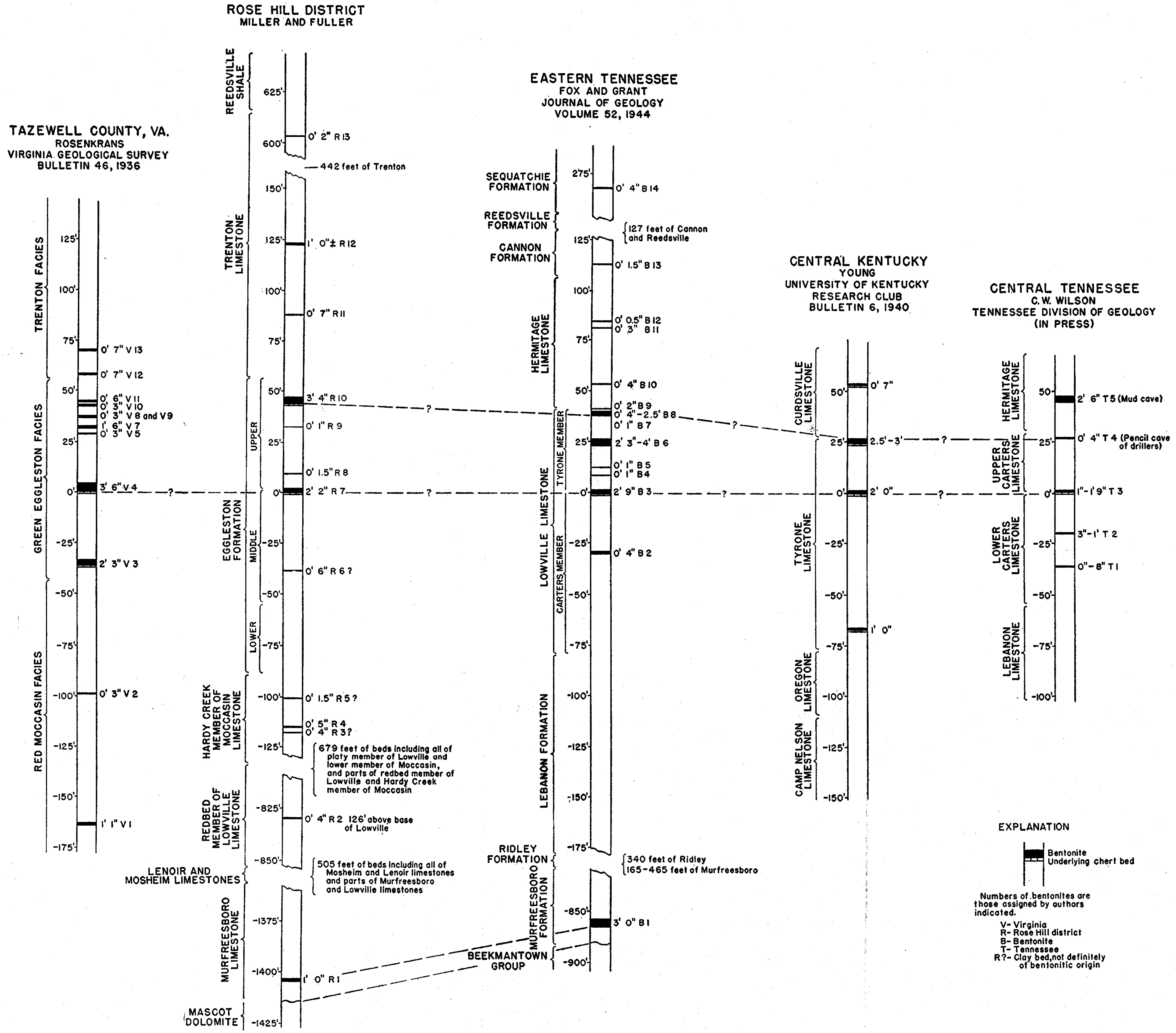
[150] Cooper, B. N., Geology and mineral resources of the Burkes Garden quadrangle, Virginia: Virginia Geol. Survey Bull. 60, p. 99, 1945.

[151] Ulrich, E. O., Revision of the Paleozoic systems: Geol. Soc. America Bull., vol. 22, Pl. 27, 1911.

name has been used in Lee and Wise counties, Virginia, by Ulrich, Butts, and Stose for a sequence of shales of Eden and Maysville age lying between the Trenton limestone below, and the Sequatchie formation above. Elsewhere in the Appalachian Valley of Virginia the beds of Trenton age are also shaly, and the entire sequence of shale and limy shale of Trenton, Eden, and Maysville age is called the Martinsburg shale. In the Rose Hill area the Reedsville shale forms the middle slopes of both Poor Valley Ridge and Wallen Ridge. One short belt of Reedsville shale cuts across the Low Hollow section of the Dean fenster.

Character.—About midway between the base and crest of Poor Valley Ridge and Wallen Ridge the Reedsville shale forms rows of very distinctive rounded knobs (Pl. 8). These knobs rise sharply about 150 feet above the highest level of the Trenton limestone. Along Poor Valley Ridge the knobs are isolated from the main ridge by a shallow depression eroded at or near the Reedsville-Sequatchie contact, and the knobs are separated from one another by ravines draining the steep upper slopes of the ridge. The knobs on Wallen Ridge are somewhat less prominent, being nearly flat on top and not isolated from the main ridge. Rounded, steep-sided hills of this type are characteristic of thick units of shale. They are prominent even in the very short belt of Reedsville in the Dean fenster. Most of the Reedsville outcrop area has been cleared of timber but the slopes are almost everywhere too steep for cultivation and are in pasture. Closely spaced cattle trails make steps around most of the hills.

Good outcrops of Reedsville shale are rare and good sections of the shale are extremely rare. The best section is along the Louisville and Nashville Railroad switchback near Hagan, Virginia (Geologic Section 9). This section is the source of most of the detailed knowledge about the Reedsville. Two other sections were studied in detail, one in the Dean fenster where the contact with the underlying Trenton limestone is exposed, and the other a mile north-northeast of Ewing, where deeply weathered but undisturbed beds are exposed along a farm road that crosses Poor Valley Ridge. The Reedsville shale appears to contain a greater proportion of interbedded limestone at Hagan, where unweathered beds appear in the railroad cut, than it does elsewhere in the region. This is largely, if not entirely, due to solution of carbonate from the limy beds in weathered exposures leaving an earthy residue only slightly different from the weathered shale beds.



Comparison of bentonite sections in southwest Virginia, Kentucky and Tennessee.

The shale, which composes well over half of the formation, is greenish-gray on fresh surfaces and weathers yellowish-brown. It is mostly a soft grit-free shale which breaks in chips less than a quarter of an inch thick. Interbedded with the shale are two types of limestone; one is a coquina similar to the coquinal limestone in the Trenton and the other is a fine-crystalline siliceous limestone. The coquina is light gray to brownish gray and coarse crystalline, with brachiopods the dominant fossils and with large bryozoans very abundant in some beds. Beds of coquinal limestone are usually 1 to 3 inches thick but in the upper third of the formation there are beds as much as 5 feet thick. Deep weathering of the coquina produces a rotten porous orange rock or clay with abundant fossils or fossil molds. The color resembles that of the yellow-weathering shale and these weathered limestones easily pass as weathered shale unless the beds are examined closely. The siliceous limestone is a fine-crystalline steel-gray rock in beds 2 to 10 inches thick. Weathering first alters it to a brown color and then with leaching of the lime to a limonite-brown laminated rock. In thin section the rock shows equigranular grains 0.065 to 0.097 mm. in length (Pl. 24D). About 60 percent of them are calcite, 30 percent are angular quartz, and a few are angular grains of andesine feldspar. Accessory minerals such as limonite, muscovite, kaolin, glauconite, carbon streaks, and zircon are scattered through the rock in small quantities. The lamination of the rock is caused by alternating bands of calcite and the other minerals.

Interbedding of the shale and the two types of limestone is not regular throughout the formation. In the lower two-thirds of the formation the first 50 feet is almost entirely shale with only a few limestone interbeds but, above this, zones of limestone and shale alternate. The upper one-third of the formation, however, is dominantly limestone and, because most of the beds are thicker than those in the lower part of the formation, outcrops are more numerous.

West of Ewing a thick coquinal limestone in the upper Reedsville forms the crest of the knobs on the south slope of Poor Valley Ridge. To the east this limestone thins and an underlying siliceous limestone, which thickens in this direction, becomes the knob-forming unit. The latter limestone contains coarser sand grains than is characteristic of the siliceous limestone of the Reedsville and upon weathering it forms a coarser-grained residue than is normal. These two beds are only a few feet apart and they roughly mark the division between the more limy upper one-third and the more shaly lower two-thirds of the Reedsville.

Stratigraphic relations.—The Reedsville shale of the Rose Hill area has conformable contacts at both the base and the top. The Trenton-Reedsville contact is readily recognized because the topmost beds of the Trenton limestone are massive, coarse, crystalline, fossiliferous limestone and the lowest beds of the Reedsville are weak shales with only a few thin interbeds of limestone. The lithologic contrast of the two formations is illustrated in the photograph of the contact at Hagan (Pl. 25B), in which the contact, marked by the hammer, lies at the top of the massive ledges. The contact of the Reedsville shale with the overlying Sequatchie formation is equally sharp. It is placed at the horizon where fine crystalline limestone and interbedded shales of the topmost Reedsville change to red or mottled red calcareous mudstone of the Sequatchie (Pl. 27A).

Thickness.—The best measurement of the thickness of the Reedsville shale was made at Hagan where the outcrops are good enough to observe and correct for the folds and high-angle reverse faults which are common to the formation. The thickness at Hagan is 357 feet and that of the only other accurately measured complete section, north of Ewing, is 327 feet. Any thickness measurements derived from partly covered sections tend to be excessive due to unobserved duplication of beds by folding and faulting. We believe that this condition may account for the thicknesses of 400 to 500 feet of Reedsville reported by other workers in Lee and Wise counties, rather than any appreciable thickening of the formation in the localities where their measurements were made.[152]

Paleontology.—Fossils can be found in most of the beds of the Reedsville shale but the coquinal limestones, which are most abundant in the upper third of the formation, are the only beds with abundant fossils. Brachiopods, especially *Rafinesquina* and *Zygospira,* and unidentified bryozoans are the most numerous forms, but pelecypods are quite common. *Holtedahlina hallie, Sowerbyella rugosa,* and abundant

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[152] Stose, G. W., Pre-Pennsylvanian rocks, *in* 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, p. 28, 1923.

Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. I, Geologic text and illustrations, p. 218, 1940.

Bates, R. L., Geology of Powell Valley in northeastern Lee County, Virginia: Virginia Geol. Survey Bull. 51-B, p. 54, 1939.

Rafinesquina indicate Eden-Maysville age.[153] The exact line of separation between beds of Eden and Maysville age within the Reedsville is not known, but it is believed to correspond approximately with the lithologic change from dominant shale of the lower two-thirds of the formation to dominant limestone of the upper one-third. In Table 9 the fossils from the lower two-thirds are believed to represent beds of Eden age and those from the upper one-third, beds of Maysville age. In the upper one-third the very large *Platystrophia ponderosa* is indicative of Maysville age.[154] *Orthorhynchula linneyi* is abundant at the top of the Reedsville.

TABLE 9.—*Fossils identified from the Reedsville shale of the Rose Hill district*

LOWER TWO-THIRDS OF REEDSVILLE SHALE	UPPER THIRD OF REEDSVILLE SHALE
Stony bryozoans	Stony bryozoans
Hebertella sinuata (Hall)	*Hebertella sinuata* (Hall)
Holtedahlina hallie (Miller)	*Orthorhynchula linneyi* (James)
Plectorthis fissicosta (Hall)	*Platystrophia ponderosa* Foerste
Plectorthis sp.	*Plectorthis* sp.
Rafinesquina fracta (Meek)	*Rafinesquina fracta* (Meek)
Rafinesquina nasuta (Meek)	*Zygospira kentuckiensis* James
Rafinesquina sp.	*Zygospira modesta* (Say)
Resserella emacerata (Meek)	*Zygospira* sp.
Sowerbyella rugosa (Meek)	*Byssonychia radiata* (Hall)
Zygospira kentuckiensis James	
Zygospira modesta (Say)	
Zygospira sp.	
Modiolopsis sp.	

The following additional fossils have been identified by Butts[155] from the upper 146 feet of the Reedsville shale southeast of the village of Cumberland Gap, Tennessee (Pl. 13):

- *Amplexopora cingulata* Ulrich
- *Amplexopora pustulosa* Ulrich
- *Batostoma?* sp.
- *Constellaria florida* (Ulrich)
- *Cyphotrypa semipilaris* (Ulrich)
- *Eridotrypa* sp.
- *Escharopora hilli* (James)
- *Monotrypa* sp.
- *Monticulopora molesta* Nicholson
- *Platystrophia laticosta* (Meek)
- *Rafinesquina alternata* (Emmons)?
- *Modiodesma modiolare* (Conrad)
- *Modiolodon truncatus* (Hall)
- *Pterinea demissa* (Conrad)
- *Bellerophon* sp.
- *Lophospira?* sp.

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[153] Cooper, G. A., personal communication.
[154] Cooper, G. A., personal communication.
[155] Butts, Charles, op. cit., pp. 217-218.

Additional forms, not appearing in the above lists, that were collected and identified by Bates[156] from the Reedsville shale of northeastern Lee County are as follows:

Heterorthis clytie (Hall)?
Dalmanella sp.
Cyrtolites ornatus Conrad
Eotomaria? sp.
Sinuites cancellatus Hall
Calymene granulosa (Foerste)

Age and correlation.—The Reedsville shale is of Upper Ordovician age. Cooper[157] states that the identified fossils are Eden and Maysville types. According to Butts[158] an *Orthorhynchula* zone, which is probably the best horizon marker in the Appalachian Valley, is found throughout Virginia at the top of the Reedsville or at the top of its partial equivalent, the Martinsburg shale. The presence of abundant *Orthorhynchula* at this horizon in the Rose Hill district thus serves to correlate the top of the Reedsville in Lee County with the top of the Martinsburg elsewhere in western Virginia.

SEQUATCHIE FORMATION

Name.—Ulrich[159] originally included in the Sequatchie formation all beds of Richmond age in the southern Appalachian Valley. The name has since been restricted to cover only the marine limy beds in the western part of the Appalachian Valley in northern Alabama, eastern Tennessee and southwestern Virginia. These beds, which overlie the Reedsville shale and and underlie the Clinch sandstone in southwest Virginia and adjacent Tennessee, have previously been considered of Richmond age, but in the Rose Hill district beds in the lower part of the Sequatchie were found to carry a Maysville fauna.

Distribution and character.—Because of its position directly beneath the resistant Clinch sandstone, the Sequatchie formation crops out in narrow belts high on the steep slopes of Poor Valley Ridge and Wallen Ridge. The contact with the Reedsville shale lies at the break in slope at the base of the last steep rise to the ridge crests. Where the Reedsville shale forms isolated knobs on the sides of the ridges, this break in slope lies at or very near the lowest point of the sag separating the knob from the main ridge. The contact of the

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[156] Bates, R. L., Geology of Powell Valley in northeastern Lee County, Virginia: Virginia Geol. Survey Bull. 51-B, p. 55, 1939.

[157] Cooper, G. A., personal communication.

[158] Butts, Charles, op. cit., p. 208.

[159] Ulrich, E. O., The Ordovician-Silurian boundary: 12th Internat. Geol. Cong. Comptes Rendu, pp. 593-667, 1913.

Sequatchie with the Clinch lies at the top of the steep slopes, normally only a few dozen feet below the ridge crests. Because of its tendency to disintegrate under the influence of weathering, outcrops of the Sequatchie are few even on the steep mountain sides. The only other areas of Sequatchie in the Rose Hill district are in the southern parts of the Fourmile and Dean fensters.

The Sequatchie formation is composed of maroon and green calcareous mudstone with considerable quantities of limestone and argillaceous limestone in its lower part. The mudstone is dominantly green in the lower part of the formation, and dominantly maroon in the upper part. Many outcrops are composed of interbedded or mottled maroon-and-green mudstone, but surfaces of weathered ledges are almost entirely maroon, owing in part to change in the color of some of the green mudstone as the result of weathering, and in part to washing of maroon mud over the green beds. Plate 24E is a photomicrograph of a typical specimen of mottled maroon-and-green mudstone. Small lathlike crystals of calcite are scattered through a fine-grained carbonate groundmass, some of which is maroon, owing to finely disseminated hematite, and some is gray. Some of the calcite laths and patches are fragments of fossils, and perhaps many of them have this origin. Clear subangular grains of quartz are scattered through the rock, and several areas of disseminated light-green glauconite are present, the largest of which shows as a lighter gray nearly circular area in the lower part of the photomicrograph. The hematite, which colors much of the mudstone of the Sequatchie, is probably formed by alteration of finely disseminated glauconite, which when unaltered imparts a greenish color to the rock.

The mudstone of the Sequatchie is thinly and evenly bedded, but most of the bedding planes, which may be deeply etched on weathered surfaces, are discontinuous. The rock thus forms units, several feet thick, between prominent bedding planes. Some of the beds show parallel laminae on weathered surfaces, others weather to produce subparallel wavy cracks which impart a nodular appearance to the rock.

The distinction between calcareous mudstone and argillaceous limestone is vague, and Butts, for example, has referred to the whole Sequatchie as an argillaceous limestone. We recognize a somewhat more limy facies in the lower part of the Sequatchie, to which we apply the name argillaceous limestone, but no clear-cut line of demarcation exists between the types. The argillaceous limestone is greenish-gray and well bedded. Locally it contains beds and lenses of fairly pure gray limestone, some of which contains abundant fossils, mostly fragmentary. The appearance of the argillaceous limestone in outcrop is shown in the left half of the photograph (Pl. 27A).

Stratigraphic relations.—The base of the Sequatchie formation has been drawn at the base of the lowest unit of maroon-and-green mudstone or argillaceous limestone. The contact is excellently exposed at Hagan (Pl. 27A), where the top unit of the Reedsville shale is massive-bedded coquinal limestone. This unit also contains *Orthorhynchula linneyi,* which Butts[160] has found at the top of the Reedsville or Martinsburg from central Pennsylvania to eastern Tennessee. The criteria just mentioned for placing the Reedsville-Sequatchie boundary are the same that have been applied elsewhere in Virginia and Tennessee. The lower 85 feet of the Sequatchie formation at Hagan and the lower 88 feet at Cumberland Gap, Tennessee (Pl. 13) consist of zones of maroon mudstone intertonguing with gray and green zones of argillaceous limestone. The zones of argillaceous limestone are more limy than the remainder of the formation, and they contain scattered beds of relatively pure limestone, some of which is coquinal. A fauna was found in these beds, which has been dated by G. A. Cooper[161] and corroborated by Butts and Bassler as of Maysville age. Butts[162] also reports having found *Amplexopora angulata,* which he considers to be a Maysville fossil, in the southern part of the Fourmile fenster, where it could have come only from the Sequatchie formation.

If the Sequatchie were to be restricted to the beds of Richmond age in the Rose Hill district, the base would probably lie at or above the base of the calcareous mudstones that form the upper two-thirds of the mapped formation. This horizon both at Hagan (see Geologic Section 9) and at Cumberland Gap, Tennessee, is at the top of beds of greenish-gray argillaceous limestone, which form the most massive unit in the Sequatchie. The interval between the mapped base of the Sequatchie and the base of the part of the Sequatchie that may be of Richmond age is 85 feet at Hagan and 88 feet at Cumberland Gap. It may eventually be advisable to make a new formation of these beds, which resemble in character the type Sequatchie but which are of Maysville age. The beds in question are excellently exposed in the Hagan switchback, where they make up units 47 to 50 of the measured

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[160] Butts, Charles, op. cit., p. 208, 1940.

[161] Cooper, G. A., personal communication.

[162] Butts, Charles, Fensters in the Cumberland overthrust block in southwestern Virginia: Virginia Geol. Survey Bull. 28, p. 2, 1927.

section (Geologic Section 9). They may also be seen along the woods road which branches off from U. S. Route 25E at the high point of the wind gap through Poor Valley Ridge near Cumberland Gap, Tennessee.

The Sequatchie formation is unconformably overlain by the Clinch sandstone. Although a hiatus exists at this contact, there is no evidence in the Rose Hill region to indicate extensive erosion or any folding or warping of beds in the time interval between deposition of the youngest beds of Ordovician age (Sequatchie) and the oldest beds of Silurian age (Clinch).

Thickness.—At Hagan the Sequatchie formation is 274 feet thick, and at Cumberland Gap, Tennessee, it is 255 feet. Butts[163] lists it as 295 feet thick on Powell Mountain in Lee County, and Stose[164] estimates the formation to be about 200 feet thick in southern Wise County. Bates[165] gives a measured section of the Sequatchie in northeastern Lee County that is 135 feet thick, but of this the upper 54 feet would be included by us in the Clinch sandstone. The reason for this unusually thin section of the Sequatchie formation is not known. It does not seem to be representative of the formation, as Bates estimates the Sequatchie to be 200 feet thick in northeastern Lee County.

Paleontology.—The Sequatchie formation is fossiliferous throughout, but the fossils are scarce and very poorly preserved in the upper two-thirds. In this upper two-thirds, the part of the formation possibly of Richmond age, the fossils consist mainly of internal and external molds of brachiopods and pelecypods. The shell markings are apt to be indistinct and the fossils crumble to pieces when removed from the bedrock. In the Rose Hill district no fossils have been identified from these beds.

In the lower 85 feet of the formation fossils are more abundant and in some beds are fairly well preserved. They consist mainly of bryozoans, brachiopods and pelecypods. A few beds contain very abundant large and medium size bryozoans. Faunules, which have been dated as Maysville by G. A. Cooper, have been collected from beds 10

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[163] Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. I, Geologic text and illustrations, p. 288, 1940.

[164] Stose, G. W., Pre-Pennsylvanian rocks, *in* 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, p. 29, 1923.

[165] Bates, R. L., Geology of Powell Valley in northeastern Lee County, Virginia: Virginia Geol. Survey Bull. 51-B, p. 56, 1939.

feet, 25 feet and 50 feet above the base of the formation. The identified forms follow:

Hebertella sinuata (Hall)
Platystrophia ponderosa Foerste
Zygospira aff. *Z. kentuckiensis* James
Byssonychia radiata (Hall)
Sactoceras sp.
Lophospira tropidophora (Meek)

Age and correlation.—As previously described, the upper two-thirds of the Sequatchie may be of Richmond age. If so, it is the marine equivalent of the nonmarine Juniata formation in central and northern Virginia, Maryland, and Pennsylvania. The lower third of the Sequatchie, which contains the Maysville fauna, has not previously been recognized. In stratigraphic position it is identical with the nonmarine Oswego sandstone, which in northern Virginia lies between the Martinsburg shale of Trenton, Eden and Maysville age and the Juniata formation of Richmond age. Butts[166] considers the Oswego to be of uppermost Maysville (McMillan) age. Correlation of the lower part of the Sequatchie of the Rose Hill district with the Oswego sandstone seems probable.

SILURIAN SYSTEM

CLINCH SANDSTONE

Name.—The Clinch sandstone was named by Safford[167] from exposures on Clinch Mountain 15 miles southeast of the Rose Hill district.

In the Rose Hill district, the Clinch sandstone consists of a two-fold division. The lower member, which is composed dominantly of shale, is here named the Hagan member and the upper member, composed of ridge-making sandstone interbedded with shale, is named the Poor Valley Ridge member. Both names come from just northeast of the Rose Hill district where the members are completely exposed along the Louisville and Nashville Railroad cut in the gap through Poor Valley Ridge near the town of Hagan (Geologic Section 10). These members are recognizable throughout all of Lee County and are probably also identifiable in Wise County, Virginia, and in Claiborne County, Tennessee.

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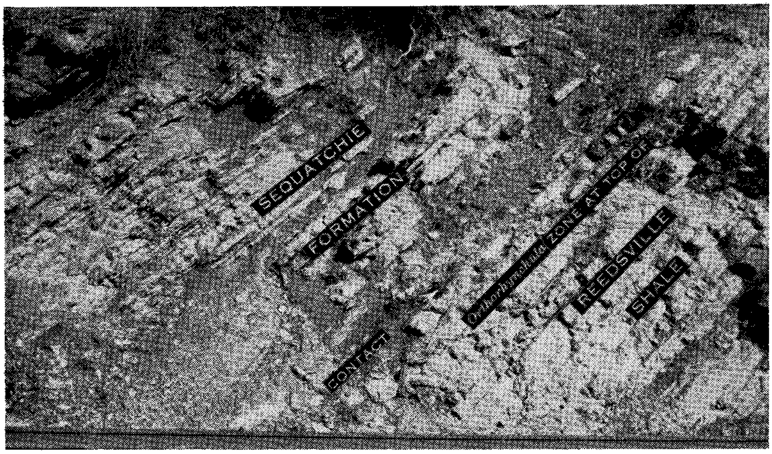
[166] Butts, Charles, op. cit., p. 221, 1940.
[167] Safford, J. M., A geological reconnaissance of the State of Tennessee: p. 157, Nashville, Tennessee, 1856.



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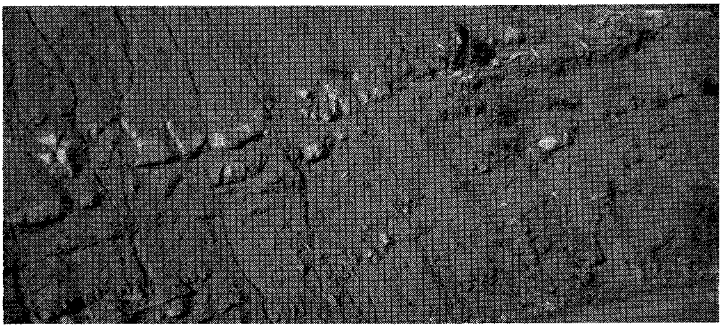
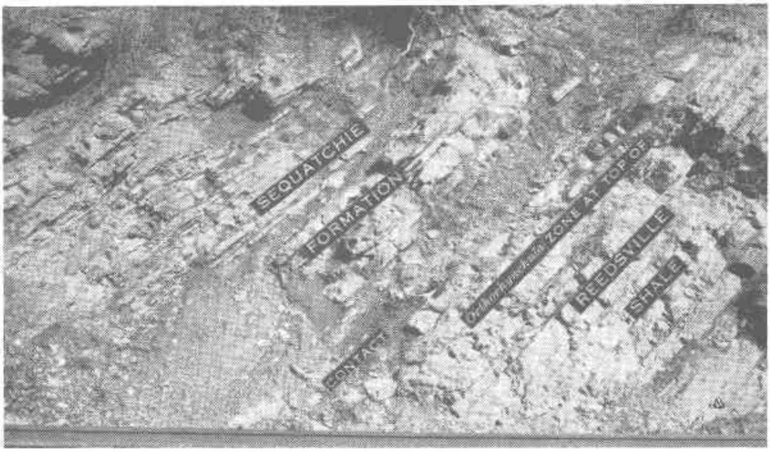


C

A, Reedsville-Sequatchie contact in the railroad cut at Hagan. B, Clinton-Cayuga contact along the highway near the south end of the Martin Creek fenster. Hammerhead is at contact. C, Unconformity at the base of the Cayuga dolomite along U. S. Route 58 near Cumberland Gap. Contact is at man's right foot.



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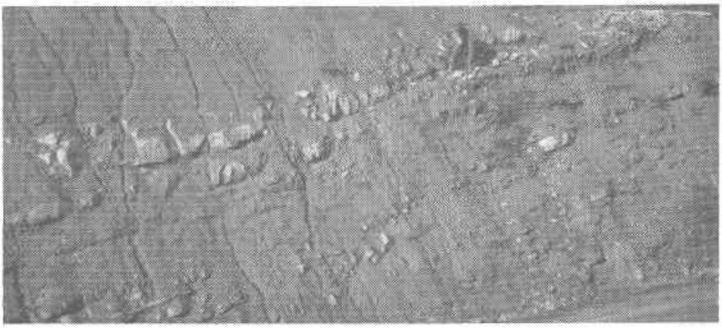

C

A, Reedsville-Sequatchie contact in the railroad cut at Hagan. B, Clinton-Cayuga contact along the highway near the south end of the Martin Creek fenster. Hammerhead is at contact. C, Unconformity at the base of the Cayuga dolomite along U. S. Route 58 near Cumberland Gap. Contact is at man's right foot.

Distribution.—The Clinch sandstone forms Poor Valley Ridge and Wallen Ridge which border Powell Valley on the northwest and southeast. The outcrop belts of the Clinch sandstone are relatively broader than those of less resistant formations, because the Clinch extends considerable distances down the back slopes of the ridges. The Clinch is also exposed in both the Dean and Fourmile fensters, where it also forms ridges, but these belts of Clinch in the fensters are so short that the resultant ridges have not been named.

HAGAN MEMBER

Character.—The Hagan member is largely composed of nonresistant shale, but it is overlain by the ridge-making sandstones of the Poor Valley Ridge member, so that it crops out near the crests of Poor Valley and Wallen Ridge. It commonly forms moderate slopes between the ridge crests and the steep slopes of the underlying Sequatchie formation. In a few places, however, on both Wallen Ridge and Poor Valley Ridge the Hagan member forms the ridge crests for short distances, and east of the gap of Mulberry Creek through Wallen Ridge, beds at the base of the member are the ridge formers.

In the section of the Hagan member at Hagan (Geologic Section 10) the basal bed of the member consists of a buff-weathering sandstone, 15 inches thick. This bed is found consistently over the Rose Hill district and serves as an excellent marker for the base of the Clinch sandstone. It ranges from 1 to 3 feet in thickness in different parts of the district. Even where thinnest it is conspicuous because it normally crops out, and also because it is thicker bedded and more earthy than any other sandstones in the Hagan member. The overlying beds of the Hagan member are composed mainly of greenish-gray shale, but contain numerous platy interbeds from 1 to 3 inches thick, of silty to sandy limestone.

The shale is very fissile and breaks into small flat chips. The limestone beds carry fucoid markings, and some have knobs on the undersurfaces. Fossils are sparingly present in both the shale and limestone. They are mainly pelecypods and brachiopods. These beds are rarely seen in normal outcrop, for the fissile shale disintegrates on weathering, and the silty limestone, though tough and hard when fresh, dissolves readily on weathering. At Hagan a 5-inch bed of very low-grade "Clinton-type" hematitic iron ore lies 21 feet above the base of the member. Other "Clinton-type" hematite beds have been noted in the Hagan member in a number of places on Wallen Ridge, but all are so thin that no attempts have been made to mine them. The Hagan section described above is typical of the lower member of the Clinch sandstone throughout the Rose Hill district.

Stratigraphic relations.—The Hagan member of the Clinch sandstone unconformably overlies the Sequatchie formation. There is, however, little relief along the contact. No conspicuous channels in the Sequatchie and no conglomerate at the base of the Clinch have been observed in the Rose Hill district. The normally maroon beds of Sequatchie directly beneath the contact are, however, commonly bleached to a gray or nearly white color to a depth varying from 1 to 5 feet. This evidence of pre-Clinch weathering is excellently exhibited along the Low Hollow road just south of Dean Store, and also at Hagan.

Northeastward from the Rose Hill district, the distinctive basal sandstone bed of the Clinch disappears. In the railroad cut at Ben Hur (Pl. 13) a transition zone, 8 feet 7 inches thick, containing beds similar in character to both overlying Clinch and underlying Sequatchie is present at the contact. In Turkey Cove in northeastern Lee County, the contact is somewhat obscure, but was placed at the base of a 9-inch zone containing the lowest platy-bedded, fine-grained sandstones. A transition zone, 6 feet 7 inches thick, is above this contact. In the section measured by Bates[168] in Turkey Cove, the base of the Clinch as mapped in the Rose Hill district lies 12 feet 8 inches above the base of his Unit 7. Thus 54 feet of beds, which have been included by Bates in the upper part of the Sequatchie, would be considered by us to be the lower part of the Hagan member of the Clinch sandstone.

Thickness.—In the section at Hagan, the Hagan member is 77 feet thick. On Poor Valley Ridge northwest of Rose Hill it is 70 feet thick and at Cumberland Gap, Tennessee, it is about 75 feet thick. It appears to be thinner on Wallen Ridge, but no reliable thickness measurements were obtained on this ridge in the Rose Hill district. The member maintains about the same thickness northeast of the district, being 73 feet thick where U. S. Route 58 crosses Wallen Ridge near Stickleyville, and 84 feet thick where the same highway crosses Powell Mountain, the next ridge of Clinch sandstone to the southeast. In the gap where the Louis-

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[168] Bates, R. L., Geology of Powell Valley in northeastern Lee County, Virginia: Virginia Geol. Survey Bull. 51-B, p. 56, 1939.

ville and Nashville Railroad cuts through Poor Valley Ridge northwest of Ben Hur (Pl. 13), the member is 129 feet thick, its greatest known thickness in Lee County.

In Clinch Mountain and other ridges formed by the Clinch sandstone to the east and northeast in Virginia, the Clinch is described as consisting entirely of massive-bedded nonfossiliferous sandstone. Apparently the Hagan member of the Clinch is not recognizable east of Powell Mountain.

Paleontology.—The Hagan member is sparingly fossiliferous. We have collected linguloid brachiopods, a possible *Coelospira,* numerous pelecypods, and several gastropods, trilobites, and cephalopods from different localities in and near the Rose Hill district. The following forms have been identified from these collections:

Ctenodonta (2 species)
Liocalymene sp.
Mendacella? sp.

POOR VALLEY RIDGE MEMBER

Character.—The Poor Valley Ridge member of the Clinch sandstone is the only prominent ridge-making formation in the Rose Hill district. Normally beds at or near the base of the member are the resistant units and the main part of the member is poorly exposed on the back slopes of the ridges. For this reason good sections of the Poor Valley Ridge member are rare. The only complete well-exposed section we know of in or near the Rose Hill district is at Hagan (Geologic Section 10).

The Poor Valley Ridge member is composed of interbedded sandstone and shale, with the sandstone predominant in the lower part of the member and the shale in the upper part. The prominent sandstones are light gray to greenish-white, fine to medium grained, and are in massive beds, from 1 to 10 feet thick. The grains are subrounded and imbedded in a sericite and carbonate matrix. The latter dissolves away near the surface leaving a friable sandstone. Plate 24F is a photomicrograph of a typical sandstone, showing the poorly rounded grains. The very black patches are limonite and the indistinct interstitial material is mainly sericite. A few grains of microcline, albite, zircon, tourmaline, and apatite are also present. Most of the beds are uniform throughout, but some show parallel laminations or cross-bedding.

Poorly preserved fossils, mainly brachiopods, have been found at numerous places in some of the sandstones, thus indicating their marine origin. In most sections of the member there are a few beds consisting of oval green shale pebbles, up to 2 inches in length, in a sandy matrix. The shale pebbles commonly weather out at the surface leaving a deeply pitted porous sandstone. Lenses of gravel are also present in some beds, and at Hagan there is a conspicuous bed of gravel in the upper part of the member, containing pebbles up to half an inch in diameter. A somewhat thicker bed at Ben Hur contains pebbles of quartz up to an inch in diameter. The only signs of organic remains in the conglomeratic or gravelly beds are vague fucoidal markings, and occasional occurrences of the worm tube *Arthrophycus*. These beds seem to have had a continental or littoral origin and represent the thin westernmost tongues of a facies which makes up the whole Clinch sandstone to the east and southeast.

Interbedded with the sandstones are units composed of greenish-gray shale, which may contain thin beds of fine-grained platy sandstone. These units are thin or absent in the lower part of the member but make up most of the middle and upper parts. A few zones or individual beds of massive sandstone, from 1 to 10 feet thick, are present above the lower third of the member, but they become less numerous and thinner upward and are practically absent in the upper third of the member. Both the platy and the more massive sandstone have numerous ripple-marked surfaces. Most of the massive sandstone beds are lenticular or grade into shaly beds along the strike, so that sections only a short distance apart show different arrangements and thicknesses of the resistant sandstone and nonresistant shale units.

At Hagan the ridge-forming beds are near the base of the member and consist of two units of massive sandstone, 9 feet and 7 feet thick, separated by 4 feet of shaly sandstone and shale. At Ely Gap in Poor Valley Ridge the ridge-maker is one massive sandstone unit, 15 feet thick. On Wallen Ridge, however, the ridge-making sandstones are thicker. The greatest thickness observed was on the ridge crest opposite the mouth of Fourmile Creek, where more than 55 feet of massive, poorly bedded sandstone was present with no shaly interbeds.

Red shale, which is abundant in the overlying Clinton shale, is rare in the Poor Valley Ridge member of the Clinch, but red hematitic iron-ore beds of "Clinton-type" are not uncommon. Only one or two iron-ore beds are normally present at any one place and they are usually considerably less than a foot thick. In a few places, however, on both Poor Valley Ridge and Wallen Ridge, hematitic iron-ore beds were thick enough to warrant the digging of prospect pits, and a little ore may actually have been mined from some of these pits. The iron-ore beds are lenticular, and most are not traceable more than a quarter to half a mile along the strike. They occur both in the massive sandstones of the lower part of the member and in the shale and sandstone in the middle and upper parts. A more complete description of the hematitic beds in the Clinch sandstone is given in the section on economic geology.

Stratigraphic relations.—The contact between the Hagan and Poor Valley Ridge members of the Clinch sandstone is drawn at the base of the lowest thick-bedded medium-grained sandstone. Because the massive sandstone may grade laterally into shaly sandstone and shale, the base of the Poor Valley Ridge member is not everywhere at the same horizon. Unquestionably some of the shaly beds, which are placed in the upper part of the Hagan member on Poor Valley Ridge, have become more sandy and massive and are in part continental on Wallen Ridge. Still farther to the southeast the Clinch is entirely massive sandstone, and the identity of the two members is lost. Measured sections of the Clinch sandstone near the Rose Hill district are shown in Pl. 28 and the relation between the marine and continental facies of the Clinch is diagrammed in Figure 11. It has not been established, however, that the marine beds of the Rose Hill district are the exact time equivalents of the more continental facies of the Clinch to the southeast, as is implied by the diagram.

Between the Poor Valley Ridge member of the Clinch and the shale of the Clinton formation the contact is drawn at the top of the zone containing massive sandstones interbedded with green shale, and at the base of interbedded shales and platy sandstones containing abundant *Coelospira (Anoplotheca) hemispherica.* A bed of "Clinton-type" iron ore commonly lies a foot or two above the contact and abundant red shales begin several feet above the contact.

Thickness.—Reliable measurements of the thickness of the Poor Valley Ridge member of the Clinch sandstone are obtainable in

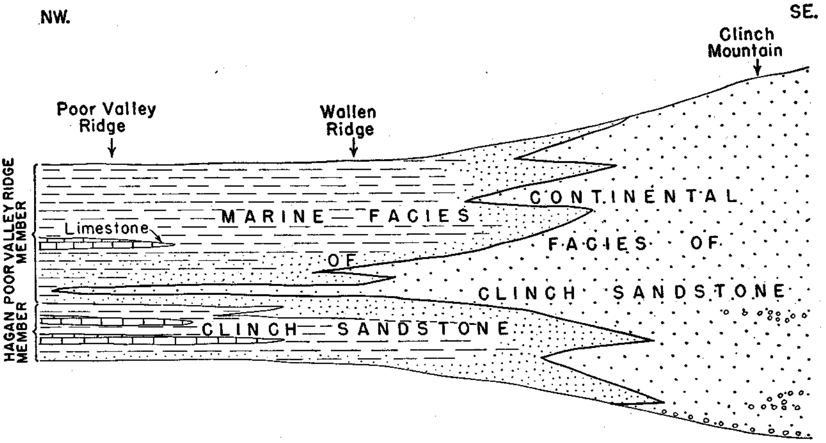

FIGURE 11.—Restored section showing generalized relations of continental and marine facies of Clinch sandstone from the Rose Hill district southeast to Clinch Mountain. Length of section is 23 miles. Greatest thickness of the Clinch Sandstone is 500 feet.

only a few places. This is because the Clinch-Clinton contact is almost everywhere covered by talus and soil on the back slopes of Poor Valley and Wallen Ridge, and also because the contact is not easily recognized except where exposures are nearly perfect. At Hagan just east of the district and at Ben Hur, several miles farther east, lower and upper contacts of the Poor Valley Ridge member are distinct. At Hagan the member is 183 feet thick and at Ben Hur 180 feet thick (Pl. 28). On the crest of Powell Mountain along U. S. Route 58 near Pattonsville more than 102 feet of massive sandstone make up the lower part of the member with the top not exposed. In the section measured by Butts[169] at Cumberland Gap, Tennessee (Pl. 13) only the lower 72 feet of the member are exposed.

Paleontology.—The marine sands and shales of the Poor Valley Ridge member are locally fossiliferous, but normally only the molds of casts remain in the friable sandstone and fissile shales. *Stegerhynchus* sp. cf. *S. neglecta* was found at several localities and a somewhat larger species of *Stegerhynchus* associated with it is more abundant. A species of *Lingula* is also quite widespread. Beautifully preserved specimens of the bryozoan *Helopora* sp. cf. *H. fragilis* and of a small

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[169] Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. I, Geologic text and illustrations, p. 232, 1940.

fairly high-spired gastropod are numerous in unit 10 (Geologic Section 10) of the Hagan section, and a fragment of an orthoceratid was found in the same bed. These fossils are hematite-coated internal molds in a medium-grained sandstone. One of the Heloporas magnified 25 times is shown in Plate 23B. Fragments, probably of *Helopora,* have also been found at about this horizon in well cuttings.

Butts[170] has described a fauna of 27 species from what he takes to be the basal unit of the Clinch sandstone in the gap of Poor Valley Ridge southeast of Cumberland Gap, Tennessee (Pl. 13). His measured section at this locality is given below.

Clinch sandstone measured by Charles Butts half a mile southeast of Cumberland Gap, Tennessee. (Section abridged from Virginia Geol. Survey Bull. 52, p. 232, 1940)

	Feet
Clinton formation	
Exact boundary with Clinch not determined	540
Clinch-Brassfield formation (250 feet)	
11. Sandstone, shaly	30
10. Limestone, crystalline, fossiliferous	5
9. Shale, green	15
8. Sandstone	2
7. Shale, green	15
6. Sandstone, gritty, quartz pebbles as much as ⅛ inch in diameter, highly fossiliferous; contains *Helopora fragilis* Hall, *Phaenopora explanata* Hall, *Lingula cuneata* Conrad, and *Phacops pulchellus* Foerste	5
5. Shale, green	10
4. Sandstone, red	1
3. Sandstone, thin, green; fossils, small pelecypods	10
2. Not exposed	137
1. Sandstone and grit, rusty, pebbles ⅛ inch in diameter; highly fossiliferous (27 species listed)	20
Sequatchie formation	

This section begins in the windgap at highway level above the "Little Tunnel" of the Louisville and Nashville Railroad and continues

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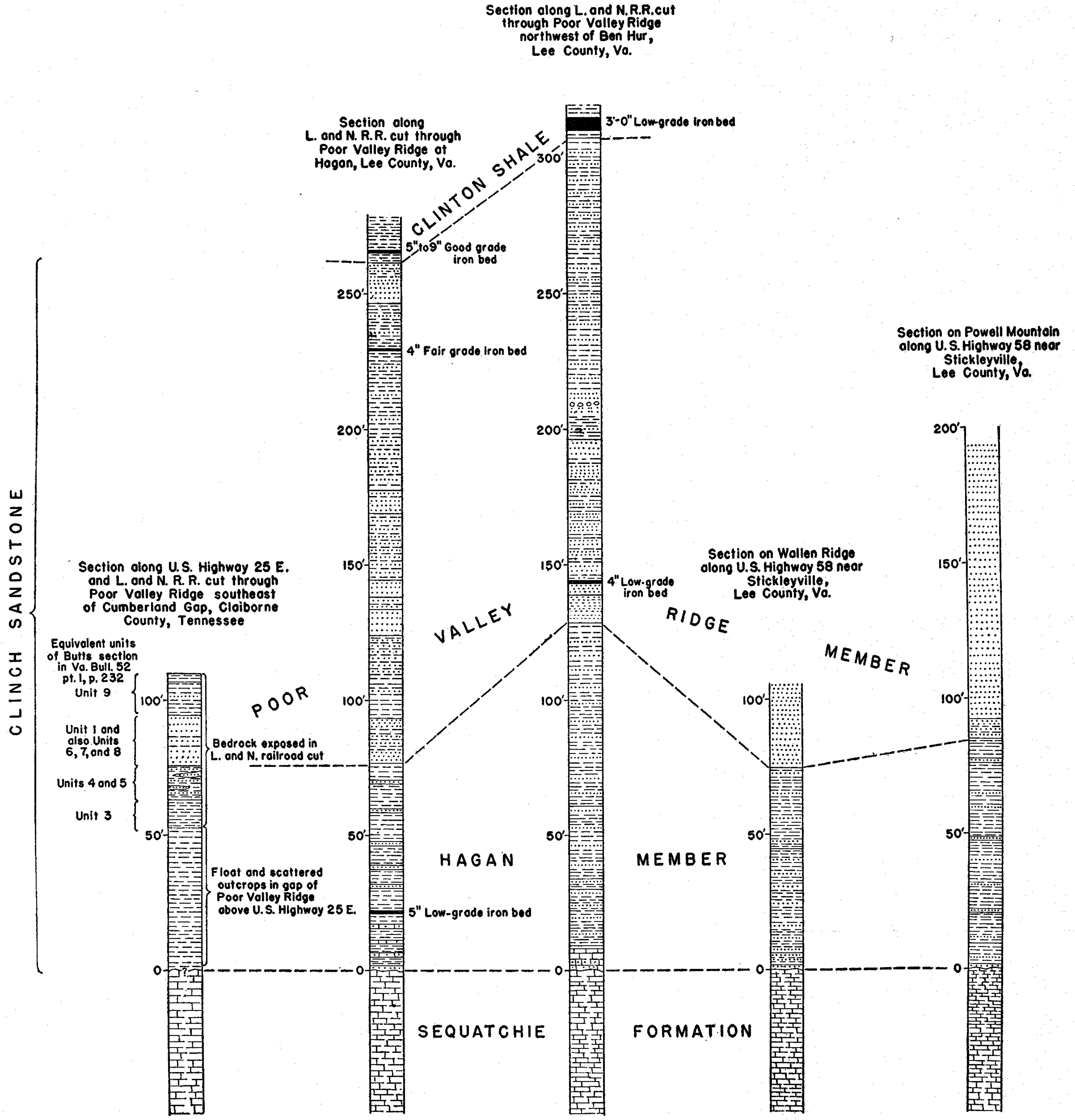
[170] Butts, Charles, op. cit., pp. 232, 236, and Pl. 60B.

in the railroad cut at the northwest portal of the tunnel. Plate 29A shows a graphic representation of this section as drawn by Butts. He calculated that 137 feet of unexposed beds of the Clinch sandstone occupy the long covered interval between the basal fossiliferous unit at road level and the first exposed beds in the railroad cut. Inasmuch as Butts' fauna from this locality is by far the largest yet found in the marine Clinch of Virginia, the stratigraphic position of the fossiliferous units becomes a matter of importance. We examined this section and are convinced that the fossiliferous sandstone at road level (Pl. 29A, Unit 1) is identical with the fossiliferous sandstone and overlying beds in the railroad cut (Pl. 29A, Units 6 to 8). Unit 1 consists of massive ledges of sandstone separated by shaly sandstone and shale. Units 6 to 8, which have the same total thickness as Unit 1, are lithologically identical to it. Furthermore, Butts describes both Unit 1 and Unit 6 as containing pebbles up to ⅛ inch and as being fossiliferous. Both are characterized by abundant *Helopora fragilis,* and the other three species he identified from Unit 6 are all present in Unit 1. Unit 1 at highway level is underlain by approximately 75 feet of poorly exposed greenish-gray shale, before the Sequatchie formation is reached. This represents the full thickness of our Hagan member of the Clinch sandstone, and the fossiliferous sandstone thus lies at the base of our Poor Valley Ridge member.

After the preceding conclusions based on stratigraphic evidence had been reached, a section was constructed to scale using measurements taken by us. The results, drawn on the same scale as Butts' section, are shown in Pl. 29B with the position of the northwest portal of the tunnel in our section directly beneath its position in Butts' section. The erroneous relation of Units 1 to 6 shown in Butts' section is due to the fact that the horizontal distance from the outcrop of Bed 1 at highway level to the northwest portal of the tunnel is only 430 feet rather than 900 feet as Butts shows, and the total length of the tunnel, as given by the Louisville and Nashville Railroad, is 1038 feet, rather than over 1700 feet as in Butts' section. It thus seems certain that the large fauna collected and identified by Butts from this locality comes, not from the base of the Clinch sandstone, but from the ridge-making sandstones at the base of the Poor Valley Ridge member of the Clinch and about 75 feet above the base of the Clinch.

AGE AND CORRELATION OF THE CLINCH SANDSTONE

Butts' fossiliferous unit at Cumberland Gap is in a similar stratigraphic position to the *Helopora*-bearing units in the lower part of the



Relations of the Hagan and Poor Valley Ridge members of the Clinch sandstone in measured sections near the Rose Hill district.

Poor Valley Ridge member in our measured section at Hagan (Geologic Section 10). Forms that Butts identified as *Helopora fragilis* Hall and *Subulites,* are probably identical with our *Helopora* cf. *H. fragilis* and undetermined gastropod. Butts states that his Cumberland Gap fauna from his Units 1, 6, and 10 is of Brassfield age and he correlates it with the Albion sandstone of New York and the Brassfield limestone of Ohio. Inasmuch as no hiatus exists between the Poor Valley Ridge member and the Hagan member, whereas the later unconformably overlies the upper Sequatchie, of Richmond age, it seems certain that all of the Hagan member is also of Brassfield age. Since *Coelospira (Anoplotheca) hemispherica,* which occurs at the base of our Clinton shale, is considered by Swartz[171] to be of lower Rose Hill (Clinton) age, it seems likely that the sparingly fossiliferous middle and upper parts of the Poor Valley Ridge member of the Clinch are also of Brassfield age. If this is correct, the beds of Brassfield age in the Rose Hill district would total 259 feet of sandstone and shale.

CLINTON SHALE

Name.—The Clinton shale, which received its name from Clinton, Oneida County, New York,[172] includes, in the Rose Hill area, rocks that conformably overlie the Clinch sandstone and that are unconformably overlain by Cayuga dolomite.

Distribution.—Along Poor Valley on the northwest flank of the Powell Valley anticline the Clinton shale forms a continuous belt of outcrop but in the corresponding position on the southeast flank it is in places partly or completely cut out by the Wallen Valley fault. Southwest of Mulberry Creek the Clinton crops out in isolated lens-shaped areas on the north side of the fault near the foot of Wallen Ridge, but northeast of Mulberry Creek the Clinton forms a belt which gradually widens until the whole formation is present and the overlying Cayuga dolomite lies against the Wallen Valley fault. All the large fensters except the Sugarcamp fensters contain belts of Clinton shale, which are normally wider than the belts of any other formations in the fensters owing in large part to the gentle dips or nearly horizontal position of the Clinton strata.

Character.—Because the Clinton shale is nonresistant it has very

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[171] Swartz, Frank, personal communication.

[172] Conrad, T. A., Observations on the Silurian and Devonian systems of the United States, with descriptions of new organic remains: Acad. Nat. Sci. Philadelphia Jour., vol. 8, pp. 228-235, 1842.

few good outcrops. The lower part of the Clinton, which lies on the back slopes of Wallen Ridge and Poor Valley Ridge, is largely covered by talus from the Clinch sandstone, and the higher parts which normally lie on the floors of Poor Valley and of Rebel and Sulphur Hollows are commonly covered by alluvium or soil. The most abundant outcrops of Clinton are in the Fourmile and Dean fensters. The best section of the Clinton is at Hagan (Geologic Section 10), but even here much of the middle part of the formation is covered.

In contrast with the underlying Poor Valley Ridge member of the Clinch sandstone, the Clinton is composed mostly of shale with a few interbedded thin platy sandstones and is thus more like the Hagan member of the Clinch. The Clinton is roughly divisible into three parts on the basis of lithologic character, but these parts are not sufficiently distinct to warrant being classified as members. The lower part of the formation consists of about 100 feet of beds, of which the lowest 85 feet are completely exposed in the Hagan railroad cut (Geologic Section 10). Here the basal unit of the Clinton is a 5-foot zone of greenish-gray to blue-gray shale with thin fine-grained sandstone beds, fucoid markings, and ripple-marks. Above this is a bed of typical "Clinton iron ore" composed of oolitic hematite in a matrix of calcite. This is one of the thicker and higher-grade beds of "Clinton-type ore" and has been mined at several localities in the Rose Hill area. It ranges in thickness from 5 inches to nearly 3 feet. Above these basal beds the lower part of the Clinton is composed largely of red shales but includes a few zones of greenish-gray, purple, and blue shales and also a few beds 1 to 8 inches thick of platy fine-grained sandstone. Several beds of iron ore similar to the basal bed may also be present, but they are in most places only a few inches thick. The sandstone is greenish-gray to gray when fresh but it weathers limonite brown, and many of the beds show water-markings and fucoids. Some sandstones have a calcium carbonate cement and a few might better be called siliceous limestones. In thin section one of the limy sandstones showed 50 percent of angular quartz in grains averaging 0.03 to 0.065 mm. in size, and 40 percent calcite as cementing material of the quartz and as nearly pure laminae between the sandy layers. Accessory minerals, chiefly limonite, pyrite, zircon, muscovite and glauconite, accounted for the remaining 10 percent. Both sandstones and shales contain the characteristic Clinton brachiopod *Coelospira (Anoplotheca) hemispherica* in abundance.

The middle part of the Clinton, which is normally very poorly exposed, is about 165 feet thick. It seems to consist mainly of interbedded blue to gray shale and thin-bedded fine-grained greenish-white sandstone, some of which is limy and some quartzitic. A few red sandy shales, red shales and thin hematitic iron beds are also present. The upper part of the Clinton, which is better exposed, is of similar lithology throughout most of its 100-foot thickness except that it contains more interbedded sandstone. In much of the area the top 20 feet of the Clinton consists of fine- to medium-grained sandstone in beds 6 inches to 4 feet thick. These beds are much more resistant than most of the Clinton and form conspicuous ledgy outcrops which are especially well exposed in the Hamblin Branch, Martin Creek, and Possum Hollow fensters (Pls. 2 and 27B). The rock is blue gray to white on fresh surfaces but weathers to a limonite-brown. Most of the thick-bedded sandstones have calcium carbonate cement but a few are quartzitic. Both types contain fucoidal markings, oscillation ripple-marks, clay galls, pits formed by the removal of clay galls, and fossils. Interbedded with the thick, somewhat lenticular beds of sandstone are a few beds of platy sandstone and greenish-gray shale. We interpret the absence of this sandstone at the top of the Clinton in some places to be due to its erosion before deposition of the basal beds of the Cayuga dolomite.

Stratigraphic relations.—The Clinton shale overlies the Clinch sandstone conformably in the Rose Hill district and, according to Butts,[173] throughout the Appalachian Valley of Virginia. The lower contact is drawn at the top of the sequence containing thick beds of medium-grained sandstone (Clinch sandstone) and below a thick zone of red shale (Clinton shale). In most places a bed of "Clinton-type" iron ore near the base of the Clinton helps to mark the contact but the appearance of abundant *Coelospira hemispherica* in the lowest beds of the Clinton is an even better criterion. Throughout most of the area thick-bedded limy or quartzitic sandstone at the top of the Clinton is unconformably overlain by Cayuga dolomite, which has a prominent coarse sandstone at the base (Pl. 27B). Locally the basal sand of the Cayuga dolomite lies on nonsandy Clinton shale.

Thickness.—Because no sections of the Clinton are completely exposed and because there are likely to be faults and folds in covered areas, no reliable measurements of the thickness of the Clinton were obtained from the surface in the Rose Hill district. The best concept of the thickness is gained from the Brooks well, where 320 feet of beds

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[173] Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. I, Geologic text and illustrations, p. 237, 1940.

are assigned to the Clinton. The formations immediately below the Clinton have their true thicknesses in the well and, therefore, seem to be flat-lying, so that 320 feet probably represents nearly the true thickness of the Clinton. In Possum Hollow, where all except the top beds of the Clinton were penetrated by several wells, the formation is calculated to be about 330 feet thick. In the Hagan section a thickness of 423 feet of Clinton was measured, but the section includes a wide covered zone representing all of the middle part of the formation. If the experience with the exposed lower Clinton and with the other shaly formations in the section at Hagan can be taken as a guide, there is probably some duplication of beds caused by folds and reverse faults in the concealed middle part of the Clinton. The figure of 423 feet for the thickness at Hagan is therefore probably too large. In Wise County, which adjoins Lee County on the northeast, Stose gives the thickness of the Clinton as about 400 feet but states "that no complete continuous section was seen where the thickness could be measured."[174]

Paleontology.—The Clinton fauna collected from the Rose Hill district does not represent the whole formation because no collections were made from the poorly exposed middle part of the Clinton. The fossils listed in Table 10 are, therefore, divided into two groups, those coming from the lower 100 feet of the formation and those from the upper 60 feet. C. K. Swartz[175] and F. M. Swartz[176] have divided the Clinton of the Appalachian region into 8 faunal zones on the basis of ostracodes as follows:

8. *Mastigobolbina typus* zone
7. *Bonnemaia rudis* zone
6. *Mastigobolbina modesta-Zygosella postica* zone
5. *Mastigobolbina lata* zone
4. *Zygobolbina emaciata* zone
3. *Zygobolba bimuralis* zone
2. *Zygobolba decora* zone
1. *Zygobolba anticostiensis* zone

In the collections from our area numerous fossils of the top or *Mastigobolbina typus* zone were identified by F. M. Swartz. He also indicates that collections from the lower part of our Clinton probably

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[174] Stose, G. W., Pre-Pennsylvanian rocks, *in* 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, p. 33, 1923.

[175] Swartz, C. K., Stratigraphic and paleontologic relations of the Silurian strata of Maryland: Maryland Geol. Survey, Silurian, p. 30, 1923.

[176] Swartz, F. M., personal communication.

span the lower 5 faunal zones, although *Zygobolba anticostiensis* was the only one of the key ostracodes found. Inasmuch as there is no evidence for an unconformity in the Clinton of the Rose Hill district, faunal zones 6 and 7 are probably also present, and lie in the middle part of the Clinton from which no fossil collections were made.

TABLE 10.—*Fauna of the lower and upper parts of the Clinton shale in the Rose Hill district*

UPPER 60 FEET OF THE CLINTON SHALE	MIDDLE 165 FEET OF THE CLINTON SHALE
Anoplotheca sulcata (Prouty)	No fossils collected.
Chonetes sp.	LOWER 100 FEET OF THE CLINTON SHALE
Chonetes "*novascoticus*" Hall (=*C. parascoticus* Swartz ms.)	Crinoid stems, some round, some pentagonal
Uncinulus sp.	*Brachyprion* sp.
Pelecypods	*Brachyprion pleuristriata* (Foerste)
Bucanella trilobata (Conrad)	*Coelospira* sp.
Hormotoma sp.	*Coelospira hemispherica* (Sowerby)
Subulites sp.	*Coelospira hemispherica* var.
Tentaculites sp.	*Lingula* sp.
cf. *Dalmanites clintonensis* Ulrich	*Schuchertella* sp.
Liocalymene clintoni (Vanuxem)	Pelecypods
cf. *Bonnemaia crassa* Ulrich and Bassler	Gastropods
Bonnemaia crassa Ulrich and Bassler	*Tentaculites* sp.
Dizygopleura loculata Ulrich and Bassler	*Calymene* sp.
Mastigobolbina typus Ulrich and Bassler	*Calymene* sp. cf. *C. vogdesi* (Foerste)
Mastigobolbina new sp.	*Eophacops* sp.
Plethobolbina typicalis Ulrich and Bassler	*Zygobolba anticostiensis* Ulrich and Bassler
Zygosella vallata Ulrich and Bassler	*Zygobolba* aff. *Z. excavata* Ulrich and Bassler

Age and correlation.—The Clinton shale of the Rose Hill district is of Middle Silurian age. It is identical with the Clinton formation of Bates[177] in northeastern Lee County and with the Clinton formation of Butts[178] of the Appalachian Valley in Virginia. The Clinton in our area is mainly a sequence of homogeneous shales with thin layers of sandstone, and thus resembles the Cumberland facies of Butts.[179] Butts describes this facies of the Clinton as being present at the northeast and southwest ends of the Valley of Virginia. One highly ferruginous sandstone is present in the Fourmile fenster, however, and a similar bed observed in a section described by Bates on State Highway 64 at the Lee-Wise County

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[177] Bates, R. L., Geology of Powell Valley in northeastern Lee County, Virginia: Virginia Geol. Survey Bull. 51-B, pp. 58-60, 1939.

[178] Butts, Charles, op. cit., pp. 237-251.

[179] Butts, Charles, op. cit., p. 238.

line suggests that a few beds of Butts' Iron Gate facies of the Clinton, which is developed in the middle part of the Appalachian Valley, may extend into southwestern Virginia. The massive sandstones at the top of the Clinton in our area also resemble Butts' description of the Keefer sandstone member, which, however, makes up the whole upper half of the Clinton where the Iron Gate facies is well developed. The Clinton shale of the Rose Hill district seems to contain a greater quantity of red shale than is characteristic of the Clinton of the rest of the Valley, and there may be a significant relationship between the greater abundance of iron ores in Lee and Wise counties and the greater quantity of red shale.

The fauna of the Clinton shale of the Rose Hill district and that of the Clinton of the Appalachian Valley from New York to Alabama contain in common many significant forms, such as *Coelospira hemispherica* (Sowerby), *Liocalymene clintoni* (Vanuxem), *Chonetes novascoticus* Hall, *Mastigobolbina typus* Ulrich and Bassler, and *Zygobolba anticostiensis* Ulrich and Bassler. Other fossils found in the Clinton elsewhere in the Appalachian Valley are also present in the Clinton of the Rose Hill district and, thus, the identity of our Clinton with the Clinton previously mapped in the Appalachian Valley is certain.

CAYUGA DOLOMITE

Name.—The Cayuga group was named from Cayuga Lake, New York.[180] In northwestern Virginia the group includes in ascending order the McKenzie limestone, Bloomsburg formation, Wills Creek formation, and Tonoloway limestone, but in southwestern Virginia only the Wills Creek and Tonoloway seem to be present.[181] These two formations have been mapped together by previous workers in southwestern Virginia as Hancock limestone (in part),[182] Cayuga limestone,[183] formations of Cayuga age,[184] and Cayugan series[185].

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

[181] Butts, Charles, op. cit., pp. 251, 258.

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

[183] Stose, G. W., Pre-Pennsylvanian rocks, *in* 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. 36-40, 1923.

[184] Butts, Charles, Geologic map of the Appalachian Valley of Virginia with explanatory text: Virginia Geol. Survey Bull. 42, pp. 26-27, map, 1933.

[185] Bates, R. L., Geology of Powell Valley in northeastern Lee County, Virginia: Virginia Geol. Survey Bull. 51-B, pp. 60-61, 1939.

Butts and Bates both recognized that beds of Cayuga age in Lee County seemed to contain Wills Creek and Tonoloway equivalents but did not separate them. In the Rose Hill district the upper part of the Cayuga is missing owing to faulting, and a subdivision of the beds of Cayuga age is not practical. Because of the dominance of dolomite in the sequence, the unit is called the Cayuga dolomite.

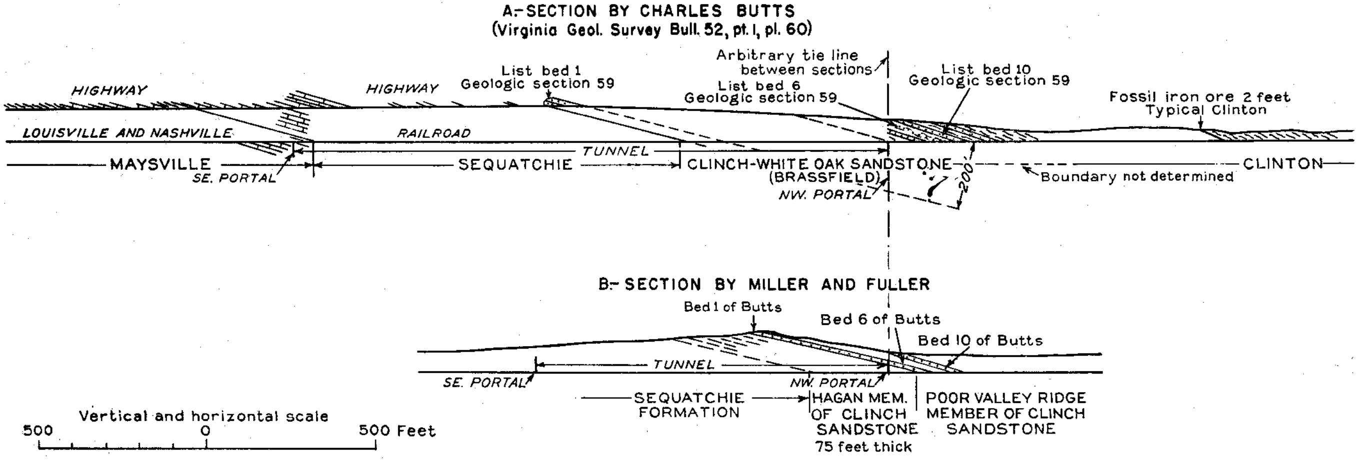
Distribution.—Within the area here mapped all exposures of the Cayuga dolomite are in the fensters, with the exception of a very narrow belt along the southeastern border of the district, where the basal sandstone of the Cayuga lies between the Clinton shale and the Cambrian rocks along the Wallen Valley fault. The Cayuga dolomite is exposed in the five northeastern fensters as narrow bands, some short and crescent shaped, others extending partly or completely around the rims of the fensters. In these fensters Cambrian and Ordovician rocks of the Cumberland overthrust block rest directly on the Cayuga dolomite. Northwest of the area mapped in Plate 1, the Cayuga dolomite is present as a continuous belt in Poor Valley, but it has almost no natural outcrops and very few artificial exposures because of the deep mantle of talus and alluvial fans from Cumberland Mountain that cover the floor of the valley.

Character.—In the fensters the Cayuga dolomite normally lies on the slopes below the steep walls of the overthrust rocks and above the characteristic flat-bottomed valleys. The dolomite is widely exposed in massive steplike ledges and in a few places in small cliffs, the highest of which is on the northeast side of Blackberry Hollow. Because the upper part of the formation has been removed by faulting, a complete section of the Cayuga in the Rose Hill district is not obtainable. At Hagan, just outside the district, the top and base of the Cayuga are both exposed, but all the middle part of the formation is covered. The best section of the Cayuga we have seen (Geologic Section 11) is at Ben Hur, Virginia, 16 miles northeast of the Rose Hill area. The lower part of the section at that place is very similar in lithologic character to the Cayuga in the fensters of the Rose Hill district.

The Cayuga dolomite consists in general of a basal sandstone, several feet thick, overlain by about 20 feet of blue-weathering limestone, and then by thick-bedded dolomite, which varies in thickness because it lies directly beneath the overthrust fault plane. The basal bed is everywhere a coarse-grained sandstone or pebbly sandstone which normally crops out, but is also conspicuous as float in covered areas. At some localities it is only a few inches thick, but the overlying limestones may contain lenses of coarse sandstone or scattered quartz pebbles up to ⅛ inch in length. A good exposure of the basal bed near the south end of the Martin Creek fenster is illustrated in Plate 27B. Here the topmost Clinton is even, thick-bedded limy sandstone, and the basal bed of the Cayuga consists of 5 inches of fine- to coarse-grained quartzitic sandstone with scattered pebbles, overlain by beds of light-blue limestone containing lenses of pebbly sandstone. Elsewhere the basal bed is thicker and consists of friable pebbly sandstone containing pebbles as much as half an inch in diameter. The pebbles are of white quartz, are well-rounded and lie in a matrix of finer grained less-rounded white quartz sand. At some places the sandstone is medium grained and contains lenses of coarser material. Also at some places it is crossbedded and at Hagan it contains abundant gastropods, trilobites, and ostracodes. The sandstone is normally stained with limonite, and the cementing material is limonite and calcite. At one locality the pore spaces are filled with pyrite or marcasite, which produces a very heavy impervious rock.

The limestone, above the basal sandstone, is mostly a ribbon limestone or is mottled. The banding and mottling are caused by slightly more argillaceous material which weathers yellow-brown and normally stands in relief above the layers and patches of purer limestone that weathers light blue-gray. The pure limestone has at places a pinkish or tan cast. On fresh surfaces the rock is fine- to coarse-crystalline and dark blue-gray, and the detection of any differences in composition between the bands or patches which weather so differently is difficult. Scattered through the lower beds are rounded small to large quartz grains, and some sandy lenses or beds may be interbedded with the limestone. The upper beds of limestone, however, are relatively free of sand. A bed of intraformational limestone conglomerate was observed at one locality. Fossils are fairly common in the limestone. A branching stem-like coral *(Coenites* sp.) is almost invariably found, and *Halysites* and *Favosites* are common. In places these fossils are silicified and are abundant in the red residual soil.

Another less abundant but quite characteristic type of limestone of the lower part of the Cayuga dolomite is an even-bedded



A, Section of Charles Butts at Little Tunnel, Cumberland Gap, Tennessee. B, Interpretation of Clinch sandstone part of section drawn to same scale, based on measurements of Miller and Fuller.

fine-crystalline laminated rock which is light gray and weathers a limonite brown. The discoloration penetrates weathered surfaces to a depth of a quarter to half an inch and forms a clean-cut colored rim around the unweathered interior. A few beds of limestone are medium-crystalline steel-gray rock, which weathers first to a light chocolate-brown color, but with prolonged weathering turns blue-gray. The limestone commonly contains vugs lined with dolomite crystals. Some of the dark-colored limestone has a petroliferous odor.

Although sandstones and limestones make up the lowest part of the Cayuga dolomite, practically all the remainder of the formation is dolomite. The dolomite is light brown and fine crystalline, and is in even beds 1 to 2 feet thick. Carbonaceous streaks are common on some fresh surfaces. On weathering the rock becomes light brown and the rock surfaces are crisscrossed by closely spaced grooves weathered along incipient joints ("butcher-block structure"). On the south side of the Wilson fenster a 7-inch bed of limestone was found in the dolomite sequence 57 feet above the base of the Cayuga. It is composed mainly of fine-crystalline light-gray limestone, but it has a mottled appearance due to patches of sandy and argillaceous limestone, which weather red, green or brown. This bed is noteworthy because it contains the only fossils found in the middle or upper parts of the Cayuga in the Rose Hill district. In the section at Ben Hur (Geologic Section 11) several beds of limestone are interbedded with the dolomite in the upper part of the Cayuga.

At Hagan the top 34 feet of the Cayuga make one massive dolomitic unit which differs from any of the dolomite seen in the fensters or in the section at Ben Hur. The unit consists of laminated, fine-crystalline, and light brownish-gray dolomite, and it contains one zone of intraformational conglomerate. Bedding planes are spaced a few feet apart but are inconspicuous.

Around many of the fensters the Cayuga dolomite is overlain along fault contacts by dolomites of the Chances Branch member of the Maynardville limestone or of formations of the Knox group. The Cayuga dolomite can normally be distinguished from these overlying dolomites by its slight pinkish cast, by its finer textured "butcher-block structure" and by its smoother and more rounded weathered surfaces. In a few places, however, dolomites of the Maynardville and Cayuga are almost identical in appearance and can be distinguished from each other only with the greatest difficulty. A case in point is exhibited on the west bank of Martin Creek at the north end of the Martin Creek fenster, where almost continuously outcropping ledges of massive bedded dolomite are known to consist of Cayuga dolomite at the south end of the exposure and of dolomite of the Maynardville limestone at the north end. Nevertheless the position of the Wilson fault, by which the Cambrian and Silurian formations are brought into contact with each other, was determined only after extremely careful bed-by-bed study of the exposure.

Stratigraphic relations.—The Cayuga dolomite unconformably overlies the Clinton shale, as shown by its basal pebbly sandstone and by a slight undulatory surface at the contact. The unconformity represents a hiatus which included all of Lockport time and probably some of early Cayuga time. It is well exposed in a road cut on U. S. Route 58 a quarter of a mile east of its junction with U. S. Route 25E near Cumberland Gap 12 miles to the southwest of the Rose Hill area. Plate 27C is a photograph of the road cut with the Cayuga-Clinton contact at the right foot of the man. The bed at the level of the man's knee is the pebbly basal sandstone of the Cayuga and the beds below the man's feet are sandstones and shales of the Clinton, whose uppermost bed is cut out near the center of the picture by the unconformity. The massive limy sandstones of the upper part of the Clinton at this locality are lithologically identical with the limy sandstones just below the contact in most of the Rose Hill area and also at Ben Hur 28 miles to the northeast. This suggests that, although there may have been considerable erosion during the pre-Cayuga hiatus, the final erosion surface had little relief and was at approximately the same stratigraphic horizon throughout the Rose Hill district and the immediately adjacent areas.

The Cayuga dolomite is the youngest Silurian formation in the region. Following its deposition there was a long hiatus covering all of Lower and Middle Devonian time, for the overlying deposits of black shale are believed to be of Upper Devonian age. In northeastern Lee County the Helderberg limestone, of Lower Devonian age, overlies the Cayuga dolomite and farther northeast in Virginia other Devonian formations are present in the section. Despite the length of the hiatus the contact of the Brallier shale and Cayuga dolomite at Hagan appears essentially conformable.

Thickness.—The true stratigraphic thickness of the Cayuga dolomite is impossible to determine within the mapped area because the exposed Cayuga represents only the part of the formation that was not removed by the Pine Mountain overthrust fault. It ranges, where present, from a thin film to a possible 90 feet in the Possum Hollow fenster. Just outside the Rose Hill district at Hagan the thickness of the Cayuga dolomite, in a partly covered section, is 158 feet. At Ben Hur, 16 miles to the northeast, the Cayuga dolomite is 188 feet thick and in Wise County Stose[186] reports it to be 225 feet thick. Near Cumberland Gap, 12 miles southwest of the Rose Hill district, it is only 19 feet thick. These measurements show that the formation thins from northeast to southwest in Wise and Lee counties.

Paleontology.—The fauna of the Cayuga dolomite contains only a few genera, but several of these genera are fairly abundant in the lower limestone beds. The corals *Favosites, Halysites, Coenites,* and an unidentified stromatoporoid are the most common. No fossils whatever were found in the dolomites of the Cayuga, but a species of *Calymene* and an unidentified orthoceratid were found in a limestone interbedded with the dolomites, 57 feet above the base of the formation. F. M. Swartz[187] and G. A. Cooper[188] identified the following forms from the Cayuga dolomite in the Rose Hill area:

Algal? structures
Stromatoporoid
Coenites? sp.
Favosites sp.
Halysites cf. *H. catenularia* (Linnaeus)
Crinoid fragments
Spiriferoid brachiopod
Whitfieldella sp.
Orthoceratid
Calymene sp.
Liocalymene clintoni (Vanuxem)
Bonnemaia cf. *B. oblonga* Ulrich and Bassler
Leperditia? sp.
Zygosella cf. *Z. vallata* Ulrich and Bassler

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[186] Stose, G. W., Pre-Pennsylvanian rocks, *in* 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. 37, 1923.

[187] Swartz, F. M., personal communication.

[188] Cooper, G. A., personal communication.

Zygosella cf. *Z. vallata, Bonnemaia* cf. *B. oblonga* and *Liocalymene clintoni* are present in the basal sandstone at Hagan, and the other forms were collected from the overlying limestones.

In Wise County, which adjoins Lee County on the northeast, Stose[189] reports the following fossils from the Cayuga limestone:

Stromatoporoids
Favosites sp.
Meristella sp.
Spirifer vanuxemi Hall
Pterinea sp.
Beyrichia sp.
Kloedenia sp.
Leperditia alta

In addition, Bates [190] reported *Leperiditia alta* and *L. elongata* var. *willsensis* in the Cayuga of northern Lee County.

Age and correlation.—According to Swartz[191] the fossils identified from the Rose Hill area were not definitive enough to limit the age of the beds any closer than Niagaran to Keyser. In northeastern Lee County, 20 miles northeast of the Rose Hill area, a similar series of rocks has been mapped and described by Bates[192] as the Cayugan series, and he reports that "The type fossil of the Wills Creek, *Leperditia elongata* var. *willsensis,* was collected * * * and that of the Tonoloway, *L. alta* was also found." In Wise County these rocks are called Cayugan limestone and described as "largely a thin-bedded finely-laminated magnesian limestone with some thicker dolomite beds."[193] It has a basal pebbly sandstone, and *Stromatopora* and *Favosites* similar to those found in the Rose Hill district. In discussing the Cayuga limestone of Wise County, Butts[194] correlates the lower 37 feet of the sequence with the Wills Creek formation and the upper 190 feet with the Tonoloway limestone. Because the formation in the Rose Hill area has the same general lithologic sequence and the same

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[189] Stose, G. W., Pre-Pennsylvanian rocks, *in* 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. 37, 39, 1923.

[190] Bates, R. L., Geology of Powell Valley in northeastern Lee County, Virginia: Virginia Geol. Survey Bull. 51-B, p. 61, 1939.

[191] Swartz, F. M., personal communication.

[192] Bates, R. L., op. cit., pp. 60-61.

[193] Stose, G. W., op. cit., p. 36.

[194] Butts, Charles, op. cit., pp. 258-260.

relationship to the underlying Clinton shale as do the Cayuga beds of Wise and northeastern Lee counties, it also probably correlates with the Wills Creek shale and Tonoloway limestone.

The measured section at Ben Hur (Geologic Section 11) lies between Wise County and the Rose Hill district but closer to Wise County. As might be expected it is intermediate both in lithologic character and thickness, being thinner and more dolomitic than the Cayuga described by Stose in Wise County, but thicker and with more limestone at the base and more interbedded limestone in the upper part than the Cayuga dolomite of the Rose Hill district. Thus a change of facies, as well as a thinning, from northeast to southwest is indicated.

In Hancock County, Tennessee, 10 miles southeast of the Rose Hill area, rocks in the same stratigraphic position as the Cayuga dolomite were called Hancock limestone by Keith.[195] This formation according to Keith "consists entirely of interbedded, massive and shaly limestones of blue, gray or dove color. The thickness of these strata is 450 feet." We examined these beds at several localities and found a considerable thickness of dolomite overlying the limestone. About a mile southwest of Howard Quarter, Hancock County, Tennessee, good outcrops along the road are dominantly dolomite, which looks like the Cayuga dolomite of the Rose Hill area and also contains *Favosites* and stromatoporoids. Near Elm Springs School, 2½ miles northwest of Sneedville, Hancock County, Tennessee, the Hancock consists of about 22 feet of fossiliferous limestone at its base overlain by 83 feet of beds, chiefly dolomite. At this locality the limestones contain abundant ostracodes and numerous brachiopods, which Swartz[196] believes to be of Tonoloway age. No fossiliferous beds of this type have been seen in the lower limestones of the Cayuga dolomite in the Rose Hill district.

Campbell[197] described the Hancock limestone in Lee County, Virginia, northeast of the type locality of the Hancock. This area was later mapped by Bates[198] who, as previously stated, designated the same beds the Cayugan series. The Hancock limestone, which has been mapped extensively in Tennessee, thus appears to be partly if not entirely equivalent to the beds designated Cayuga in southwest Virginia.

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[195] Keith, Arthur, U. S. Geol. Survey Geol. Atlas, Morristown, Tennessee, folio (No. 27), p. 3, 1896.

[196] Swartz, F. M., personal communication.

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

[198] Bates, R. L., op. cit., pp. 60-61.

DEVONIAN SYSTEM

BRALLIER SHALE

Name.—The Brallier shale was named from Brallier station, Bedford County, Pennsylvania.[199] Butts[200] has used the name in southwestern Virginia for the sequence of shales between the Cayuga dolomite or Genesee shale below, and the Price formation above. This shale sequence has been called Portage shale, and Big Stone Gap shale by Stose,[201] Olinger and Big Stone Gap members of the Chattanooga shale by Swartz,[202] and Portage shale and Chattanooga shale by Bates.[203]

Distribution.—Within the mapped area the Brallier shale crops out only in a thin fault sliver in the Wilson fenster. The shale is also present northwest of the mapped area at the base of the slope of Cumberland Mountain but it is so largely covered by talus that outcrops are extremely rare. The best exposure of the Brallier immediately adjacent to the Rose Hill area is at Hagan.

Character.—On the north side of the Wilson fenster there is an occurrence of about 6 inches of the Brallier shale that is in fault contact with the Cayuga dolomite below and the Maynardville limestone above. Here, most of the shale is a contorted black shaly mass with shiny coal-like luster and slickensides. On the south side of the fenster there is a slightly larger exposure of the Brallier, consisting of about 5 feet of interbedded black and greenish-gray shale whose topmost beds are highly contorted. The only large exposure of the Brallier near the Rose Hill district is at Hagan, where a thickness of more than 136 feet of the shale is visible in the railroad cut just south of the mouth of the Cumberland Mountain tunnel. Directly overlying the Cayuga dolomite in this section there is at the base of the Brallier an 8-inch zone of shiny black shale containing specks of sulfur and tiny sulfate

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

[200] Butts, Charles, Geology of the Appalachian Valley in Virginia: Virginia Geol. Survey Bull. 52, pt. I, Geologic text and illustrations, pp. 317-322, 1940.

[201] Stose, G. W., Pre-Pennsylvanian rocks, *in* 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. 45-53, 1923.

————, The black shale of southwestern Virginia: Jour. Geology, vol. 32, pp. 311-315, 1924.

[202] Swartz, J. H., The Chattanoogan age of the Big Stone Gap shale: Am. Jour. Sci., 5th ser., vol. 14, pp. 485-499, 1927.

[203] Bates, R. L., op. cit., pp. 63-65.

crystals. Above this is 76 feet of dark-gray shale which weathers light-gray and contains some thin sandy beds. Overlying the gray shale is a black to greenish-black slaty shale with large siderite concretions near the base. The concretions have a maximum diameter of 4 feet and are slightly flattened at right angles to the bedding. Both the concretions and some of the brown shale just above the concretions contain abundant small reddish-brown spores less than 1/32 of an inch in size. The black shale weathers a black, brown, or yellow color, and is much more resistant than the underlying gray shale. About 60 feet of the black shale unit is exposed before a reverse fault is reached which may duplicate most of the sequence. The folding and faulting of these units in the Hagan railroad cut are shown in Plate 36B.

Stratigraphic relations.—At Hagan the lower contact of the Brallier shale with the Cayuga dolomite appears conformable in spite of the fact that a long hiatus between deposition of the two formations is indicated by the complete absence of Lower and Middle Devonian beds. The upper contact with the Price formation is not visible at Hagan and has not been seen in or near the Rose Hill district.

Thickness and paleontology.—At Hagan the lowest 137 feet of the Brallier is exposed, but the middle and upper parts of the formation have not been seen and its full thickness is not known. Butts[204] says: "At Big Stone Gap, it [the Brallier] is about 700 to 1000 feet, according to whether the 350 feet of black shale at the top is Brallier. At Cumberland Gap the thickness of the black shale seems to be about 400 feet, but it may or may not be Brallier."

The only fossils found in the Brallier are the brown spores that are abundant in the concretionary zone at Hagan. Throughout Virginia the Brallier has very few fossils.

Age and correlation.—The part of the Brallier shale exposed in the fensters and in the Hagan cut is believed to be of Upper Devonian age. The terminology and correlation of the so-called "black shale" sequence is not a concern of this report and only a few facts can be contributed toward these matters. First, if any black shale at Hagan is equivalent to the Genesee shale, it would seem to be the basal 8-inch bed immediately above the Cayuga

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[204] Butts, Charles, op. cit., p. 319.

dolomite. Second, the visible sequence at Hagan of gray shale overlain by black shale with spores is similar to that described above the Genesee shale at Big Stone Gap, 30 miles to the northeast. Third, unless sections of the black shales in the Appalachian Valley are perfectly exposed, it seems inadvisable to correlate from locality to locality on the basis of sequence and thickness of lithologic units, because the shales are peculiarly susceptible to the sort of crumpling and faulting visible in the Hagan railroad cut (Plate 36B). Sections measured at this locality before and after excavation of the cut in 1937 show little resemblance.

QUATERNARY SYSTEM

The sediments of Quaternary age in the district are all unconsolidated. They consist of recent deposits of boulders, gravel, sand, silt and clay which have been transported and deposited by streams. The deposits that have been mapped are of three different types—terrace deposits, alluvial fans, and floodplain deposits. The terraces along Powell River have been separated into three sets, low, middle and high terraces, but along Indian Creek only low terraces are well preserved. Isolated gravel remnants on the hills of the Indian Creek lowland have been mapped as high terraces, but they do not represent a well-defined set of terraces. Alluvial fans are prominent on the north slope of Wallen Ridge and also in the Indian Creek lowland. Floodplain deposits, which are shown as alluvium on Plate 1, are found along Powell River and Indian Creek below the lowest set of terraces, and also along many of the smaller streams. They have been mapped only where the width of the flood plain approaches or exceeds 100 feet. The character and origin of the terrace deposits, fans, and floodplain deposits are discussed at length in the section on physiography.

GEOLOGIC SECTIONS

Geologic Section 1.—Rome formation, based on cuttings from the Brooks well, 2 miles south of Ewing, Lee County, Virginia

	Feet
Conasauga shale	
16. Sandstone, limestone, and shale interbedded; sandstone, medium grained, speckled, glauconitic; limestone, brown, coarse crystalline, oolitic; shale, green to gray, sericitic (?)	24

	Feet
Rome formation (thickness penetrated in well 1660 feet)	
15. Sandstone, greenish white, tan and gray, speckled, medium grained, partly glauconitic and micaceous	38
14. Sandstone, light and dark, medium grained, with carbonate cement, partly glauconitic and micaceous	93
13. Sandstone, limestone and shale interbedded; sandstone, white, greenish white and gray, medium grained with some beds having abundant phlogopite; a little gray sericitic to micaceous shale; a little flesh-colored to white fine-crystalline limestone	85
12. Sandstone, shale, and limestone, interbedded; sandstone, white, gray, and green, medium grained, with abundant glauconite; shale, bronze to greenish gray; a little interbedded limestone	142
11. Limestone, and sandstone; limestone, gray fine-crystalline; sandstone, green and gray, medium grained	45
10. Sandstone, green and gray, medium grained, locally with abundant phlogopite and glauconite	155
9. Shale, green and gray with a little red; a little glauconitic sandstone and flesh-colored limestone	76
8. Sandstone, green, medium grained, with abundant large glauconite grains; a little red and green shale	197
7. Sandstone, medium grained, green and white, glauconitic; a very little green and red shale; this is believed to be a ridge-forming member of the Rome formation	294
6. Shale and sandstone; shale, micaceous, green and gray with a little red; sandstone, gray, medium grained	83
5. Shale and sandstone; shale, red and green, micaceous; sandstone, green and gray, medium grained, locally with abundant glauconite	115
4. Sandstone and shale; sandstone, white and green, medium grained; shale, micaceous, green with a little red	104
3. Dolomite, light brown, medium crystalline, with a few glauconite grains	67

	Feet
2. Sandstone, shale, and dolomite; sandstone, gray and white, fine grained, locally with glauconite; shale, gray, micaceous; a little brown and white medium-crystalline dolomite	166(?)
Pine Mountain fault	
Clinton shale (Silurian)	
1. Shale, mainly red with a little green; no glauconite; some shale micaceous	82

Geologic Section 2.—Maynardville limestone along Fourmile Creek beginning at the Virginia-Tennessee State line 3 miles south-southeast of Ewing, Virginia

	Feet
Copper Ridge dolomite	
9. Dolomite, dark gray, coarse crystalline, massive bedded, with petroliferous odor; contains interbeds of light-gray, fine-grained dolomite	20
Maynardville limestone (302 feet)	
Chances Branch dolomite member (160 feet)	
8. Dolomitic limestone, light gray, fine grained, in even, angularly jointed beds; and dolomite, dark gray and brown, medium to coarse crystalline, with petroliferous odor	55
7. Dolomitic limestone, light gray, fine grained, argillaceous, in beds 6 inches to 3 feet thick; some beds show laminae on weathered surfaces; interbeds of dark-gray limestone in lower part; tan chert in thin lenses; intraformational conglomerate locally	105
Low Hollow limestone member (142 feet)	
6. Limestone, dark gray, massive bedded, mottled, with thin interbeds of shale in lower part and of light-gray dolomite in upper part	47
5. Dolomitic limestone, light gray, silty, with closely spaced laminae showing on weathered surfaces	22
4. Limestone, dark gray, fine grained, ribboned and mottled, with some beds oolitic; silty limestone layers separate pure limestone layers, and silty limestone patches give mottled effect; trilobite fragments near base; ribbon limestone shown in Plate 11A.	73

	Thickness	
	Ft.	In.
Conasauga shale		
3. Shale, dark fissile	3	0
2. Limestone, tan to gray, gnarled, ribbon-bedding poorly developed; contains trilobite fragments; transitional from Conasauga to Maynardville type of limestone	7	6
1. Shale and limestone, in beds one inch thick; shale, dark gray; limestone, gray, fine grained	3	0

Geologic Section 3.—Chances Branch dolomite member of the Maynardville limestone and lower two-thirds of the Knox group along Chances Branch half a mile southwest of Ewing, Lee County, Virginia

	Thickness	
	Ft.	In.
Kingsport dolomite (88+ feet)		
46. Covered; float of saccharoidal dolomite; brown to reddish-brown soil derived from saccharoidal dolomite; one ledge of nearly white fine-grained dolomite; abundant white chert, some oolitic	85	1
45. Conglomerate, consisting of gnarled and mottled blue-gray limestone containing irregular dolomite pebbles and green shale lenses	3	0
Longview dolomite (239 feet)		
44. Dolomite, partly covered; white to light brown, coarse saccharoidal; irregular chert nodules and some oolitic chert	40	10
43. Chert, white with *Lecanospira conferta?*		5
42. Dolomite, white to light brown, medium to coarse crystalline, saccharoidal, in massive beds; scattered rounded quartz grains and lenses of sandstone less than 1 inch thick; a few shaly and limy beds; abundant white chert	54	10
41. Dolomite, largely covered, brown to reddish-brown soil with abundant white chert masses; some chert lenses and some light-brown coarse-crystalline saccharoidal dolomite	94	10

	Thickness	
	Ft.	In.
40. Dolomite, interbedded, white, fine grained, and light gray, medium crystalline, saccharoidal; scattered rounded quartz grains in latter; abundant beds of white chert with a maximum thickness of 4 feet.	48	3
Chepultepec dolomite (705 feet)		
Argillaceous dolomite member (433 feet)		
39. Sandstone, white, fine to medium grained, friable, with limonite stain; grades upward into sandy dolomite	1	8
38. Dolomite, partly covered; grayish white, fine grained; scattered friable sandstone beds; sandstone and chert float	38	4
37. Sandstone, white, medium grained, friable, limonite-stained	1	9
36. Dolomite, partly covered, light gray, fine grained, argillaceous, laminated, massive, in beds 1 to 6 feet thick; scattered chert nodules and beds; scattered interbedded tan medium-crystalline saccharoidal dolomite, some with petroliferous odor; *Cryptozoa*	134	11
35. Dolomite, tan to gray, fine grained in very massive beds; some limy and coarse-crystalline saccharoidal dolomite; a little light to dark nodular chert	30	10
34. Dolomite, light gray, fine grained, laminated, argillaceous in even beds 1 to 4 feet thick; some sacchaoridal beds; abundant chert lenses	103	7
33. Dolomite, largely covered, light gray, fine grained with chert fragments	121	10
Sandy member (272 feet)		
32. Sandstone, white, medium to coarse grained; slightly limonite-stained	3	10
31. Dolomite, largely covered, light gray to tan, coarse crystalline, saccharoidal; chert in beds and irregular masses; thin sandstone beds	128	4
30. Sandstone, white, fine grained, limonite stained; grading upward into sandy dolomite	1	11

		Thickness	
		Ft.	In.
29.	Dolomite, grayish white to tan, medium crystalline with chert; some oolite	12	9
28.	Sandstone, white, fine to medium grained, limonite-stained, grading upward into sandy dolomite	2	11
27.	Dolomite, light gray, tan, and medium gray, medium crystalline, saccharoidal, weathering with rounded surfaces; light-colored chert lenses and some oolitic chert	20	8
26.	Dolomite, sandy and sandstone, dolomitic; interfingering	1	9
25.	Dolomite, light gray, fine crystalline with light-colored oolitic chert; some dark-brown medium-grained saccharoidal dolomite with petroliferous odor	50	9
24.	Shale, sandstone and dolomite interbedded	1	6
23.	Dolomite, light gray, fine to medium crystalline; some dark-gray medium-crystalline dolomite with petroliferous odor; oolitic chert	45	9
22.	Shale, tan, calcareous; and dolomitic sandstone which is friable and limonite stained when weathered (see Pl. 11C)	2	3
Copper Ridge dolomite (840 feet thick)			
Upper member			
21.	Dolomite, light gray and white, fine and medium crystalline; contains light to white oolitic chert in irregular masses and in beds several inches thick; occasional shale interbeds; forms light-brown soil	135	
20.	Covered; forms brown soil containing small cobbles of silicified dolomite	97	
19.	Dolomite, light to medium gray, coarse crystalline, saccharoidal, with some beds of fine-crystalline dolomite; bedding poorly developed; soil brown	70	
18.	Covered; brown soil containing white brecciated chert cobbles	92	
17.	Dolomite, light gray, coarse crystalline and light brown, cryptocrystalline; forms deep-red soil	12	

	Thickness	
	Ft.	In.
Lower member		
16. Covered; soil contains chert and silicified dolomite cobbles Contact of lower and upper members lies in this covered interval.	177	
15. Dolomite, medium and dark gray, coarse crystalline, vuggy, with abundant white dolomite veins and patches; gives strong petroliferous odor (see Pl. 11B).	172	
14. Dolomite, medium gray, mottled, coarse crystalline; gives strong petroliferous odor, lower part contains possible algal reef (see Pl. 12A)	16	
13. Covered	34	
12. Dolomite, medium to dark gray, coarse crystalline, with strong petroliferous odor; contains several beds of light-gray cryptocrystalline dolomite of upper Maynardville type	35	
Maynardville limestone (229 feet+)		
Chances Branch dolomite member (209 feet)		
11. Dolomitic limestone, light gray, fine crystalline, even bedded, and dolomite, dark gray, coarse crystalline, with petroliferous odor	56	5
10. Dolomitic limestone, light gray, fine crystalline, with several medium-crystalline beds; 2 shale beds, each 1 inch thick	35	9
9. Covered	26	10
8. Dolomite, dark gray, medium crystalline with petroliferous odor, and dolomitic limestone, light gray, fine crystalline in one massive bed; lowest occurrence of Copper Ridge type of dolomite	6	9
7. Dolomitic limestone, light gray, fine grained, even bedded	36	5
6. Limestone, bluish gray, mottled; highest occurrence of Low Hollow member type of limestone	3	2
5. Dolomitic limestone, light gray, fine crystalline, laminated or mottled on weathered surfaces	25	2
4. Limestone, blue, fine crystalline, with calcite eyes	3	0

	Thickness Ft.	Thickness In.
3. Dolomitic limestone, light gray, fine grained with fine laminae and indistinct intraformational conglomerate showing on weathered surfaces	10	5
2. Dolomitic limestone, gray, fine grained with intraformational conglomerate chips averaging ⅛ inch in length, formed by break-up of beds of thinly laminated, dolomitic limestone similar to those in Unit 3	4	9
Low Hollow limestone member		
1. Partly covered; limestone, blue, mottled, massive bedded; contains, at top, scattered tiny chips of white-weathering dolomitic limestone	20+	

Geologic Section 4.—Upper part of the Copper Ridge dolomite (as mapped) along Hardy Creek north of Grabeels Mill, Lee County, Virginia

	Thickness Ft.	Thickness In.
Chepultepec dolomite (91+ feet)		
13. Dolomite, light tan, argillaceous with laminae showing on weathered surface, some fine-crystalline brown saccharoidal dolomite; light-gray to light-brown chalcedonic chert in irregular masses and nodules; *Cryptozoa*	37	0
12. Sandstone, white, medium grained, platy, weathering limonite-brown; a little interbedded shale ..	2	2
11. Dolomite, light tan to dark gray, fine to medium grained, argillaceous; white saccharoidal dolomite; oolitic chert; shale partings	49	0
10. Sandstone, white, medium grained, friable, limonite-stained	3	0
Copper Ridge dolomite (204+ feet)		
9. Chert, light bluish gray with medium-sized, scattered to closely packed oolitic spherules; 9 to 15 inches thick	1	0
8. Dolomite, light tan, fine grained, argillaceous, with purplish-brown impurities	4	8

	Thickness	
	Ft.	In.
7. Dolomite, dark brownish gray, medium crystalline cropping out in partly covered interval; light-gray chalcedonic chert and abundant small- to medium-sized *Cryptozoa*	86	2
6. Dolomite, interbedded light to dark brownish gray, fine to medium grained, laminated, argillaceous, and dark brownish-gray, medium-grained, oolitic chert, *Cryptozoa*	48	2
5. Dolomite, light to dark brown, medium crystalline, saccharoidal; 5 inches of bluish-gray shale at top	3	1
4. Conglomerate, consisting of light-gray fine-grained sandy dolomite with lenses of pure sandstone and of light-gray fine-grained dolomite; an undulatory surface at base indicates unconformity; contact with Unit 3 in middle of massive ledge	3	0
3. Dolomite, interbedded, light gray, fine grained, laminated, argillaceous and light gray to brown, medium crystalline, saccharoidal; scattered irregular dark-gray chert masses	48	10
2. Chert, white, with closely packed, medium-sized oolitic spherules		10
1. Dolomite, light to brownish gray, medium crystalline	9	4

Geologic Section 5.—Mascot, Kingsport, and Longview dolomites at Lambs Chapel along Hardy Creek one mile north-northwest of the mouth of Hardy Creek, Lee County, Virginia

	Thickness	
	Ft.	In.
Murfreesboro limestone (14+ feet)		
23. Dolomite, yellow to greenish brown, argillaceous, breaking irregularly and weathering with rounded surfaces	10+	
22. Conglomerate, composed of greenish argillaceous dolomite with chert and fine-grained light-gray dolomite pebbles up to 1½ inches thick	2	0

	Thickness	
	Ft.	In.
21. Conglomerate, coarse; composed of argillaceous dolomite with pebbles and cobbles of light-gray fine-grained dolomite, mottled dark-brown to black dolomite and chert; largest conglomerate boulder, 13 inches by 22 inches. The dark-brown to black dolomite is of the "stinkstone" type found in the Copper Ridge dolomite	2	4+
Mascot dolomite (462 feet)		
20. Dolomite, sandy with a few scattered quartz pebbles; undulating erosion surface at top		8
19. Dolomite, light gray, fine crystalline, in thin beds 2 inches to 15 inches thick; small lenses and some irregular masses of chert	18	4
18. Dolomite, light gray to brownish gray, fine crystalline and medium crystalline, saccharoidal; abundant chert nodules, lenses, and masses	348	11
17. Dolomite, light grayish white, fine crystalline, with scattered small nodules of light-gray chert; beds thinner and more argillaceous near top of unit; chert beds 1 foot thick; green shale partings	93	7
16. Conglomerate, in part intraformational; consisting of light-gray fine-crystalline dolomite with scattered rounded sand grains and rounded pebbles of chert and argillaceous dolomite	1	0
Kingsport dolomite (181 feet)		
15. Dolomite, light gray, fine crystalline, in even massive beds 1½ to 4 feet thick; some beds argillaceous; some with scattered sand grains; blue chalcedonic chert in beds 6 to 13 inches thick	75	1
14. Dolomite, light gray, fine crystalline, argillaceous in beds 1 to 3 feet thick, with some coarse-crystalline saccharoidal dolomite; lenses and nodules of blue chalcedonic chert; some green shale partings	75	5
13. Dolomite, light gray, coarse crystalline saccharoidal; some beds mottled light and dark gray with		

	Thickness	
	Ft.	In.
vugs lined with dolomite crystals; beds from 1½ to 6 feet thick; irregular masses of light-blue to gray chalcedonic chert.	30	0
12. Sand grains in matrix of chert ("chert-matrix sand"); known from float only		3
Longview dolomite (272 feet)		
11. Dolomite, brownish gray, vuggy, medium to coarse crystalline, saccharoidal; chert masses and lenses; a few light-gray fine-grained dolomite beds; dark-blue chalcedonic chert with scattered oolitic spherules in beds 1 foot thick	155	4
10. Shale, light green		3
9. Dolomite, interbedded white, fine crystalline, and light gray, medium to coarse crystalline, saccharoidal; saccharoidal dolomite contains irregular masses, lenses, and nodules of light bluish-gray to brownish-gray chert with scattered oolitic spherules; beds of chert up to 4 feet thick	93	9
8. Dolomite, white, fine crystalline, slightly argillaceous, laminated, with lenticular white chert nodules half an inch thick and several inches long	6	0
7. Dolomite, brown, coarse crystalline, saccharoidal, with scattered sand grains	2	2
6. Chert, oolitic; most oolites small with scattered lenses of larger oolites; bed 9 to 14 inches thick	1	0
5. Dolomite, interbedded light gray, argillaceous, and gray, fine crystalline, saccharoidal; top bed sandy with medium-sized grains in dolomite matrix	7	8
4. Chert, oolitic, light blue-gray, with sandy lenses and irregular masses of nonoolitic chert	0	10
3. Dolomite, light gray, fine grained	5	0
Chepultepec dolomite (385+ feet)		
2. Sandstone, white, limonite stained, medium grained	0	6

	Thickness Ft.	Thickness In.
1. Dolomite, gray, fine crystalline, argillaceous, laminated, and brown, slightly coarser crystalline, saccharoidal; contains sandstone lenses and scattered chert lenses and nodules	384	4

Geologic Section 6.—Murfreesboro and Mosheim limestones half a mile north of Rob Camp Church, Hancock County, Tennessee

	Thickness Ft.	Thickness In.
Lenoir limestone		
23. Covered, with abundant chert float in soil		
Mosheim limestone (137 feet)		
22. Limestone, massive bedded, light brownish gray, dense, fine grained, with birdseyes and fluted weathering	136	9
Murfreesboro limestone (210 feet)		
Cherty member (58 feet)		
21. Limestone, partly covered, light brown, fine grained to dense, with birdseyes; top bed shaly	6	10
20. Limestone, brownish gray, dense, with birdseyes; weathers light blue-gray; nodules and lenses of dark-gray chalcedonic chert; *Tetradium*	4	0
19. Limestone, argillaceous, light brown, fine grained, in platy or nodular beds; mud cracks	16	8
18. Limestone, brownish gray, dense, birdseye, with dark-gray chalcedonic chert in nodules and lenses; argillaceous partings; *Tetradium cellulosum* (Pl. 16B), gastropods, ostracodes	11	1
17. Limestone, brown to dark gray, medium crystalline and argillaceous, greenish gray, thin bedded with mud cracks	12	2
16. Mudstone, greenish brown, fine to medium grained, limy, with dendrites; cross-bedding	0	10
15. Limestone, partly covered, argillaceous, greenish gray, fine to medium crystalline; abundant fossils; *Tetradium*, bryozoa, ostracodes; one bed with black chert nodules	5	6

		Thickness	
		Ft.	In.
14.	Limestone, argillaceous, mottled, brownish gray with greenish-gray streaks and patches; abundant fossils; some dark chalcedonic chert	1	3
Limestone member (118 feet)			
13.	Limestone, partly covered, brown, dense, and greenish gray, argillaceous; abundant ostracodes	17	3
12.	Limestone, partly covered, argillaceous, fine grained, brown to greenish gray, with dendrites and some argillaceous dolomitic limestone	13	6
11.	Limestone, light tan to brown, dense, with birdseyes; thin bedded, mud cracked; colonial type of *Tetradium*	36	6
10.	Limestone, light tan, dense, with birdseyes; fluted	3	11
9.	Limestone, light brownish gray, fine grained, with calcite birdseyes; some argillaceous beds	8	5
8.	Limestone, dark gray, fine crystalline; dark-gray chalcedonic chert in nodules and layers; abundant ostracodes	4	0
7.	Limestone, largely covered, light blue-gray to brownish gray, fine grained; some intraformational conglomerate; interbedded argillaceous, buff, fine-grained dolomite	29	0
6.	Limestone, light tan to greenish tan, dense, with irregular purple partings; thin bedded; *Tetradium* sp. cf. *T. cellulosum,* abundant ostracodes	5	3
Dolomite member (34 feet)			
5.	Dolomite, argillaceous, buff, fine grained, weathering with rounded surfaces and dendrites; interbedded light brownish-gray, fine-grained, mottled, argillaceous limestone; ostracodes	15	8
4.	Dolomite, partly covered, argillaceous, fine grained with light-brown and purplish splotches; weathers buff with rounded surfaces	8	5
3.	Dolomite, partly covered, conglomeratic; greenish-gray, fine-grained dolomite with pebbles under 1 inch in length and larger pebbles of Mascot-type dolomite	9	3

	Thickness Ft.	In.
2. Conglomerate made of chert and dolomite pebbles from Mascot dolomite averaging 3 inches in diameter in matrix of light-gray fine-grained dolomite	0	7
Mascot dolomite (10+ feet)		
1. Dolomite, light gray, fine grained; beds 1 to 2 inches thick; some oval chert nodules	9	10

Geologic Section 7.—Murfreesboro, Mosheim, and Lenoir limestones along road 500 feet west of mouth of Martin Creek, Hancock County, Tennessee

	Thickness Ft.	In.
Lowville limestone		
36. Limestone, chert free, argillaceous, dense, fine grained; *Tetradium*		
Lenoir limestone (128 feet)		
35. Limestone, similar to Unit 33, *Tetradium*	21	0
34. Limestone, similar to Unit 33, but without chert	12	0
33. Limestone, interbedded, light brown, argillaceous, laminated, dense, fine grained, with black chert nodules; and limestone, brownish gray, fine crystalline; *Tetradium*	13	4
32. Limestone, mottled, brownish gray, fine grained, with shale partings and black chert	0	11
31. Limestone, interbedded, light brown, dense, birdseye, and light gray, fine grained; both with chert nodules and lenses	24	9
30. Limestone, interbedded, light brown, dense, birdseye, and light gray, fine grained, laminated	17	8
29. Limestone, dark gray, fine crystalline; abundant black chert nodules; silicified bryozoa and brachiopods weathering in relief; black chert lenses several feet long	26	8
28. Limestone, dark brown, dense, fine grained, with brachiopods and black chert nodules	3	4

	Thickness	
	Ft.	In.
27. Limestone, dark, mottled, fossiliferous, with a few chert nodules	2	5
26. Limestone, dark gray, fine to medium grained, with dark carbonaceous streaks; a few limestone pebbles; sealed contact with Mosheim is exposed in field to west of road	6	0
Mosheim limestone (84 feet)		
25. Limestone, brownish gray, dense, fine grained, with birdseyes; thick bedded; fluted weathering; large gastropods	37	1
24. Limestone, greenish, argillaceous, dolomitic; weathering with rounded surfaces	1	5
23. Limestone, brownish gray, dense, fine grained, with birdseyes; thick bedded and fluted; some brown calcite eyes; gastropods	45	1
Murfreesboro limestone (136 feet)		
Cherty member (42 feet)		
22. Limestone, interbedded; dark-gray, fine-crystalline limestone with black chert lenses 1 to 2 inches thick and 6 inches long; thin-bedded, dense, fine-grained limestone; and greenish argillaceous, dolomitic limestone of lower Murfreesboro type	13	10
21. Limestone, partly covered, similar to Unit 20.	22	2
20. Limestone, dark gray, fine crystalline to dense; with abundant chert nodules; and interbedded greenish, argillaceous beds	6	0
Limestone member (94 feet)		
19. Limestone, interbedded, thin bedded, impure, dense, fine grained, and dolomite, argillaceous	21	0
18. Limestone, light brownish gray, massive bedded, dense, fine grained, with calcite birdseyes; a few small chert nodules; massive birdseye limestone No. 1	11	6
17. Limestone, thin platy, dense, fine grained	14	10
16. Limestone, dense, fine grained; colonial *Tetradium*	6	2
15. Covered	1	8
14. Limestone, dense, fine grained; beds average 6 inches thick	3	9

	Thickness	
	Ft.	In.
13. Limestone, dense, fine grained; beds average 18 inches thick; not fluted	5	8
12. Dolomite, argillaceous, buff; weathers rounded	1	9
11. Covered zone, with float of dense, fine-grained limestone	5	3
10. Dolomite, argillaceous, buff; weathers rounded	1	6
9. Covered zone with float of fine-grained limestone; straight cephalopods	6	7
8. Limestone, dense, fine grained with argillaceous streaks	2	0
7. Covered	3	6
6. Limestone, argillaceous with calcite birdseyes	1	0
5. Dolomite, argillaceous, buff; weathers rounded	3	10
4. Covered	2	0
3. Dolomite, argillaceous, buff; weathers rounded; angular chert pebbles up to 1 inch in length	0	10
2. Covered zone, with float of coarse conglomerate	1	0
(Dolomite member absent)		
Mascot dolomite (30+ feet)		
1. Dolomite, massive and thin bedded, light gray, fine grained	30	0

Geologic Section 8.—Lowville and Moccasin limestones on the meander spur on the south side of Powell River opposite the mouth of Fourmile Creek in Hancock County, Tennessee, beginning along lane 100 yards north of woods which cover all of the southern part of the spur, and ending along a tributary creek of Powell River 0.45 mile due south of the starting point

	Thickness	
	Ft.	In.
Eggleston limestone		
31. Mudstone, calcareous, buff, earthy, deeply weathered		
Moccasin limestone (297 feet)		
Hardy Creek member (154 feet)		
30. Limestone, gray fine and medium crystalline, in thin platy beds; contains gastropods and straight cephalopods	6	0

	Thickness	
	Ft.	In.
29. Limestone; brown, cryptocrystalline, massive birdseye limestone containing scattered chert nodules; this bed is a prominent marker in the Rose Hill district	2	0
28. Limestone, tan, gray and mottled, cryptocrystalline, and fine crystalline, in platy beds from 1 to several inches thick; beds with large oval chert nodules in middle and near base	12	4
27. Limestone, tan and gray, cryptocrystalline and fine crystalline, containing some thin silty lenses; bed with oval chert nodules at top	53	8
Lower member (143 feet)		
26. Limestone, tan and gray, cryptocrystalline, weathering to a buff earthy shaly rock; contains numerous mud cracks	14	0
25. Limestone, tan, cryptocrystalline; beds 1 to 6 inches thick; does not weather shaly	3	0
24. Limestone, tan and gray, cryptocrystalline, weathering to a buff, earthy shaly rock; contains numerous mud cracks	120	6
23. Limestone, gray and light brown, cryptocrystalline to fine crystalline in platy beds with abundant *Zygospira* and small bryozoans	5	6
Lowville limestone (580 feet)		
Platy member (244 feet)		
22. Limestone, tan, cryptocrystalline, in thin platy beds; abundant *Camarocladia,* which weather to form wormy-looking surfaces	30	6
21. Limestone, gray and brown, fine and coarse crystalline, with a few beds of cryptocrystalline limestone; chert nodules abundant in several beds in upper 18 feet; *Cryptophragmus* in lower part, *Camarocladia* throughout; lone *Stromatocerium* 44 feet from base; *Öpikina, Leperditia,* unidentified gastropods and cephalopods.	103	0
20. Limestone, tan and gray, cryptocrystalline, fine crystalline and coarse crystalline in even beds;		

	Thickness	
	Ft.	In.
abundant brachiopods and gastropods in crystalline beds; *Cryptophragmus* and *Camarocladia* near top	48	5
19. Limestone, tan and gray, cryptocrystalline, fine crystalline and coarse crystalline; a massive bed of birdseye limestone 1 foot thick at top; *Öpikina* and unidentified brachiopods, gastropods, and cephalopods	49	2
18. Limestone, tannish gray, mottled, cryptocrystalline with calcite "birdseyes", in platy beds; abundant *Stromatocerium rugosum* in several beds; *Tetradium*	13	4
Redbed member (336 feet)		
17. Limestone, tan, cryptocrystalline with calcite birdseyes; chert lenses	30	8
16. Limestone, gray, cryptocrystalline with birdseyes; forms one massive ledge; No. 6 massive birdseye limestone	2	0
15. Limestone, tan, cryptocrystalline with calcite birdseyes; *Tetradium, Leperditia*	27	0
14. Limestone, argillaceous, green on fresh surface, weathering pink or yellowish green; this is "the big red"	13	4
13. Limestone, greenish, cryptocrystalline, with abundant calcite birdseyes	6	1
12. Limestone, greenish gray to greenish tan, cryptocrystalline with calcite birdseyes; in massive beds weathering fluted; No. 5 massive birdseye limestone	36	10
11. Limestone, greenish tan, cryptocrystalline in platy beds; *Tetradium* and *Leperditia*	23	7
10. Limestone, argillaceous, weathering greenish gray and pink; forms small swale	4	7
9. Limestone, greenish gray, cryptocrystalline, in beds about 1 foot thick	28	1
8. Limestone, greenish gray, cryptocrystalline, with calcite birdseyes, in massive beds that weather fluted; a bed of green clay 1 foot thick, probably		

	Thickness	
	Ft.	In.
a bentonite, lies 3 feet above base; No. 4 massive birdseye limestone	34	0
7. Limestone, greenish tan, argillaceous, weathering pink or yellow and shaly	8	2
6. Limestone, tan to gray, cryptocrystalline, in beds several inches thick	17	10
5. Limestone, brown, cryptocrystalline, with calcite birdseyes and veinlets, in beds a few inches to 2 feet thick; thick beds weather fluted; No. 3 massive birdseye limestone	15	0
4. Limestone, tan, cryptocrystalline with calcite birdseyes and veinlets, in platy beds 1 to 3 inches thick; *Tetradium cellulosum* and radiating *Tetradium, Leperditia, Ancistrorhyncha* sp.	57	1
3. Limestone, brownish gray, fine and coarse crystalline, with "Lenoir-type" chert lenses and nodules; *Tetradium cellulosum, Strophomena* sp., *Leperditia* sp.	1	0
2. Limestone, tan and greenish tan, cryptocrystalline in platy beds, some of which are argillaceous to shaly; *Tetradium cellulosum, Bathyurus* aff. *B. superbus*	30	5
Lenoir limestone		
1. Limestone, dark brown and tan, cryptocrystalline; abundant chert nodules 1½ feet below top; top few feet only exposed; abundant chert in soil derived from underlying beds	5	

Geologic Section 9.—Moccasin, Eggleston, Trenton, Reedsville and Sequatchie formations along the Louisville and Nashville Railroad switchback at Hagan, Lee County, Virginia

	Thickness	
	Ft.	In.
Clinch sandstone (50+ feet)		
Hagan member		
53. Shale, greenish gray, with interbedded limestone, and a 15-inch sandstone bed at base; contact at base poorly exposed in bank along straight		

	Thickness	
	Ft.	In.
switchback; well exposed at east end of deep cut on curving track	50+	
Sequatchie formation (274 feet)		
52. Largely covered; several outcrops of maroon calcareous mudstone	103	5
51. Mudstone, calcareous, mainly maroon with some green beds or mottled green patches, abundant mud cracks	85	5
50. Limestone, greenish gray, fine crystalline, massive bedded, argillaceous; most massive unit in Sequatchie; probably top of Maysville part of the Sequatchie	13	11
49. Limestone, greenish gray, argillaceous, *Platystrophia ponderosa, Sactoceras* sp.	33	8
48. Limestone, greenish gray, argillaceous, in massive beds; abundant bryozoa and *Herbertella sinuata, Platystrophia ponderosa, Byssonychia radiata, Lophospira tropidophora*	13	1
47. Mudstone, maroon, mottled, with shaly interbeds in lower part; abundant bryozoa in upper part; *Herbertella sinuata*	24	2
Reedsville shale (358 feet)		
46. Limestone, medium gray, fine crystalline, siliceous; some coarse-crystalline coquina; shaly partings abundant; *Herbertella sinuata, Orthorhynchula linneyi, Platystrophia ponderosa, Plectorthis* sp., *Zygospira kentuckiensis, Z. modesta, Byssonychia radiata*	72	10
45. Shale, deeply weathered yellow-brown	3	6
44. Shale, greenish gray, fine grained, siliceous; and coarse-crystalline limestone interbedded in equal amounts	14	10
43. Limestone, massive, brownish gray; coarse crystalline, coquinal; few green shale and platy siliceous limestone beds; stony bryozoans	21	2
42. Shale, greenish gray, interbedded with coarse-crystalline coquinal limestone; a few fine-grained		

		Thickness	
		Ft.	In.
	siliceous limestones; *Rafinesquina fracta, R. nasuta*	33	5
41.	Limestone, light gray, coarse crystalline, coquinal; small amounts of interbedded greenish-gray shale and fine-grained siliceous limestone; faulted	14	7
40.	Shale, greenish gray, weathering yellowish brown; fine-grained gray siliceous limestone; some beds of coarse-crystalline coquina; *Hebertella sinuata, Holtedahlina hallie, Plectorthis fissicosta, Rafinesquina fracta, Resserella emacerata, Sowerbyella rugosa, Zygospira kentuckiensis, Z. modesta, Modiolopsis* sp.	197	5
Trenton limestone (562 feet)			
39.	Limestone, brown and brownish gray, coarse crystalline, highly fossiliferous, forming one massive unit; *Hebertella* sp., *Rafinesquina trentonensis*	11	8
38.	Clay, yellow, probably a bentonite; this clay bed contains mica flakes in the Brooks well, but mica not seen here	0	2
37.	Limestone and shale; limestone, mainly gray, coquinal with some fine-grained siliceous beds; shale amounts to about one-third of the rock in lower part of unit, less in upper	33	8
36.	Limestone, fine crystalline and coarse crystalline interbedded, with shaly partings; pink coquinal limestone near top; abundant gastropods in lower part; a few chert nodules and lenses in fine-grained limestone	54	7
35.	Limestone, not exposed along railroad but scattered outcrops at base of hill to east; contains white chert in irregular thin masses; lithologically similar to Unit 34; *Glyptocrinus* sp., *Rhynchotrema increbescens,* cephalopods; large stony bryozoans in beds near top	168	
34.	Limestone, fine to medium crystalline, in beds up to 8 inches thick; most is sparingly fossiliferous		

		Thickness	
		Ft.	In.
	but some coquinal beds; chert nodules in one bed; top of unit is highest bed exposed in railroad cut near water tower; *Cyrtodonta* cf. *C. grandis*	32	4
33.	Limestone, gray, interbedded fine and medium crystalline; fine-crystalline beds siliceous; no coquinal limestones; abundant shaly partings	26	5
32.	Limestone, bluish gray, fine crystalline in even beds with shaly partings; fewer fossils than underlying units; *Zygospira recurvirostris, Rafinesquina trentonensis, Ceraurus pleurexanthemus*	24	7
31.	Limestone, gray, coarse crystalline fossiliferous and fine crystalline, unfossiliferous, interbedded, with fine-crystalline beds increasing in abundance upward; shaly partings between beds; ripple marks; unit includes a reverse fault for which thickness correction was made; *Resserella (Dalmanella) fertilis, Sowerbyella curdsvillensis, Rafinesquina trentonensis, Zygospira recurvirostris, Prasopora* sp.	77	6
30.	Limestone, gray, coarse crystalline; abundantly fossiliferous; sink hole in this unit on east side of railroad tracks	63	4
29.	Bentonite, greenish gray, poorly exposed	1	0±
28.	Limestone, gray, coarse crystalline; abundantly fossiliferous; 8-inch zone of partly silicified shale at top; abundant shale partings and shale beds except in lowest 10 feet; *Resserella (Dalmanella) fertilis, Dinorthis pectinella, Rafinesquina trentonensis, Prasopora* sp.	37	4
27.	Clay, greenish gray, probably bentonitic	0	7
26.	Limestone, gray and white mottled; highly fossiliferous; a few vugs lined with asphalt; abundant *Resserella (Dalmanella) fertilis* and *Sowerbyella curdsvillensis; Rhynchotrema increbescens, Dinorthis pectinella, Rafinesquina trentonensis*	31	4

	Thickness	
	Ft.	In.
Eggleston limestone (146 feet)		
Upper member (53 feet)		
25. Limestone, gray, cryptocrystalline and coarse crystalline, with shaly partings; forms transition zone with Trenton	9	0
24. Bentonite, greenish white, but weathers yellow; gritty; abundant flakes of brown mica	3	4
23. Chert, brownish black; represents silicified zone beneath bentonite; oscillation ripple marks on top surface	0	2
22. Limestone, gray, cryptocrystalline and medium crystalline; *Rhinidictya, Rhynchotrema, Leperditella*	6	6
21. Mudstone, calcareous, dark gray, massive bedded, with abundant white calcite patches up to half an inch in length; weathers to blue-gray color	4	7
20. Bentonite (?)	0	1
19. Mudstone, calcareous, dark gray, argillaceous, massive bedded, with abundant white calcite patches up to half an inch in length; weathers to blue-gray color	15	0
18. Limestone, light brown, cryptocrystalline with shaly partings	6	7
17. Clay, gray to buff, slightly gritty; bentonite (?)	0	1½
16. Limestone, gray, cryptocrystalline, with abundant shaly partings up to 1 inch thick	7	8
Middle member (57 feet)		
15. Bentonite, greenish white, but weathers to yellow color	2	2
14. Chert, gray; represents silicified zone at base of bentonite	0	2
13. Limestone, gray, cryptocrystalline and medium to coarse crystalline, with fossils; thin shaly partings; unit includes two small faults for which thickness corrections were made; *Camarocladia, Doleroides, Öpikina, Strophomena, Zygospira*	33	2

	Thickness	
	Ft.	In.
12. Limestone, gray, thin bedded, cryptocrystalline, with a few crystalline fossiliferous beds; a little argillaceous limestone; shaly partings and one zone of clay-shale 6 inches thick; *Pionodema minuscula, Rhynchotrema.*	21	6
Lower member (36 feet)		
11. Mudstone, calcareous; weathers greenish yellow and gnarled with no visible bedding; contains abundant small patches of white calcite	35	10
Moccasin limestone (279 feet)		
Hardy Creek member (138 feet)		
10. Limestone, brown, cryptocrystalline and fine-crystalline, in even beds 2 inches to 3 feet thick; includes shale bed 1 foot thick; unit spans fault having 19 feet of displacement for which thickness correction was made	10	8
9. Clay, gray, gritty; probably not a bentonite	0	1½
8. Limestone, brown, cryptocrystalline and fine crystalline, siliceous, in even beds 2 inches to 2 feet thick; laminated on weathered surfaces; includes one chert bed and one bed containing oval chert nodules; several beds with intraformational conglomerate	14	6
7. Bentonite (?), gray, 2 inches thick, overlain by 3 inches of fissile, white shale	0	5
6. Limestone, brown, cryptocrystalline with silty laminae	2	0
5. Bentonite (?)	0	¼
4. Limestone, brown, cryptocrystalline, with silty laminae; several beds of intraformational conglomerate, and several crystalline, fossiliferous beds	31	1
3. Limestone, brown, cryptocrystalline, in even beds 6 inches to 3 feet thick; silty laminations show on weathered surface; large oval chert nodules (Pl. 22A) in several beds; unit includes fault having 21 feet of displacement for which thickness correction was made	64	3

	Thickness	
	Ft.	In.
2. Limestone, brown, in even beds, with partings and thin beds of yellow-weathering shaly limestone; forms transition zone with underlying lower member of Moccasin limestone	15	0
Lower member (141 feet)		
1. Limestone, yellow weathering, shaly and earthy; only topmost beds exposed in railroad cut	141	

Geologic Section 10.—Clinch sandstone along Louisville and Nashville Railroad cut at Hagan, Lee County, Virginia

	Thickness	
	Ft.	In.
Clinton shale (85+ feet)		
20. Shale, red	79	7
19. Iron ore, hematitic, made up of flattened pellets; contains brachiopods		5-9
18. Shale, greenish gray, with sandstone beds half an inch to 2 inches thick; ripple marks and fucoids abundant	5	4
Clinch sandstone (259 feet)		
Poor Valley Ridge member (183 feet)		
17. Sandstone, greenish white, fine grained, in lenticular beds 6 inches to 2 feet thick; shale interbeds up to 2 feet thick in upper part; ripple marks; trails, possibly of trilobites, on one bed	15	2
16. Shale, dark gray, with thin lenticular sandstone interbeds	16	0
15. Iron ore, hematitic, fair grade, consisting of numerous flattened pellets		4
14. Shale, greenish gray, with thin ripple-marked interbeds of sandstone; one 2-inch bed of gravel with pebbles up to half an inch; unit includes reverse fault which duplicates 4 feet of beds; thickness corrected	32	11
13. Sandstone, white, fine to medium grained, quartzitic, and shale, reddish gray; ripple marks;		

	Thickness	
	Ft.	In.
Lingula sp., *Helopora* sp., *Paraechmina* sp., *Paraechmina* n. sp., ostracode n. gen., n. sp.	17	4
12. Sandstone, white, fine grained, quartzitic, in massive unit, with thin shale interbeds in upper part	8	11
11. Shale, dark gray, and sandstone, white and yellow, fine to medium grained; ripple marks; *Lingula* sp.	23	10
10. Sandstone, greenish white, medium grained, massive in lower part; contains abundant pellets and patches of red clay; abundant *Helopora* cf. *H. fragilis,* small medium-spired gastropods, *Lingula* fragments, orthoceratids	7	1
9. Shale, gray, and sandstone, greenish white, fine grained	4	2
8. Sandstone, medium grained, greenish gray; forms massive unit, which is the most resistant unit in the Clinch	8	7
7. Shale, greenish gray, becoming sandy in upper part	31	10
6. Sandstone, fine to medium grained, and shale, greenish gray; red clay pellets and pebbles in some sandstone beds	17	1
Hagan member (77 feet)		
5. Shale, greenish gray, containing platy beds of siliceous limestone; fucoids	55	1
4. Iron ore, hematitic, siliceous, composed of oval pellets; contains small poorly preserved brachiopods		5
3. Shale, greenish gray, with platy beds of siliceous limestone, from 1 to 3 inches thick	19	10
2. Sandstone, buff, medium grained, with numerous patches of clay; forms prominent beds at base of Clinch sandstone	1	3
Sequatchie formation		
1. Maroon calcareous mudstone, with top 2 feet bleached to yellow color	10+	

Geologic Section 11.—Cayuga dolomite along U. S. Route 58 at Ben Hur, Lee County, Virginia

	Thickness	
	Ft.	In.
Genesee shale		
22. Shale, dark brown to black, fissile; weathers light gray; slickensides; few outcrops, but abundant shale chips in soil		
Cayuga dolomite (188 feet)		
21. Dolomite, fine crystalline, light brown; weathers light blue-gray to gray with medium to fine "butcher-block structure"; upper half medium to dark brown, fine crystalline with petroliferous odor	26	9
20. Limestone, dense to fine crystalline, dark to medium brown with petroliferous odor; weathers light blue-gray with smooth rounded surfaces	15	2
19. Dolomite, dense to fine crystalline, light brownish gray; weathers light gray with a few red streaks and "butcher-block structure"	30	8
18. Dolomite, fine crystalline, dark brownish gray; "butcher-block structure" on weathered surfaces	24	10
17. Covered	12	8
16. Dolomite, fine crystalline, light brownish gray; weathers light tan to light gray with "butcher-block structure"	14	0
15. Dolomite, fine crystalline, brownish gray; weathers buff to bluish gray with "butcher-block structure"; some limy zones, which are laminated	24	10
14. Limestone, fine crystalline, dark blue-gray; weaththers buff with distinct outer rim; laminated in lower part, pitted in upper part; abundant corals including *Favosites*, brachiopods	4	9
13. Covered	4	4
12. Limestone, dark blue-gray with scattered zones of intraformational conglomerate, whose pebbles are more silty and weather buff	1	4
11. Limestone, massive bedded, ribboned, medium to dark blue, with scattered sand grains and peb-		

		Thickness Ft.	Thickness In.
	bles; ribbons weather silty, buff and light blue-gray; indeterminate fossil fragments	12	2
10.	Sandstone, medium grained, medium blue-gray, laminated, with lime cement; a few scattered pebbles; weathers light blue-gray and then to a brown earthy sand; some shale partings	3	2
9.	Sandstone, medium to coarse, friable, with pebbles up to half an inch in length; some silicified areas	1	6
8.	Sandstone, medium to coarse, friable; fucoids and fossil fragments	3	7
7.	Limestone, fine crystalline, medium blue, with scattered sand grains and some clay which produce irregular indistinct banding; weathers medium brown; calcite veins	2	0
6.	Shale, greenish gray; upper part fine-grained, white, limonite-stained, quartzitic sandstone	0	6
5.	Sandstone, fine grained with lime cement, scattered pebbles; weathers porous and friable	1	4
4.	Shale, brown, highly weathered; interbeds of thin quartzitic sandstone, some with cross-bedding	2	1
3.	Sandstone, irregularly bedded, medium to coarse grained and pebbly, some quartzitic; largest pebble ¼ inch long	1	6
2.	Weathered zone; white silicified rock at base with rounded medium to coarse sand grains and molds of calcite rhombohedrons; upper part yellowish-brown clay derived from weathering of limestone	1	0
Clinton shale			
1.	Sandstone, massive, fine grained, white, limonite-stained, in beds 6 to 33 inches thick; lime cement; interbedded thin bluish-gray sericitic shale; some quartzitic sandstone; fucoids; fault duplicates about 50 feet of beds, including Clinton-Cayuga contact; duplication has been eliminated in measuring the section	13	11

PHYSIOGRAPHY

PHYSIOGRAPHIC PROVINCES

The Rose Hill district lies in the western part of the physiographic province known in Fenneman's classification as the Ridge and Valley province, or in Lobeck's classification as the Folded Appalachians. This province is divided by Lobeck into a southeastern section known as the Great Valley subprovince and a northwestern section called the Valley and Ridge subprovince. The Rose Hill district lies in the last-named subprovince. In Virginia the belt of valleys and ridges that makes up the Folded Appalachians has commonly been called the Appalachian Valley. The Appalachian Valley is bounded on the northwest by a very prominent escarpment, which forms the front of the Appalachian Plateaus. Cumberland Mountain, which lies just northwest of the Rose Hill district, (Pl. 5A and Fig. 1) is the local name for this escarpment in southwest Virginia, and the part of the plateaus that comprises the Middlesboro syncline beyond is called the Cumberland Mountain section of the plateaus.

Throughout most of the Appalachians the distinction between the Folded Appalachians and the Appalachian Plateau is very marked both topographically and structurally. The plateau, which is composed in the main of the resistant coal measures, is underlain by nearly flat beds that have been uplifted and dissected into an irregular maze of mountains and valleys. The rocks of the Folded Appalachians, on the other hand, have been squeezed into folds which trend northeast-southwest. Erosion on these upturned beds has produced long parallel valleys on the weak formations and has left long sharp-crested ridges where the resistant formations come to the surface.

The relation of the Appalachian Valley to the Plateau in southwest Virginia and the adjoining part of Kentucky is complicated by the fact that structurally the whole Cumberland overthrust block is an overthrust unit that is genetically more closely related to the folded and faulted Appalachians to the southeast than to the plateaus to the northwest. The Powell Valley anticline is indeed assigned to the Appalachian Valley, but the Middlesboro syncline, also a part of the Cumberland overthrust block, falls within the Cumberland Plateau. The mountainous coal-bearing part of the overthrust block—the Middlesboro syncline—does appear more like the plateaus that enclose the block on three sides than it does like the valleys and ridges to the southeast, but actually the more deeply eroded but gentle Powell Valley anticline is no more folded and faulted than the Middlesboro syncline. Designation of the Cumberland Mountain front as the western boundary of the Appalachian Valley thus places emphasis upon the topographic aspect of the region rather than upon its structural character.

The topography of the Rose Hill district has previously been described (pp. 11-16), and the close correlation between it and the geology has been pointed out. In the following sections of the report, the development of the topography, including both the major units and some of the smaller features, is discussed.

EROSION LEVELS

SCHOOLEY PENEPLAIN

Throughout almost all the southern Appalachians one high-level peneplain has been consistently recognized. This has been called the Cretaceous peneplain by Campbell[205] in the region covered by the Estillville, Virginia, folio just east of the Rose Hill district but Wright[206] uses the name Schooley for this surface, believing that it is the same peneplain as that present on the ridge crests of New Jersey and eastern Pennsylvania. Fenneman[207] calls it the Cumberland peneplain, but correlates it with the Schooley peneplain.

The ridges in and near the Rose Hill district are not nearly as even-crested or accordant in altitude as are those in most of the southern Appalachians. Wallen Ridge rises fairly consistently to an altitude of about 2000 feet, but has considerable stretches that are both higher and lower. Poor Valley Ridge, on the other hand, has an average altitude of about 1800 feet and only the highest parts of the ridge attain a height of 2000 feet (Fig. 12). Immediately northwest of Poor Valley Ridge is towering Cumberland Mountain, which rises nearly 1000 feet above both Poor Valley Ridge and Wallen Ridge. A few miles to the north in the Middlesboro coal basin the highest peaks of the Black Mountains reach 4000 feet. East and southeast of the Rose Hill district, however, the crests of Powell Mountain, Newman Ridge and Clinch Moun-

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[205] Campbell, M. R., U. S. Geol. Survey Geol. Atlas, Estillville, Virginia, folio (No. 12), 1894.

[206] Wright, F. J., Erosional history of the southern Appalachians: Jour. Geomorphology, vol. 5, no. 2, pp. 151-161, 1942.

[207] Fenneman, N. M., Physiography of eastern United States: 714 pp., New York, McGraw-Hill Book Co., Inc., 1938.

tain are consistently at altitudes of about 2200 to 2400 feet and Pine Mountain on the northwest side of the Middlesboro coal basin is very even-crested, rising gradually from about 2300 feet at Pineville, Kentucky, west of Rose Hill to 2700 feet near Harlan, Kentucky, north of Rose Hill.

The evidence offered by Clinch, Powell, Newman and Pine mountains supports the conclusion that a peneplain was formed in extreme southwest Virginia and adjacent Tennessee and Kentucky. Recognizable remnants of this peneplain are about 2300 feet in altitude near the Rose Hill area, but become higher to the north and northeast. Obviously, these ridge crests on the resistant rocks have been somewhat reduced by erosion at the same time that the valleys were forming on the weaker formations. The amount of this reduction depends on so many variable factors that no quantitative estimate is now possible, but the lowering of the ridge crests by post-Schooley erosion has not been sufficient to destroy their general accordance. This summit peneplain will be called the Schooley peneplain.

It is clear, however, that the Schooley peneplain was imperfectly developed in and near the Rose Hill district. The section of Cumberland Mountain near Rose Hill was never reduced to the peneplain level because of the great resistance of the thick Lee formation of which it is composed. At the conclusion of the cycle of peneplanation it must still have been a prominent linear monadnock from 800 to 1000 feet above the peneplain. The Black Mountains and other slightly lower mountains in the Middlesboro basin also were not reduced to the peneplain level because they lie near the headwaters of the Cumberland and Powell rivers, where peneplanation would have been less complete than farther downstream, and because of the resistance of the flat-lying sandstones of these mountains.

Over most, if not all, of the Rose Hill district, the Schooley peneplain has been entirely destroyed, though the highest parts of Wallen Ridge rise closest to the level of the former peneplain. In Wallen Ridge the Clinch sandstone contains some thick units of massive-bedded and resistant sandstone (p. 144), like those that form the crests of Powell, Clinch, Walker and other mountains to the east and southeast. To the west in Poor Valley Ridge, however, only a few beds of massive resistant sandstone remain in the Clinch sandstone and these beds are separated from one another by weak shale and thin-bedded sandstone, so that they do not unite to form one ridge-making unit. Near the west edge of the district the Clinch sandstone has so far deteriorated as a ridge-maker that it is replaced at the crest of Poor Valley Ridge by the relatively weak Sequatchie formation causing a very abrupt drop in crest level (Fig. 12). Thus, although the Schooley peneplain is believed to have beveled the rocks of the Rose Hill district at an altitude somewhat in excess of 2300 feet, all evidence of the existence of the peneplain is drawn from outside the district.

FIGURE 12.—Sketch looking northwest across Indian Creek Valley to Poor Valley Ridge, with Cumberland Mountain in the distance. The Sequatchie formation forms the crest of Poor Valley Ridge on the left side of the view, and Clinch sandstone forms the crest in the center and to the right. By Ansel M. Miller.

Cooper[208] has recently challenged the peneplain concept as applied to the ridges and valleys of southwest Virginia. His arguments are based principally on the belief that (1) all ridges have been lowered by erosion since the time of supposed peneplanation and, (2) the weaker ridge-forming units were lowered more rapidly than the resistant ones. He deduces from this that "correlation of peneplains by comparison of altitudes is unreliable because the ridge crests are being lowered at different rates."

The belief that even-crested ridges, which lie at about the same altitude, indicate the presence of former peneplains is based on one of two assumptions: (1) either the lowering of ridge crests in the post-peneplain cycle is so small that the skyline symmetry of peneplaned resistant formations is not destroyed, or (2) the same ridge-forming formation or several formations of nearly comparable resistance will be lowered evenly and at approximately the same rate during the erosion following the uplift of a peneplain so that skyline symmetry of ridge crests is not destroyed. Cooper seeks to disprove the first assumption, as have Ashley[209]

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[208] Cooper, B. N., Geology and mineral resources of the Burkes Garden quadrangle, Virginia: Virginia Geol. Survey Bull. 60, pp. 205-217, 1944.

[209] Ashley, G. H., Studies in Appalachian mountain sculpture: Geol. Soc. America Bull., vol. 46, no. 9, pp. 1395-1436, 1935.

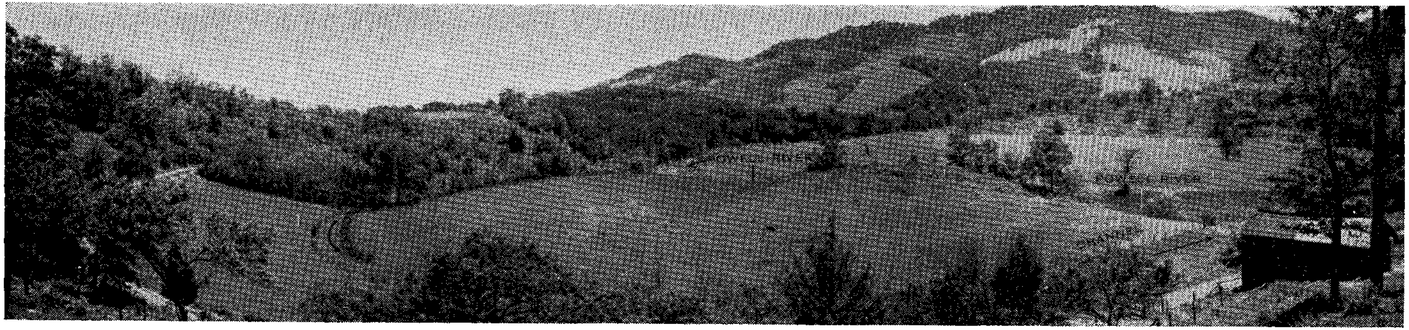
and others, but he goes to considerable lengths to demonstrate the second assumption in his discussion of the formation of even-crested ridges. His conclusion that even-crested ridges at many different altitudes probably do not represent multiple peneplains but rather differential rates of lowering of ridges composed of different materials with different dips is eminently justified. It appears to us, however, that the ridges of southwestern Virginia first developed their even-crests at a time of widespread peneplanation, and that these accordant crestlines have been preserved in post-Schooley time where conditions were favorable, despite some lowering of the ridge crests by erosion.

HARRISBURG PENEPLAIN

Only one other peneplain is known in the Rose Hill region. This is a valley floor peneplain, that is very restricted in areal extent and should probably be called a partial peneplain. It has developed only on the Ordovician limestones of the Powell River lowland. The peneplain has not been traced outside the district, but is probably the same surface that has been developed on weak limestones in other valleys of western Virginia and has been called the Harrisburg or Valley Floor peneplain.

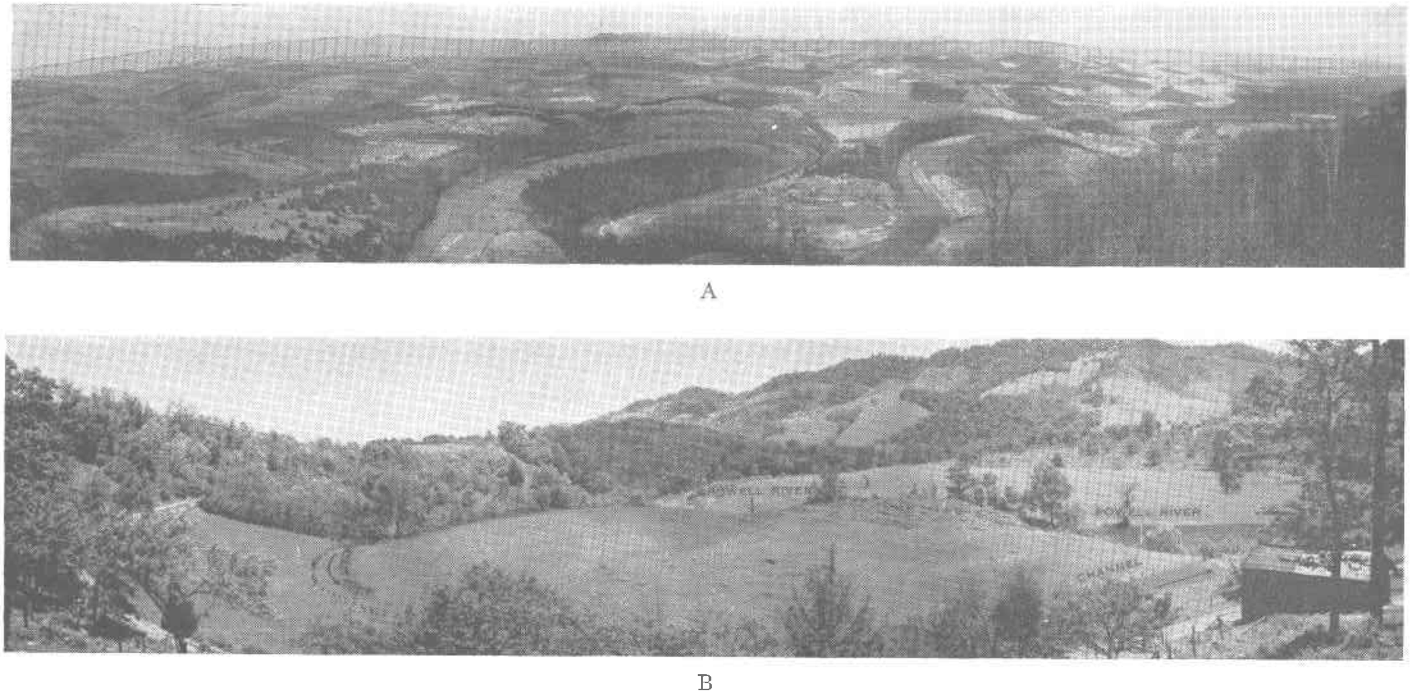
The Harrisburg peneplain represents a pause in the uplift and dissection of the Rose Hill region. This stage was sufficiently long to permit the formation of broad flat-floored valleys on the weak Ordovician limestones along or near the master streams. The cycle did not persist long enough, however, to develop broad valleys in the more resistant Ordovician and Cambrian dolomites of the Chestnut Ridge upland. In the Powell River lowland, the remnants of the Harrisburg surface stand at about 1300 feet above sea level. In the narrowest part of the valley most of the surface has been destroyed by the post-Harrisburg downcutting of the meandering Powell River, but locally parts of the surface are preserved between the river and the edge of the Chestnut Ridge upland. The remnants appear as nearly flat, usually cultivated areas below which the tributaries of Powell River flow in deep narrow valleys. Many of the meander spurs of Powell River also rise to or nearly to the level of the Harrisburg surface. Several of the Harrisburg remnants may be seen on the far side of the river in the panoramic photograph (Pl. 30A), which was taken looking north from near the crest of Wallen Ridge. The peneplain

A



B

A, Panoramic photograph of the Rose Hill district looking north across Powell River. B, Cut-off of the tip of a Powell River meander.



A, Panoramic photograph of the Rose Hill district looking north across Powell River. B, Cut-off of the tip of a Powell River meander.

shows best, however, as the densely wooded flat lowland near the right edge of the panorama where its relation to the Chestnut Ridge upland on the left and Wallen Ridge on the right is much more apparent. Cumberland Mountain forms the skyline of the photograph except in the central part of the picture where the irregular crests of the Black Mountains in the Middlesboro coal basin overtop Cumberland Mountain. Since the completion of the Harrisburg cycle the region has been rejuvenated and Powell River has cut about 130 feet below the Harrisburg surface.

Although the Indian Creek lowland on the north flank of the Powell Valley anticline was also eroded below the level of the Chestnut Ridge upland during the Harrisburg erosion cycle, it was not peneplaned in the Rose Hill district. This is because the lowland is here drained by the headwaters of Indian, Martin and Hardy creeks, which have to cross all or part of the Chestnut Ridge upland to reach Powell River. Although the wave of local baseleveling was propagated up the valleys of streams tributary to Powell River, the standstill of Harrisburg time did not persist long enough for it ever to reach the headwaters of the streams in the Indian Creek lowland.

SURFACE DRAINAGE FEATURES

PATTERN OF THE DRAINAGE SYSTEM

The drainage system of the Rose Hill district is shown in Plate 31. All the streams are tributary to Powell River, either within the area of the map, or by Hardy Creek, which enters Powell River just east of the map, or by Indian Creek, which flows into Powell River in the middle of the Chestnut Ridge upland 10 miles southwest of the area shown on the map.

The map reflects very clearly the adjustment of drainage to structure. On the north flank of the Powell Valley anticline subsequent streams have developed continuous lowlands on the weak Ordovician limestones south of Poor Valley Ridge and on the weak Clinton and Brallier shales north of it. These streams, together with their tributaries, produce an excellent trellis pattern of drainage. On the south flank of the anticline the Sulphur Hollow-Rebel Hollow lowland which corresponds to Poor Valley on the north is formed by the Clinton shale in fault contact with the Maynardville limestone. The trellis pattern of the drainage is masked somewhat by the free-swinging meanders of Powell River in the lowland of Ordovician limestones.

In the Chestnut Ridge upland, the dolomite rocks are of rather uniform resistance, and are relatively gently dipping so that only locally is one direction of stream flow favored over another. Martin Creek near the center of the upland has several tributaries, which parallel the regional strike of the bedrock. The two more northern of these alined tributaries follow relatively weak belts of Maynardville limestone, except where the headwaters of the eastern tributary flow on the rocks of the Possum Hollow fenster. The two tributaries of Martin Creek, a mile farther south, have developed their courses along a belt of dolomite in the upper part of the Copper Ridge dolomite, which is somewhat less resistant than the belts of lower Copper Ridge and lower Chepultepec dolomites on either side. Elsewhere in the central part of the upland the stream pattern is dendritic, but near the edges of the upland the small streams, tributary to Indian Creek and Powell River, show a considerable degree of parallelism as they flow down the slopes of the upland toward the lowlands.

The surface drainage system of the whole area is only partly integrated. Many of the small streams and some of the larger ones end in sinkholes. This is true both in the upland and the lowlands.

Powell River flows into Clinch River a short distance above Norris Dam in Tennessee. Their combined waters are tributary to Tennessee River and reach the Gulf of Mexico by the extremely circuitous route of the Tennessee, Ohio and Mississippi rivers. The total distance the water travels from the Rose Hill district to the Gulf of Mexico is 1900 miles, as compared with an airline distance from Rose Hill to the Atlantic of 340 miles and from Rose Hill to the Gulf of Mexico of 470 miles.

DRAINAGE SYSTEM DURING THE SCHOOLEY CYCLE

The major outlines of the present drainage system were developed at least as far back as the time of the Schooley peneplain. This is shown by the fact that only minor changes in stream courses have been recorded during the downcutting that followed completion of the Schooley cycle. The Schooley peneplain, though formed at an altitude probably only a few hundred feet above sea level, was later uplifted and eroded. For reasons that have already been discussed it is believed now to lie at an altitude somewhat in excess of 2300 feet or above the tops of all ridges in the area except Cumberland Mountain. At the time of the Schooley peneplanation, the same major elements of topography were present as now but they were very much more subdued. There was then as now a contrast in resistance between the Ordovician and Cambrian dolomites and the Ordovician limestones. This contrast was sufficiently great to cause smaller streams to favor courses on the limestones rather than across the dolomites. Thus, Indian Creek and the tributaries of Martin Creek followed subsequent courses on the lowland. Even Powell River, the master stream of the area, favored a course on the limestones, as shown by its location within the southern belt of limestones in the Rose Hill district. Powell River was, however, large and powerful, so that it locally flowed on the belt of dolomites within the Rose Hill district, and the course of the river was entirely within the belt of dolomites east of Jonesville and also west of the Rose Hill district (Pl. 13).

The smaller tributaries of Powell River, for the most part, had the same courses during the Schooley cycle as they now do. Even at the end of the Schooley cycle Wallen Ridge must have been a low barrier, because Mulberry Creek alone now crosses it and there are no recognizable windgaps in the ridge to show where other streams might formerly have crossed and have since been diverted. Poor Valley Ridge, on the other hand, has four watergaps and several possible windgaps in about the same distance. This is due partly to the fact that the Clinch sandstone is less resistant in Poor Valley Ridge than in Wallen Ridge, so it would have been eroded nearer to base level and formed a lower and less continuous barrier to transverse streams. More important than this, however, is the fact that Cumberland Mountain stood as a prominent monadnock ridge probably as much as 800 feet above the Schooley peneplain. Then, as now, fans from the mountain face built out across the lower areas at the foot of the mountain. At the present time, Poor Valley Ridge is partly buried by such a fan at the very west edge of the Rose Hill district, and a short distance farther west it is completely buried. In Schooley time when Poor Valley Ridge was undoubtedly only a low barrier between the Ordovician limestone lowland and the Clinton and Brallier shale lowland, it was probably buried in many places and may even have been completely covered by fans from Cumberland Mountain. Streams now crossing the ridge in watergaps were originally consequent on the surfaces of these fans and were later superposed across the belt of Clinch sandstone when they cut downward through the fans after uplift of the Schooley peneplain.

No definite windgaps are present in Poor Valley Ridge but several prominent sags in the ridge may be windgaps. In a ridge as serrate as Poor Valley Ridge, it is difficult to distinguish a high windgap from an unusually low sag caused by headward sapping of a stream or of two streams on opposite sides of the ridge. One of the most prominent of the possible windgaps lies northwest of Rose Hill, and was formerly utilized by a tramline that hauled iron ore to Rose Hill from iron mines on the north side of the ridge. If streams did traverse this and other low sags in post-Schooley time, they undoubtedly developed their courses in Schooley time as consequent streams flowing southward on alluvial fans from Cumberland Mountain. After uplift the alluvial fans were eroded and the streams became superposed across the belt of Clinch sandstone. They cut watergaps into it as continued erosion of the weak rock belts on either side etched out subsequent valleys and left Poor Valley Ridge in relief. Later, however, the streams were diverted by tributaries of more powerful and still existent transverse streams working headward along the weak belt of the Clinton and Brallier shales.

CHANGES IN DRAINAGE FOLLOWING THE CLOSE OF THE SCHOOLEY CYCLE

At the end of the Schooley cycle an excellent balance between different units of the drainage system had been established. In post-Schooley time that balance has, for the most part, been consistently maintained. Possible changes in the drainage of Poor Valley, as described above, may have taken place, but elsewhere only a few significant changes have occurred, the most important of which will be mentioned briefly.

At the end of the Schooley cycle more of the drainage of the dolomite belt was by way of subsurface channels than at present. Since uplift the areas of subsurface drainage have been less rapidly reduced than the areas of active erosion by streams, with the result that tributaries of the upland streams have been working headward into the higher sinkhole areas. This process still continues, and many streams that formerly flowed into sinkholes have now been brought into the surface drainage system. An excellent example of imminent capture of a sinkhole stream is clearly shown on the geologic map (Pl. 2) just east of Possum Hollow.

Most of the major streams of the area seem well adjusted. Thus Martin and Indian creeks are waging a rather equal contest on opposite sides of their common divide in the Indian Creek lowland. Though Martin Creek has less than half as far to go to reach Powell River as does Indian Creek, it must traverse the entire Chestnut Ridge upland, whereas Indian Creek flows across only about one-third of the upland before entering Powell River. Martin Creek does seem slightly the more powerful of the two and appears to be driving the divide very slowly westward. Subsequent streams in Poor Valley have great difficulty extending their drainage areas, for the valleys are largely choked by talus and fans from Cumberland Mountain. Consequently none of the streams that cross Poor Valley Ridge in watergaps is in any imminent danger of being diverted by subsequent streams working headward in Poor Valley. In the Chestnut Ridge upland most of the major streams are believed to have had substantially the same courses at the end of the Schooley cycle as at present, but they have developed more elaborate networks of tributaries in the recent downcutting. Fourmile Creek is an exception, in that it has a very striking right angle bend between the upper and lower parts of its course (Pl. 31). This bend suggests strongly that the stream formerly flowed straight south across the upland into Powell River. It has since been diverted by the lower Fourmile Creek, which worked headward along the belt of Copper Ridge dolomite, and tapped the original Fourmile Creek half a mile south of the State line, forming the elbow of capture now observed. This probable capture must have taken place at a level above that of the present upland, as no recognizable abandoned channel or gap in the upland is apparent south of the elbow of capture.

POWELL RIVER

Intrenched meanders of two cycles.—Whether viewed on maps (Pls. 1 and 13), in photographs (Pls. 30A and 33A), or in the field, the intrenched meanders of Powell River are extremely spectacular. They persist for many miles east and west of the Rose Hill district, but are especially well developed within the district. The course of the river from the east to the west edge of the area is 22½ miles, whereas the airline distance between the same points is 9¼ miles. The river falls almost exactly 50 feet across the area, giving it an average gradient of slightly more than 2 feet per mile. Except at the mouth of Fourmile Creek and at the west edge of the area, the meanders lie entirely within the lowland of limestone, and are now intrenched about 130 feet below the surface of the Harrisburg peneplain developed on the limestones. Vertical cliffs have been formed where the river is strongly undercutting on the outside of its loops, and terraces and gentle slip-off slopes are present on the opposite side. The cliffs on the north side of the river are highest and steepest where the Mosheim limestone and the lower part of the Lenoir limestone unite to form one massive ledge. Higher and longer cliffs are present on the south side of the river, where it swings close to the base of Wallen Ridge. Here the upper part of the Lowville limestone and the Moccasin limestone are especially persistent cliff makers. One of the most prominent cliffs is on the south side of the meander near Fletcher Ford (Pl. 1) where a vertical cliff 150 feet high with a 40-foot talus slope at the base overlooks the river. Nowhere does Powell River cut against the base of bare rock cliffs, but talus slopes lie between the base of the cliffs and water level, even where the current impinges most directly against the banks. This is because the gradient of the river has been so reduced by the enlarging of its meanders that even in time of flood it is incapable of moving away the large blocks that fall from the cliffs. It does, however, eat away at the soil and smaller rock fragments in the talus slope so that the enlargement of the meanders still goes on though at an exceedingly slow rate.

The width of the meander belt, as determined by drawing lines tangent to the meanders on opposite sides of the river, ranges from 0.5 mile in the central part of the Rose Hill district, where the lowland is narrowest, to 1.1 mile farther east where the belt of limestones is much broader. Where Powell River enters the Chestnut Ridge upland just west of the Rose Hill district, its meanders are greatly elongated, and in places the meander belt is nearly 2 miles wide. Within the district the only meander that appears outsized is the one that lies partly within the Chestnut Ridge upland at the mouth of Fourmile Creek (Pl. 31).

There is a direct relation between the size of the meanders and the belts of rock in which the meanders lie, the explanation for which lies in the cyclic nature of the uplift and erosion of the region. The Powell River meanders were originally formed at a level that had to be above the present crest level of the Chestnut Ridge upland, and that was almost certainly the level of the Schooley peneplain. On this peneplaned surface the river broadened its floodplain until it meandered freely, in general favoring the belt of weaker limestones but swinging into the dolomite area in places. When the Schooley cycle of peneplanation was terminated by uplift of the region, the meanders incised themselves into the peneplaned surface. As the result of its increased gradient after uplift, the river was able not only to cut down, but also to attack its banks vigorously on the outer sides of the bends and thus to enlarge the meanders. This process continued until a long pause in the uplift of the region permitted a partial peneplain to develop, which has been called the Harrisburg peneplain. This pause did not persist long enough to permit the reduction of the relatively resistant dolomites of the Chestnut Ridge upland to a nearly level surface. Within the belt of weak Ordovician limestones, however, the river had adequate time to level all the meander spurs of the incised meanders inherited from the Schooley cycle and to open out a flat-floored, mature valley occupying nearly the full width of the limestone belt. On this valley floor a new set of Powell River meanders, adjusted to the size, gradient and load of the river on the Harrisburg surface, were formed. With the renewed uplift of the region that put an end to the Harrisburg cycle of partial peneplanation, incision once more began. The present intrenched meanders in the Powell River lowland are thus inherited only from the Harrisburg surface and have been enlarging only during post-Harrisburg intrenchment. Because the Harrisburg peneplanation did not level the Chestnut Ridge upland, however, the meanders within the upland have been inherited from the earlier or Schooley cycle. They are, as a result, considerably larger and the meander belt of the river is considerably wider in the upland than in the lowland. Even with a single meander, such as the one at the mouth of Fourmile Creek shown in the aerial photograph (Pl. 33A), this relationship is demonstrable. Here only the north part of the meander was caught in the upland, but because the river could not level its meander spur in the dolomites of the upland during the brief Harrisburg cycle this meander is much longer than all others in the vicinity.

Several measurements of the width of Powell River were made; all of them were between 100 and 130 feet. Using 125 feet as the average width of the present river, the ratio of the width of the river to the width of its meander belt for the intrenched meanders of the lowland is 21 to 1 at the narrowest part of the lowland where Wallen Ridge and the Chestnut Ridge upland hem in the meander belt on opposite sides. At the east edge of the area where the lowland is very broad, the meanders have been able to enlarge much more freely during post-Harrisburg intrenchment and the ratio is 46 to 1. Where Powell River flows entirely within the Chestnut Ridge upland west of the Rose Hill district, the meanders inherited from the Schooley cycle have a meander belt which is in places nearly 80 times as wide as the present river width.

Mark Jefferson[210] originally pointed out the rather constant ratio existing between width of stream and width of meander belt for streams meandering freely on floodplains. Bates[211] has recently calculated that this ratio is about 16 to 1 for streams 100 feet wide, and progressively less for wider and wider streams. For intrenched meandering streams, however, the factors that limit the width of meander belts are much less effective. The ratio of width of meander belt to width of stream for intrenching streams depends on many local factors, but Bates believes there is a fairly constant ratio, which also varies with the width of the stream. For streams 100 feet wide, his measurements show the ratio to average about 41 to 1. This is very close to the measurement for the freely meandering and incising Powell River near the east edge of the area, but much greater than where the incising meanders are constricted in the narrow part of the lowland. In the Chestnut Ridge upland, where the ratio approaches 80 to 1, a strong structural control seems to have affected the meanders, so that they have grown abnormally long without cutting themselves off by intercision.

Cut-off meanders.—During intrenchment of a freely meandering stream, the meanders may cut on opposite sides of a meander spur until the spur is entirely eaten through and a cut-off is thus affected. This shortens the course of the river and as down-cutting

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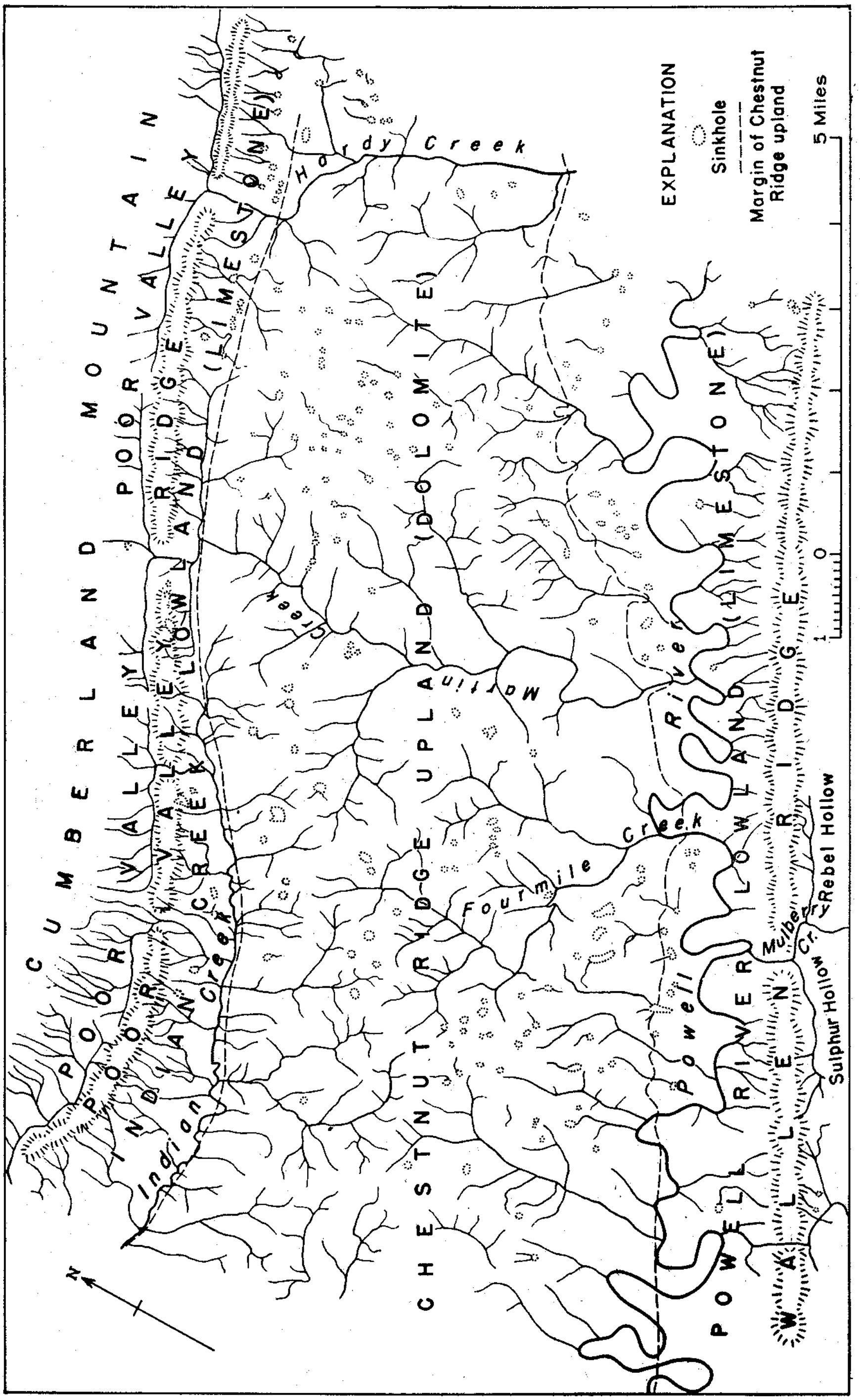
[210] Jefferson, Mark, Limiting width of meander belts: Nat. Geog. Mag., vol. 13, pp. 373-384, 1902.

[211] Bates, R. E., Geomorphic history of the Kickapoo region, Wisconsin: Geol. Soc. America Bull., vol. 50, no. 6, pp. 819-879, 1939.



Drainage map of the Rose Hill district and adjacent areas to the east and west.

continues the old river channel is left suspended as an abandoned meander. Cut-off meanders have been formed by this process at several places along Powell River, but only one of them lies in the Rose Hill district. It is on the north side of the river, 2 miles west of Parkey Bridge. There the abandoned meander appears as a semicircular cultivated swale in the aerial photograph (Pl. 32A), and the river now flows in a straight line past the neck of the loop. A meander scar on the south side of the river shows where the stream has withdrawn from part of another meander as the result of the cut-off. The former course of the river at this locality is shown in the sketch (Pl. 32B), which has been drawn to the same scale as the photograph.

Since the abandonment of the meander two streams, which formerly entered the river at the north end of the meander, have had to extend their courses. The eastern stream now enters the river near the neck of the cut-off meander at Rob Camp Church (Pl. 1), but the western stream flows into a deep sinkhole in the floor of the meander and reaches Powell River underground. The downcutting of both of these streams has somewhat destroyed the symmetry of the old meander, and the presence of an abandoned meander is not immediately apparent in the field. In fact, it was first recognized in the aerial photograph.

Five remnants of river gravel deposits were found around the rim of the abandoned meander and all lie at nearly the same altitude. They consist mainly of well-rounded cobbles and boulders of Clinch sandstone, up to 2 feet in diameter, which could only have been derived from Wallen Ridge and therefore could not have been deposited by the small streams now flowing down opposite sides of the meander. The level of these gravel remnants does not necessarily represent the level of the meander floor at the time of intercision, for they may have been terrace rather than floodplain deposits when the cut-off took place. The exact level of the meander floor at the time of cut-off is difficult to determine, for the meander has been eroded in places and has been filled by slumping and wash from the sides in other places. Apparently, it could not have been lower than 1205 feet—the level of a low rock divide in the bottom of the old meander just south of the big sinkhole—nor could it have been higher than 1230 feet—the level of the gravel remnants, all of which seem to be nearly in place. The present level of Powell River in this vicinity is about 1155 feet, and 50 to 75 feet of downcutting must have taken place since the cut-off; from 55 to 80 feet of downcutting has therefore taken place from the end of the Harrisburg cycle until the cut-off occurred.

A small cut-off of somewhat different type has been formed just east of the mouth of Martin Creek. This cut-off is shown on the geologic map (Pl. 1) and in the panoramic photo (Pl. 30B). Here a channel at the outer tip of a meander has been abandoned in favor of a course about 200 yards in from the meander-tip. In the photograph the river now occupies a channel 37 feet below the floor of the abandoned loop in the foreground. The former course of the river was from left to right around the loop. It is most unlikely that this cut-off was accomplished by intercision. A glance at the map (Pl. 1) is sufficient to show that the river current could hardly have impinged on opposite sides of the spur at this point to affect a cut-off. It is much more likely that the original meander on the Harrisburg surface had two channels with an island between occupying the location of the present rocky knob in the photograph. During intrenchment both channels were preserved for some time, but eventually the inner course gained the advantage over the outer course, and the outer course was abandoned. If this explanation is correct, the dual channel was occupied by the river through about 90 feet of intrenchment.

Cut-off tributaries of Powell River.—Along Wallen Ridge several tributaries of Powell River flow down the steep upper and middle slopes of the ridge directly toward the river, but then turn to the left and flow for some distance nearly parallel to the base of the ridge before entering Powell River. The lower courses of these streams were probably inherited from a time when the tributaries debouched onto the Powell River floodplain at a higher lever than at present, and were prevented from flowing directly into Powell River by natural levees. This type of stream is called a Yazoo stream. If a Yazoo stream and its master stream are forced into a regimen of vigorous downcutting due to regional uplift, the course of the tributary will retain the Yazoo shape though the floodplain of the master stream is entirely eroded during intrenchment. The best example of a stream of this sort is a quarter of a mile southwest of Fugate footbridge (Pl. 1).

Several streams in the region formerly had Yazoo-shaped courses of this type but the lower or Yazoo part of the stream channel has been cut off and abandoned by being undercut by a laterally shifting meander of Powell River. This appears to be the fate in store for the tributary mentioned above, if the meander at the Fugate footbridge continues to enlarge and in so doing shifts about 200 yards farther south.

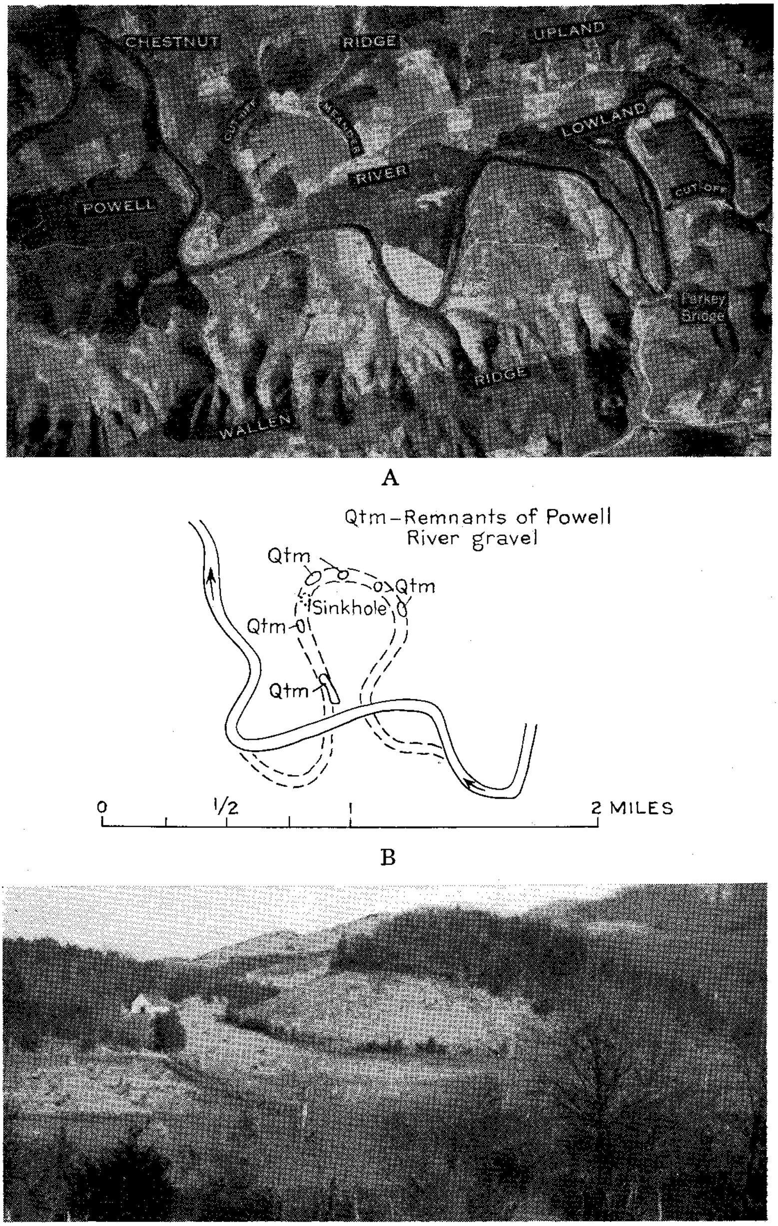
A stream that has already been undercut in this manner is visible at the extreme right edge of the aerial photograph (Pl. 32A). It now flows into the next meander east of Parkey Bridge by tumbling down the precipitous undercut cliff at the back of the meander. Formerly it turned left at the base of the ridge and flowed in a gentle open valley across the meander spur to enter Powell River a third of a mile upstream from Parkey Bridge. The stream has been diverted and the lower or Yazoo course abandoned due to the southward shifting of the Powell meander. The abandoned channel is shown in the photograph (Pl. 32C), which was taken looking directly up the channel from a point opposite the stream's former junction with Powell River. By comparing this photograph with the aerial photograph (Pl. 32A) it will be seen that the smaller and more distant of the two buildings in the abandoned channel is in a very prominent gap in the meander spur, and is at the top of a steep bluff directly overlooking Powell River. Thus the length of the abandoned channel visible in the photograph is all the channel there is, though it would appear that the channel continued around behind the hill and up the slopes of Wallen Ridge as, indeed, it did at one time.

Another small tributary has been diverted twice by being undercut at two different places by the shifting of meanders of Powell River. This stream is too small to appear on the geologic map (Pl. 1), but it is indicated by arrows in the aerial photograph (Pl. 33A). The stream originally flowed in an open ravine down the mountain side, turned left at the foot of Wallen Ridge and entered Powell River in the middle of a straight stretch (Pl. 33B, Diagram 1). It was diverted from this course by being undercut by a south-shifting meander about at the point of its right-angle turn at the base of the mountain. In this second stage it entered the river by plunging over the cliff at the back of the meander (Pl. 33B, Diagram 2), and left its lower course as a flat-floored abandoned channel, very similar in appearance to the one shown in Plate 32C, but much shorter. Still later, the upper part of the stream was undercut by the next meander to the west. Thus the upper part of the stream flowed over another meander cliff and into the river about a quarter mile downstream from its original mouth (Pl. 33B, Diagram 3). The upper abandoned channel shows in the aerial photograph as a sharply incised ravine just north of the two arrows. By this second capture the upper abandoned channel was left with a very meager catchment basin and is now occupied by a mere trickle. This drainage history is almost self-evident from a careful inspection of the aerial photograph. In the field it is made more apparent by the presence in the upper abandoned channel of fans composed largely of Clinch sandstone, blocks of which could not have reached their present position except through a former course leading from the mountain crest into the ravine in which they lie.

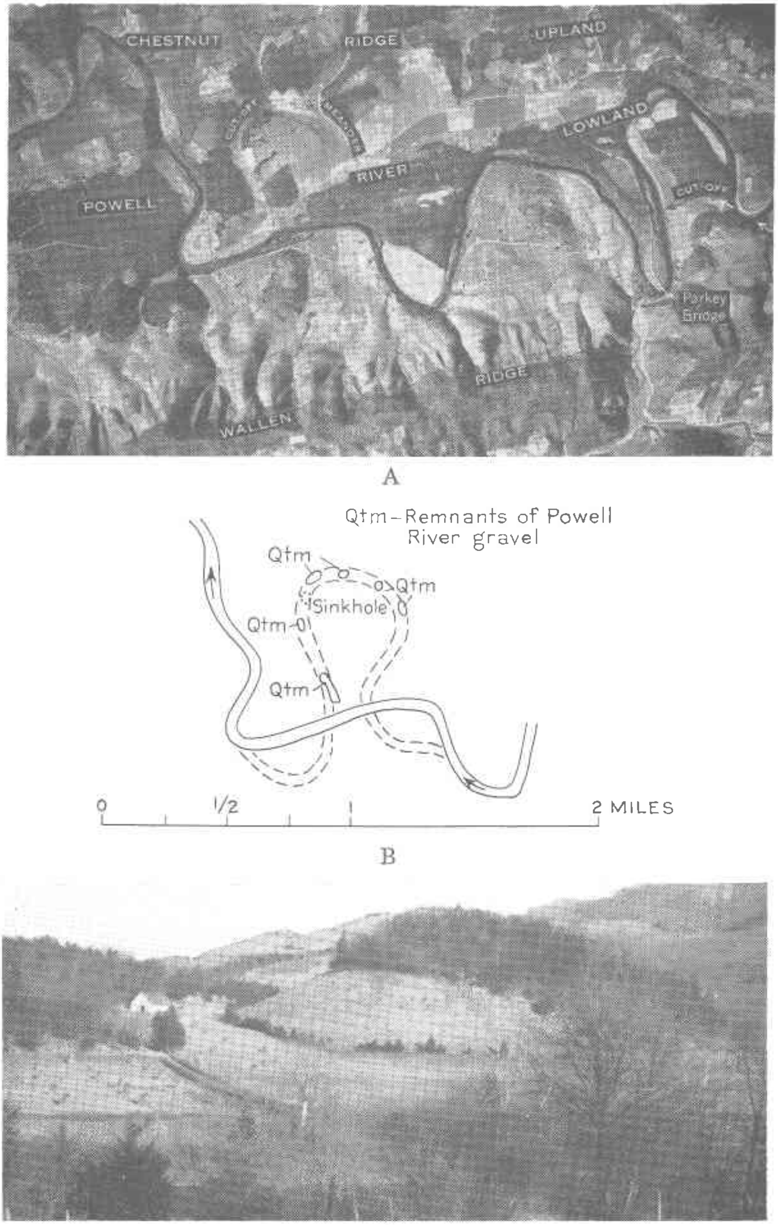
Still another tributary diversion, which is somewhat more obscure both in aerial photographs and in the field, has occurred northeast of Baldin Ford. A partly preserved abandoned channel, with gravel remnants along it, indicates that the stream from Wallen Ridge, which now enters Powell River at Fletcher Ford, formerly turned left at the base of the mountain and crossed the broad meander spur to enter the river near Baldin Ford almost 2 miles farther downstream. This former course is indicated by the dashed line on Plate 1. Here also lateral shifting of a Powell River meander has effected a cut-off and caused the abandonment of the lower stream channel of the tributary.

Other examples of this sort of tributary diversion are known and undoubtedly still others have taken place for which the evidence has been lost. In addition, all tributary streams that enter Powell River on the outside of meander loops are being shortened by the encroaching meanders. Only the larger streams are able to cut down rapidly enough to keep pace with this encroachment. All the smaller streams enter the river by way of steep ravines with cascades and small waterfalls along their courses. Conversely streams entering Powell River on the inside of meander loops should have their courses lengthened as the river migrates away from them. There are, however, very few examples of this kind, because most streams that may originally have flowed out on meander spurs have long since been diverted somewhere along their course to a more direct route to the river. The few streams that do exist on the inside of meander loops normally seep through the terrace gravel and alluvium or plunge into sinkholes and complete their course to the river through underground channels.

Terraces.—During intrenchment, Powell River has developed terraces at different levels. Three different sets of terraces have



A, Aerial photograph of Powell River showing a cut-off meander. B, Sketch to same scale as aerial photograph (32A), showing former course of Powell River. C, Abandoned channel of a tributary to Powell River to right of white barn. Near Parkey Bridge.



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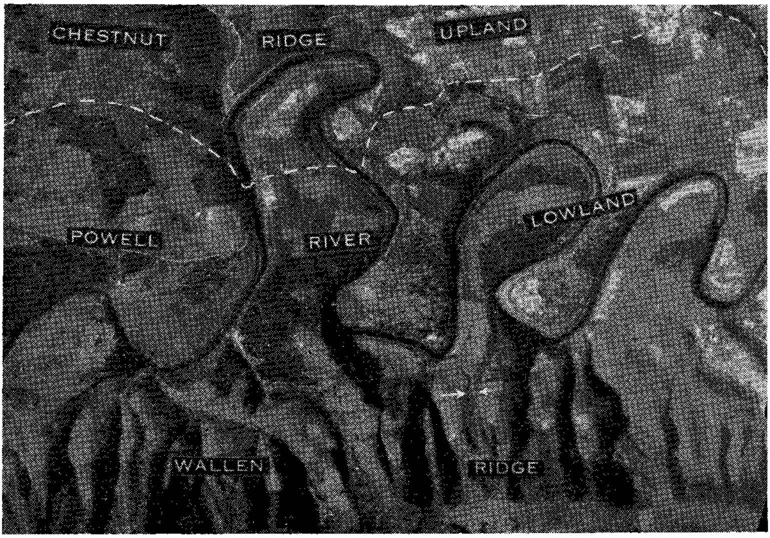

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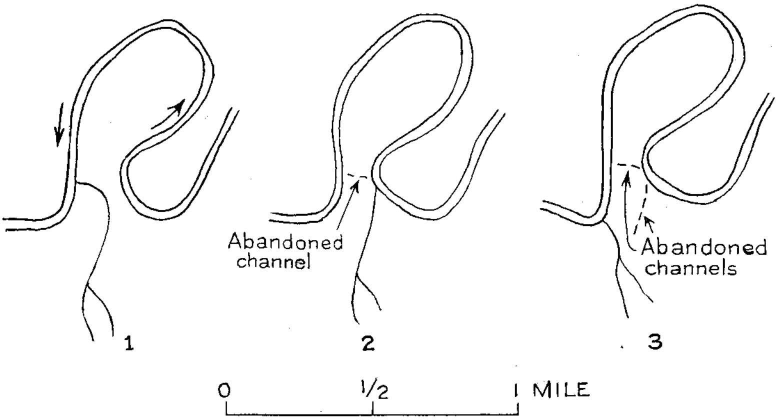
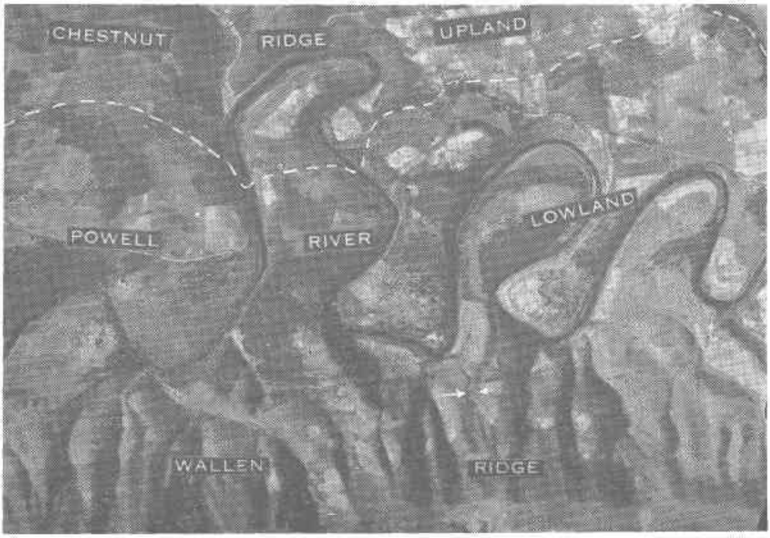


B

A, Aerial photograph of Powell River meanders showing a cut-off tributary, indicated by arrows. B, Sketch showing stages in the cut-off of a Powell River tributary. Same scale as aerial photograph (Pl. 33A).



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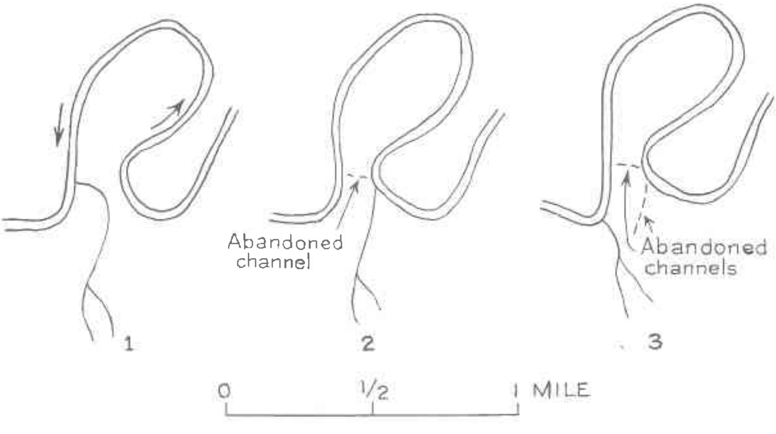


B

A, Aerial photograph of Powell River meanders showing a cut-off tributary, indicated by arrows. B, Sketch showing stages in the cut-off of a Powell River tributary. Same scale as aerial photograph (Pl. 33A).

been mapped on Plate 1, and called high, middle, and low terraces. The high terraces and middle terraces have been partly or largely destroyed by subsequent erosion, but the low terraces are well-preserved and are covered with a nearly continuous mantle of alluvium or gravel. Almost all of these terraces are on the inner or slip-off sides of the meanders. The photograph (Pl. 34A) shows the slip-off side of a meander spur on which terraces of all three sets have been preserved. The photo was taken looking west from a point 0.8 mile south of the mouth of Fourmile Creek. The highest terrace is 90 feet above river level on the crest of the meander spur near the right edge of the picture. Gravel and sand are scattered over its surface. The middle terrace was probably never very well developed, but a flattening of the slip-off slope is apparent and a sandy alluvial soil covers the surface. The top of this terrace is 45 feet above the river, but it has no well-defined lower limit, and has been shown on the map as merging with the low terrace. The low terrace is a flat alluvium-covered surface, which averages about 250 feet wide, and lies 25 feet above river level.

Not all the high terraces are members of a clearly recognized set, for they range in elevation from 70 to 105 feet above the river. Many of them lie at elevations of 85 to 90 feet above river level, however, and they suggest that extensive lateral cutting by the river was favored at this stage in the intrenchment. A thin layer of gravel covers most of the high terraces. It is composed largely of well-rounded pebbles of Clinch sandstone mostly less than 1 inch in diameter. This gravel has probably been let down somewhat, and now forms a discontinous thin mantle through which limestone ledges or residual limestone soil appear in places.

The middle terraces do not form a definite set at or near one elevation. Most of them have undulatory surfaces or slope gently in one direction so that their limits and their critical heights are obscure. Their measured heights above river level range from 35 to 70 feet, with no consistent average. Thus they seem to have been formed at various levels during downcutting as the result of purely local conditions. In many terraces the present undulatory surface is the result of the formation of sinkholes in the underlying limestone with resultant slumping of the mantle of sand and gravel.

The low terraces shown on the map (Pl. 1) were all formed when downcutting of the river was, for some reason, temporarily retarded, thus permitting the river to attack its banks for a considerable length of time at nearly the same elevation. The heights of numerous low terraces were measured and all lay between 20 and 26 feet above present river level, with 25 feet being about the average height. The floods of 1863 and of 1917 are reported by local residents to have covered these terraces, but they are well above the level of normal flood-stage. The low terraces are almost continuous along the river, first on one side and then on the other. They are covered with a silty alluvium that makes a fertile soil, and almost all of them are cultivated or are in pasture.

The long slopes between the high and middle terraces or between the high and low terraces are normally even and gentle and are covered with silt or sand. They are typical slip-off slopes, showing practically no outcrops or residual soil. On most meander spurs a sharply defined line separates the part of the spur with terraces and silt-covered slopes from the part of the spur with abundant limestone outcrops. This shows clearly in Plate 34A, where the line of separation follows the rail fence and the edge of the cedars at the extreme right of the picture. Outcrops are abundant to the right of the fence and in the woods.

INDIAN CREEK

Indian Creek is the second largest stream in the district. Like Powell River, it developed a meandering course on the Schooley peneplain and after uplift these meanders became intrenched. In the lower part of Indian Creek Valley the limestone belt was largely beveled by the creek and by its tributaries during the Harrisburg cycle, and as a result intrenched meanders along this part of the river were lost except where Indian Creek leaves the lowland and enters the Chestnut Ridge upland. One such meander, half a mile west of the edge of the mapped area, persisted until very recent time when it cut off across its neck, leaving an excellently preserved abandoned channel only 10 feet above present creek level. Other large intrenched meanders of Indian Creek are preserved in the Chestnut Ridge upland several miles west of the Rose Hill district.

Because the part of Indian Creek in the Rose Hill district represents only the headwater portion of the stream, it probably did not have well-developed meanders on the Schooley peneplain, nor was time adequate for it to develop a peneplaned surface during the relatively short Harrisburg cycle. The creek did, however, form a floodplain on which it developed a sinuous course and locally it formed small meanders. Since the uplift of the region at the close of the Harrisburg cycle, Powell River, which forms the local base level for Indian Creek, has cut its channel down about 130 feet. This wave of rejuvenation has been propagated up Indian Creek causing it to intrench itself in its floodplain, but the wave of rejuvenation is just now reaching the Rose Hill district. At the west edge of the district, terraces 6 to 20 feet above stream level show the amount of recent intrenchment, but the terraces approach the present floodplain more and more closely upstream and merge with it near Ewing. The knickpoint caused by post-Harrisburg uplift has thus migrated about 20 miles upstream from the mouth of Indian Creek to Ewing, but intrenchment has not yet begun in the part of the valley east of Ewing. This fact does not imply that there has been no lowering of the valley east of Ewing since the close of the Harrisburg cycle, but rather that the rate of downcutting which was going on at the end of the Harrisburg cycle has not yet been materially accelerated by the post-Harrisburg uplift.

In many places gravel remnants are preserved on the sides or crests of hills in the Indian Creek lowland well above present drainage level. Most of these remnants are composed largely of well-rounded pebbles of quartz, which had their source in the ledges of the Lee conglomerate near the crest of Cumberland Mountain, but they include also pebbles of white chert, which were derived from the Cambrian and Ordovician limestones and dolomites of the Indian Creek lowland and Chestnut Ridge upland. There is no apparent correlation of levels of these remnants. In some cases it has not been possible to tell whether they were remnants of floodplain deposits of Indian Creek or remnants of fans formed by smaller streams, which head against Cumberland Mountain. The most striking of these gravel remnants is a deposit capping a knob 85 feet above Indian Creek in the town of Ewing. It appears to be a terrace gravel deposit of that creek, because it contains abundant white chert pebbles as well as abundant quartz pebbles. Had it been part of a high-level fan, such as the one which debouches from Cumberland Mountain through Bales Gap at the present time, it should have been composed almost entirely of quartz pebbles derived from the Lee formation. This is the only gravel remnant in the Indian Creek lowland that is thick enough to have any economic importance. Several gravel pits have been dug in the deposit and they show that it is about 10 feet thick.

FANS

Alluvial fans are present in the Indian Creek lowland and also on the northern slopes of Wallen Ridge. The larger and more important fans in the Indian Creek lowland have been formed where streams draining from Cumberland Mountain have debouched through gaps in Poor Valley Ridge, and have dumped their load as their gradient was sharply reduced on entering the lowland. These fans are composed almost entirely of pebbles, cobbles and boulders of sandstone and conglomerate derived from the Lee formation, the great cliff-making formation near the crest of Cumberland Mountain. The boulders are in places more than 10 feet in diameter, but they average much less, and become progressively smaller the farther the fans spread out into the valley. The largest of these fans lies at the northwest corner of the mapped area (Pl. 1). It has almost completely buried Poor Valley Ridge, which is here much lower than normal, so that only knobs of the ridge rise above the fan surface.

Another large fan flares out from Bales Gap in Poor Valley Ridge north of Ewing. This fan has been built out across the full width of the lowland finally merging with the floodplain of Indian Creek at Ewing. In and near Bales Gap the surface of the fan is rough and irregular with huge boulders scattered over it (Pl. 35A), but farther downstream it becomes smooth with only an occasional small boulder on the surface.

Along Wallen Ridge fans have been formed at many places where changes from steep to gentle slopes have forced the streams to drop some of their load. Some of the large fans have been built out a short distance onto the lowland at the base of the mountain, and others have formed where mountain streams debouched onto terraces of Powell River. Still other smaller fans lie well up on the mountain side where the change from steep slopes near the crest of the ridge to gentle slopes below takes place. Some of these fans are still being formed and others are being destroyed.

FLOODPLAIN DEPOSITS

Deposits of recent alluvium border many of the streams of the area. They consist of layers of silt, sand, or gravel, which lie only a few feet above stream level and are covered in times of flood. These deposits have been mapped only where they form belts approaching or exceeding 100 feet in width. Mapped belts of alluvium lie along Powell River, Indian Creek, and several of the other large streams. Along Powell River the floodplains are narrow and lie on the slip-off sides of the meanders between the river channel and the low terraces. Along Indian Creek, the floodplain is in places only on the inner side of the bends of the stream, but elsewhere it lies on both sides especially near the headwaters of the stream where the stream course is less sinuous. Floodplains are developed only locally along the other streams of the district. They have their greatest extent on the weaker rock formations, and are absent or narrow where the more resistant belts are crossed. Most of the rocks inside the fensters are more easily eroded than are the dolomites of the Cumberland overthrust block, with the result that several of the streams that cross fensters have wide floodplains in the fensters. These floodplains narrow down or pinch out near the upper and lower edges of the fensters, as is especially well shown in the Hamblin Branch and Martin Creek fensters (Pl. 1).

SUBSURFACE DRAINAGE FEATURES

Many of the streams of the Chestnut Ridge upland and some of those in the Indian Creek and Powell Valley lowlands disappear into sinkholes and reappear as springs or seeps at lower levels. The sinkholes occur in almost all of the limestone and dolomite formations, but certain formations favor the formation of sinkholes more than others. For example, in the Indian Creek lowland sinkholes are abundant in the Trenton limestone at a zone about one-third of the way stratigraphically from the base to the top of the formation. Many small perennial and intermittent streams that head on Poor Valley Ridge flow southward till they reach this part of the Trenton limestone belt and then disappear into sinkholes. Only the larger of these sinkholes and only the perennial streams are shown on Plate 1. In the Powell River lowland, on the other hand, the entire belt of Trenton outcrop is on the steep slopes of Wallen Ridge, so that no sinkholes have developed in it. Instead, the belt of Murfreesboro limestone, lying on the north side of the lowland at the foot of Chestnut Ridge is the locus for the most numerous sinkholes. Many of the small and a few of the fairly large streams that flow south from the

Chestnut Ridge upland disappear into sinkholes in the belt of the Murfreesboro limestone and thence finish their journey to Powell River in underground channels. One of the largest of these sinkholes, half a mile west of Alanthus Hill, is shown in the photograph (Pl. 35B). At this locality the stream flows toward the observer into the pond in the foreground of the picture. Directly behind the point from which the photograph was taken the valley is completely closed on its downstream side by a wall as high as the two side walls of the valley.

In the Chestnut Ridge upland sinkholes are scattered throughout the area underlain by the Ordovician and Cambrian dolomites and the Cambrian Maynardville limestone. Some are shallow, clogged with clay, and occupied by small ponds whose water level fluctuates with the rainfall. Others are small and steep-sided and have many rock outcrops on their walls. In some of them the streams plunge into crevices or yawning holes. Many caves are known to the local residents, but we have heard of none of unusual size or beauty. The most interesting of the caves lies just above the Pine Mountain overthrust fault 200 feet from the south end of the Martin Creek fenster. Here the underground water has seeped downward through the Maynardville limestone to the fault plane and then worked laterally along the fault dissolving out the cave. This same process has happened at many other places around the rims of the fensters, but without the formation of caves. The outcrop of the Pine Mountain fault and its branches is commonly marked by springs and seeps because the rocks in the overthrust block above the fault are pervious and soluble, whereas in many places the rocks below the fault are impervious or insoluble or both.

SOIL EROSION

Soil erosion is a serious problem in the area, especially in the Chestnut Ridge upland. It has progressed farthest in the belts of the Copper Ridge dolomite and Conasauga shale, but hillsides developed on other dolomites than the Copper Ridge have been gullied in places. Locally the Ordovician limestones, particularly the Eggleston, have been badly eroded in the Indian Creek lowland. Strangely enough the extremely steep knobby hills of Reedsville shale on Wallen Ridge and Poor Valley Ridge have been gullied hardly at all. They have not been cultivated, however, but are largely in pasture. Most of the hills of the Chestnut Ridge upland have been largely cleared of timber except where bedrock crops out too abundantly to make the land desirable for agriculture. The slopes are in some places too steep to retain their soil after the forest cover has been removed and the stumps have been pulled. Although contour plowing is practiced on such slopes the prevention of rivulets during torrential rains is almost impossible. Unless immediate measures are taken to check their growth later rains enlarge the rivulets to steep-walled gullies which destroy the usefulness of the field for many years to come. Plate 35C shows a badly gullied hillside 1 mile southeast of Smith Chapel. The gullies at the lower level are in residual soil derived from the Conasauga shale, and the higher gullies in the distance are in clay of the Maynardville limestone.

Many hillslopes in the Chestnut Ridge upland have been stripped of their timber. After being cultivated for several years until bad gullies formed, much of this land has been abandoned. These slopes have now grown up with weeds and blackberries which in places form an almost impenetrable tangle.

The Civilian Conservation Corps did a great deal of useful work in the area during the decade preceding World War II. Check dams were built every few dozen feet across especially bad gullies and slopes were seeded with soil-retaining plants. Much of this work has been helpful in preventing the further spread of gullies already started, but only in a few places has it proved curative to the extent that the gullies are beginning to heal. Only at great expense can a slope that has begun to gully be reclaimed.

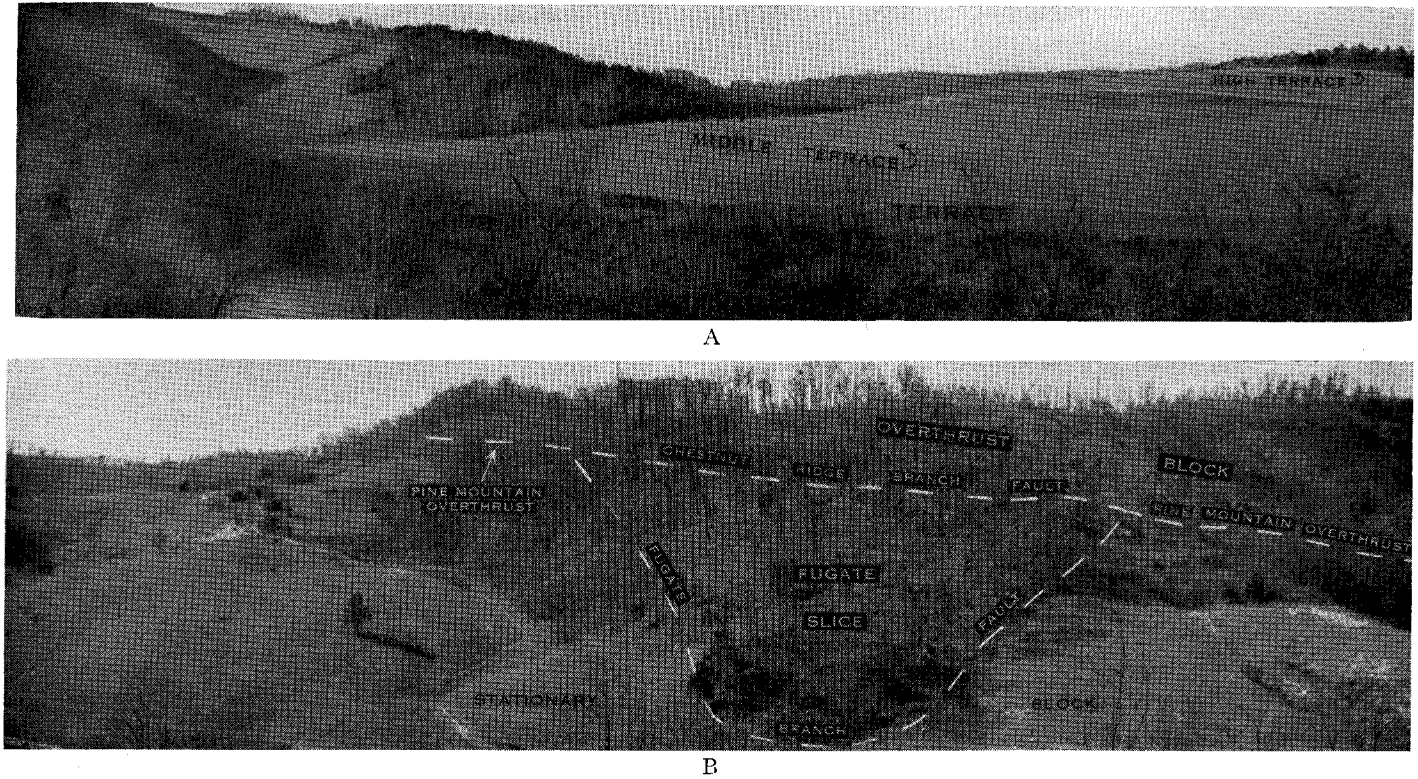
STRUCTURE

Most of the exposed rocks of the Rose Hill district belong to the Cumberland overthrust block, which has moved northwestward about 6 miles along the Pine Mountain overthrust fault. The rocks of the overthrust block have been warped into a broad gentle anticline, the Powell Valley anticline. The rocks of the stationary block beneath the Pine Mountain fault have also an anticlinal structure. The crest and south flank of the underlying anticline, however, have been truncated by the fault, and the anticlinal axis lies southeast of the axis of the Powell Valley anticline.

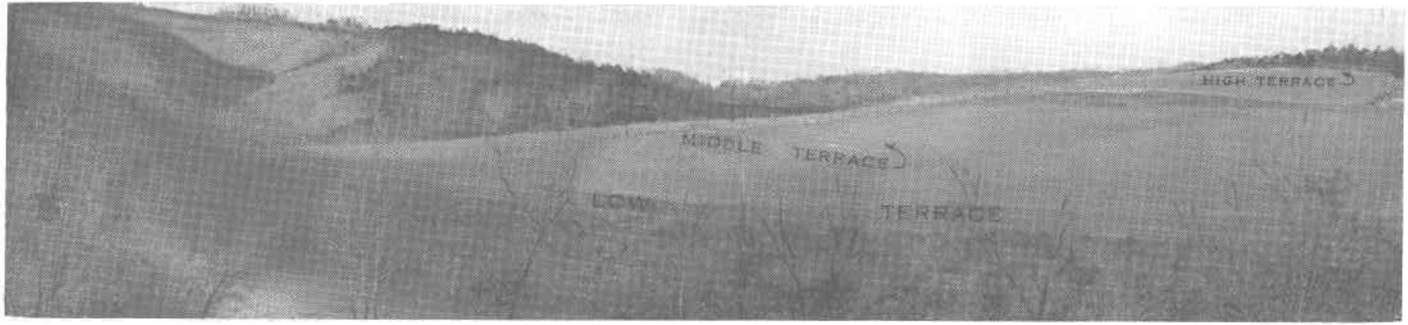
Between the overthrust block and the stationary block, three major fault slices lie between branches of the Pine Mountain fault. Though relatively thin, the fault slices cover considerable areas, and are prominent features on the geologic maps of the district. Hence the rocks of the Rose Hill district are divisible into three structural zones, which are in order from the top downward:

1. The rocks of the Cumberland overthrust block, which have been thrust to the northwest along the Pine Mountain fault.
2. The rocks in slices between the upper and lower branches of the Pine Mountain fault.
3. The rocks of the stationary block beneath the Pine Mountain fault.

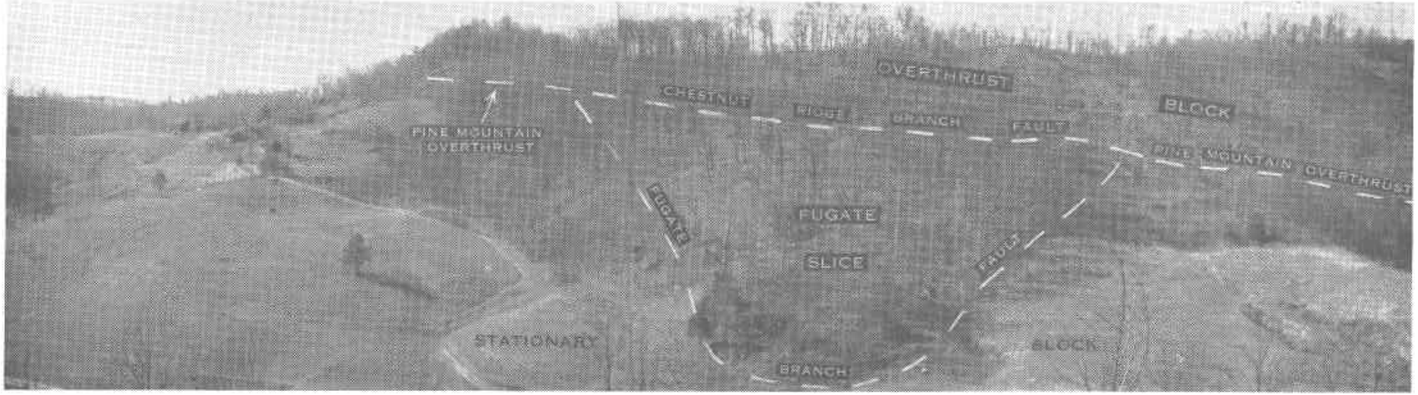
All three of these structural zones have been exposed in the Rose Hill district by erosion along the crest of the Powell Valley anticline, which has in places breached the sheet of overthrust rocks and also the slices between upper and lower branches of the overthrust. Where only one major plane of fault movement is present, erosion has formed simple fensters in which rocks of the stationary block are exposed through holes in the overthrust sheet. Where there are two major planes of movement, however, compound fensters have resulted. In this report the areas delimited by the outcrop of the lower major branch of the Pine Mountain fault have been called inner fensters. These areas include rocks of the stationary block only. The areas delimited by the outcrop of the upper major branch of the Pine Mountain overthrust are called outer fensters. The two outer fensters in the district include rocks of the fault slices and also rocks of the stationary block exposed in the inner fensters. The relations of these ele-



A, Meander spur 0.8 mile south of the mouth of Fourmile Creek, showing Powell River terraces preserved at three levels. B, View across Dry Branch in the Dean fenster, showing the stationary and overthrust blocks with a tongue of the Fugate slice between.

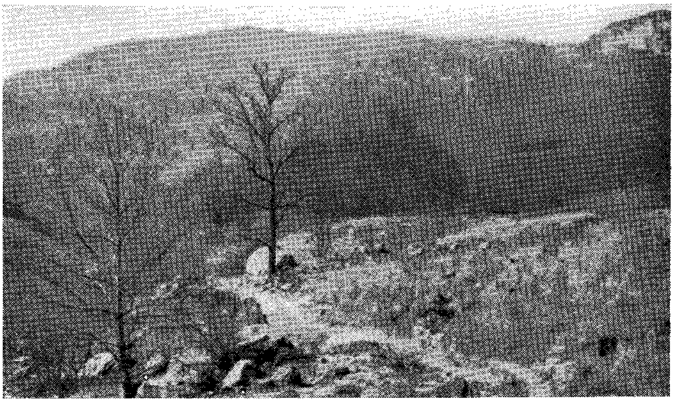


A



B

A, Meander spur 0.8 mile south of the mouth of Fourmile Creek, showing Powell River terraces preserved at three levels. B, View across Dry Branch in the Dean fenster, showing the stationary and overthrust blocks with a tongue of the Fugate slice between.



A

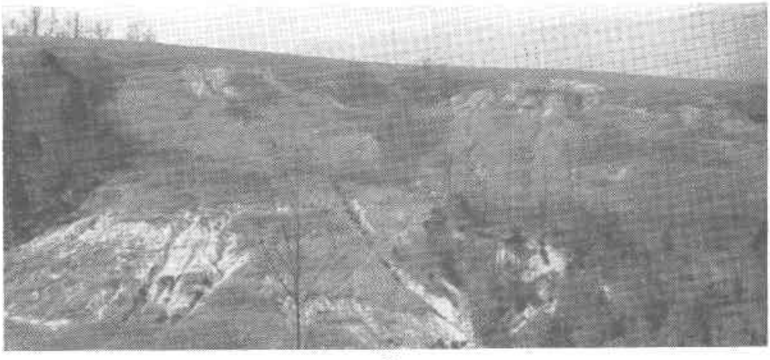
B

C

A, Surface of alluvial fan south of Bales Gap. B, Large sinkhole in the belt of Murfreesboro limestone near Alanthus Hill. C, Gullies in soil derived from the Conasauga shale in the foreground and in clay of the Maynardville limestone in the background. One mile southeast of Smith Chapel.

A

B



C

A, Surface of alluvial fan south of Bales Gap. B, Large sinkhole in the belt of Murfreesboro limestone near Alanthus Hill. C, Gullies in soil derived from the Conasauga shale in the foreground and in clay of the Maynardville limestone in the background. One mile southeast of Smith Chapel.

ments are best seen in Plate 1, where the geology of the fenster area has been generalized, and in the section (Pl. 5B).

Wentworth[212] was the first to recognize that the Pine Mountain fault of southeastern Kentucky extended at a low angle beneath the rocks lying many miles to the southeast of the outcrop of the fault. Butts[213], who later discovered the Rose Hill fensters, identified the fault rimming the fensters as the Pine Mountain fault, and showed a structure section across the Cumberland block, which differs in only minor details from Plate 5B of this report.

The name Pine Mountain fault has been used on the maps of this report where only one major plane of overthrusting is present. Where the overthrust fault splits into two branches in the Rose Hill district, the upper one is named the Chestnut Ridge fault. In the western part of the area the lower branch or plane of the Pine Mountain fault is named the Fugate fault. The planes of the Chestnut Ridge fault above and Fugate fault below merge on all sides of a more or less oval area, thus enclosing a slice of rocks named the Fugate slice. A similar lower branch or plane of the Pine Mountain fault in the eastern part of the area is named the Wilson fault and the slice of rocks between it and the Chestnut Ridge fault is called the Wilson slice.

The appearance of the overthrust sheet, a fault slice, and the stationary block in the field is shown in the photograph (Pl. 34B). The view was taken in the Dean fenster looking northwest across Dry Branch (Pl. 2). Here an isolated tongue of the Fugate fault slice, composed of Mascot dolomite (Ordovician) lies between the Clinton shale (Silurian) of the stationary block and the Maynardville limestone (Cambrian) of the Cumberland overthrust block.

The three structural zones of the rocks of the Rose Hill district differ greatly in their structural character. They will therefore be discussed separately, taking up first the Cumberland overthrust block, second the stationary block, and third, the fault slices in the Pine Mountain fault zone. In the description of the fensters, simple fensters have been included in the same section with the inner fensters, because the field characteristics of the two types are very similar.

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[212] Wentworth, C. K., Russell Fork fault of southwest Virginia: Jour. Geol., vol. 29, no. 4, pp. 351-369, 1921.

[213] Butts, Charles, Fensters in the Cumberland overthrust block in southwestern Virginia: Virginia Geol. Survey Bull. 28, 12 pp., 1927.

CUMBERLAND OVERTHRUST BLOCK

POWELL VALLEY ANTICLINE

The Cumberland overthrust block has been folded into the broad Middlesboro syncline and the equally wide Powell Valley anticline, which are separated from each other by a sharp flexure, the Cumberland Mountain monocline (Pls. 5A and 5B). The Middlesboro syncline lies entirely northwest of the Rose Hill district, but part of the Cumberland Mountain monocline and the full width of the Powell Valley anticline are included in the district.

The Powell Valley anticline is here defined as spanning the region between the Wallen Valley fault on the southeast and the Cumberland Mountain monocline on the northwest. The anticline and a part of the monocline are shown by structure contours on Plate 1. The contours have been drawn at 200-foot intervals on the top of the Maynardville limestone. No clear-cut boundary separates the anticline and the monocline in the northwestern part of the district, but to the northeast the boundary is sharply marked by the Rose Hill flexure (Pl. 1) along which the attitude of the beds changes in a horizontal distance of a few dozen feet from gentle dips of less than 20° to the northwest, to steep to nearly vertical dips in the same direction. In places along the middle part of the flexure the beds are overturned and dip steeply southeast. The change from nearly flat to steeply dipping beds along the flexure is well exposed at the town spring in the southeast part of Rose Hill, and is less well exposed along the Martin Creek road half a mile due east of Rose Hill, and along the Beatty Store road 1½ miles east of Rose Hill.

If the steeply dipping beds in the northwest part of the district are considered to be a part of the Cumberland Mountain monocline rather than a part of the Powell Valley anticline, the anticline is a nearly symmetrical structure with slightly steeper dips on the northwest limb but with a much longer southeast limb. The axis of the anticline trends almost east-west in the western part of the district and about N. 52° E. in the eastern part. This change in direction takes place along an approximate northwest-southeast line through Ewing, and is accompanied by a similar change in trend of the rock belts and topographic features on opposite sides of the line.

The axis of the anticline does not have the usual significance as a favorable site for the drilling of oil wells, because the oil-producing rocks beneath the overthrust have structural features of their own, which are independent of the anticline in the overthrust rocks.

In the vicinity of the fensters, the geology is so complex that it is difficult to recognize the larger relationships on the geologic map (Pl. 2). For this reason Plate 40 has been drawn to show the geology within each of the three major structural zones. The three maps on Plate 40 cover identically the same areas. If the blank areas on Plates 40A and 40B were cut away, and the three maps were then superimposed on one another with Plate 40C at the bottom and Plate 40A at the top, the result would be a replica of Plate 2 on a smaller scale. Plate 40A is a geologic map of the overthrust block. It is in general a map of a once continuous sheet which now contains fensters where erosion has cut down to the highest of the major fault planes of the Pine Mountain overthrust and has exposed the underlying rocks. Three small areas of Maynardville limestone which belong to the overthrust sheet have been completely isolated from it by erosion and thus represent klippen. The Harris klippe and Low Hollow klippe (Pl. 2) near the northwest and southeast corners of the Chestnut Ridge fenster are cut off from the main overthrust sheet by narrow valleys. The Lemons klippe caps a high hill in the middle of Chestnut Ridge fenster. It consists of ribbon limestone of the Low Hollow limestone member of the Maynardville, which lies on brecciated Copper Ridge dolomite.

The Powell Valley anticline is in general a very regular fold. It is nearly flat on top throughout most of the fenster area and throughout the outcrop area of the Conasauga shale. The highest point structurally along the axis of the fold lies near the middle of the area of Conasauga shale in the western part of the district (Pl. 1). Near the western edge of the district the fold plunges steeply to the west, so that the outcrop of the Maynardville limestone crosses the axis as a comparatively narrow belt and the Copper Ridge dolomite lies at the crest of the fold. At the east side of the district the fold plunges northeast and the outcrop belts of the Maynardville limestone and Copper Ridge dolomite both cross the axis. Near the east edge of the district, however, dips are so flat that the Copper Ridge-Chepultepec contact is very irregular with inliers of the Copper Ridge and outliers of the Chepultepec near the contact.

On the north limb of the anticline the dips range from about 10° to 25°, gradually and rather uniformly increasing in amount away from the axis. On the southeast limb the amount of dip likewise increases away from the axis, slowly at first, then more rapidly as Wallen Ridge is approached. The steepest dips are in the rocks farthest from the axis and nearest the Wallen Valley fault, where they average about 35°.

Only a few minor structural features interrupt the symmetry of the Powell Valley anticline. They are chiefly of two types—steep reverse faults in the rocks directly above the Pine Mountain overthrust fault, and minor folds which are confined to the incompetent formations. The reverse faults are of the imbricate type and are directly connected with the Pine Mountain overthrust beneath (Pl. 40A). They trend about N. 71° E., and cross the axis of the Powell Valley anticline at a low angle. All those that have been seen in outcrop dip steeply to the southeast. The displacement along most of the fault planes is less than 100 feet, and the upthrown beds are invariably on the southeast side. The beds on both sides of the fault plane dip southeast and in most cases at similar or identical angles. As a result the faults are readily recognized only where the fault planes are exposed or where lithologically dissimilar rocks are brought into contact with one another. Without doubt many more of these reverse faults exist than have been mapped. Some, such as those well exposed in the road cut at the south end of the Martin Creek fenster, are too small to be mapped. Other reverse faults, especially in the area between Martin Creek and the Possum Hollow fenster were not mapped because their location could not be determined, although their existence is attested by the presence at the surface of southeastward dipping ribbon limestone of the Low Hollow member of the Maynardville for distances of as much as half a mile across the strike. More than a thousand feet of beds would have to be present if no faults existed in these poorly exposed areas, whereas in actuality the Low Hollow member of the Maynardville is only about 150 feet thick. An excellent section showing three of the mapped reverse faults in the Maynardville limestone is exposed along the Martin Creek road from Edds Mill south to its junction with the Dry Branch road.

The reverse faults are confined almost entirely to the outcrop areas of the Maynardville limestone of the central and eastern parts of the district (Pl. 1). Thus they are confined to the beds directly above the Pine Mountain overthrust fault. The stresses producing the faulting were dissipated upward by probable minor slipping along the bedding, and in consequence thereof the reverse faults are only developed in the competent beds for distances of from 20 to 200 feet above the overthrust fault. The presence of numerous parallel reverse faults in competent beds of the Cumberland overthrust sheet is thus almost a sure indication that the overthrust fault lies less than 200 feet beneath, and conversely the absence of reverse faults of this type in competent formations probably indicates a greater depth to the overthrust fault.

The minor folds of the Powell Valley anticline are restricted to two formations, the Conasauga shale and the Eggleston limestone. The Conasauga shale, which is extremely incompetent, is commonly warped or folded, with the result that the dips of the Conasauga beds in most places do not reflect the larger regional structure. The folds are in general rather gentle, but locally the beds are tightly squeezed and are broken by small faults. The green and red shales of the formation are the least competent, and the more competent interbeds of limestone in the shale have been fractured and recemented or broken and strung out as isolated limestone lenses. In a road cut east of the Brooks well, green shale between two parallel undeformed zones of limestone has been so thoroughly squeezed that all trace of the original bedding of the shale is lost (Fig. 4). Thin platy beds of limestone in the green shale have been intricately folded and also been moved bodily during the squeezing of the shale so that they now cut diagonally across the shale zone from top to bottom and look more like dikes than beds.

The Eggleston limestone is the other incompetent formation that has yielded readily under deforming stresses. Especially incompetent are the lower and upper members of the formation, which are composed principally of calcareous mudstone. Flowage of the mudstone in these members has in a number of places produced minor folds in the adjacent platy limestones of the middle member of the Eggleston, of the topmost part of the underlying Moccasin limestone, and of the basal part of the overlying Trenton limestone. Most of these folds occur in the southern belt of the Eggleston along the base of Wallen Ridge. Excellent examples are exposed along the road at the south side of Powell River one mile southwest of Parkey Bridge, on the spur on the south side of Powell River directly opposite Rob Camp Church, and at the base of the belt of Eggleston directly southeast of the Yeary-Overton footbridge.

CUMBERLAND MOUNTAIN MONOCLINE

The Cumberland Mountain monocline, which lies in part in the Rose Hill district, separates the gently dipping beds of the northwest limb of the Powell Valley anticline from the gently dipping beds of the southeast limb of the Middlesboro syncline. It is here considered as a separate structural feature rather than as a part of the adjoining anticline and syncline, because it is very prominent, and differs somewhat in origin from the adjoining folds (see p. 259). In the northwest part of the district the Powell Valley anticline is transitional into the Cumberland Mountain monocline by gradual increase in dip of the beds away from the axis of the anticline. The boundary between the two is clear-cut in the northeast part of the Rose Hill district along the line of the Rose Hill flexure described on page 218.

The Cumberland Mountain monocline is distinguished by a series of small parallel reverse faults, which have no counterparts elsewhere in the district. All the faults of this type that have been seen have steep northwesterly-dipping planes along which the upthrown beds are on the northwest side. Most of the faults have a displacement of about 20 to 50 feet, which normally results in the duplication of from 5 to 15 feet of beds. None of these faults has been shown on Plate 1, because their displacement is so small as to be negligible on the scale at which the mapping was done, and because the faults are recognizable only in good exposures and few can be followed.

Several of the reverse faults are excellently exposed in the Moccasin, Trenton and Reedsville formations along the railroad cut at Hagan (Pl. 13). A fault in the Hardy Creek member of the Moccasin limestone, which is typical of all the others, is shown diagrammatically in Figure 13, and a somewhat smaller fault appears in the photograph of the Moccasin-Eggleston contact (Pl. 22B). Slickensides on the face of the fault shown in Figure 13 indicate that the beds north of the fault moved eastward as well as upward along the fault plane. There is little doubt but that many of these reverse faults exist along the Cumberland Mountain monocline though only a few have been seen. All those known in the district are of small displacement, but a reverse fault of the same type with a displacement of several hundred feet is responsible for the twin-crested ridge of Cumberland Mountain at Falling Water Gap, 1¼ miles north of Rose Hill and just outside the district. Though small, these reverse faults have a special significance, for they show that deformation stresses existed at some time that tended to push rocks on the northwest above those on the southeast, whereas all the major overthrust movements of the region were toward the northwest.

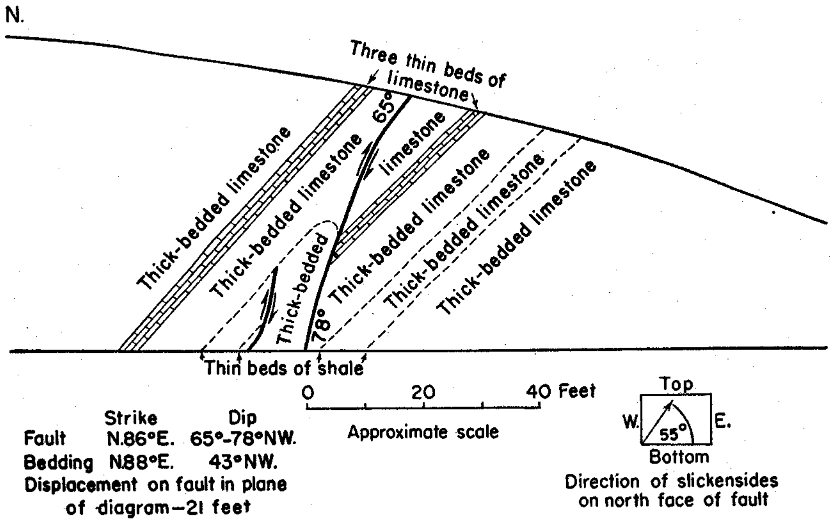


FIGURE 13.—Diagram of reverse fault in the Hardy Creek member of the Moccasin limestone in the Hagan railroad cut. Fault is typical of many reverse faults along the Cumberland Mountain monocline.

A more gently dipping reverse fault, also with the thrusting from the northwest, cuts the Devonian black shales (Brallier shale) near the mouth of the Louisville and Nashville Tunnel at Hagan (Pl. 36B). This seems to be only a special case of the type of reverse fault just described. Here the fault plane dips at a lower angle probably because the position of the fault plane was controlled by the zones of very incompetent shale. The displacement on this fault is unknown but may be large, especially as considerable crumpling and small-scale faulting are associated with the main fault.

The significance of the faulting within the Cumberland Mountain monocline is discussed in the section on interpretation of the regional structure.

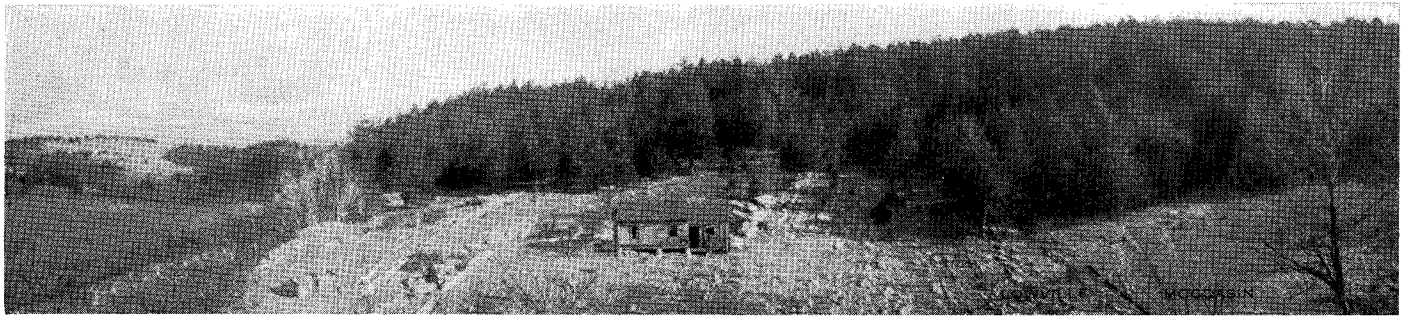
WALLEN VALLEY FAULT

The Wallen Valley fault borders the southeast side of the Powell Valley anticline. It was mapped for 5 miles along the southeast edge of the district; the state geologic maps of Virginia and Tennessee show it to be continuous for about 180 miles. In the Rose Hill district the Maynardville limestone or the Copper Ridge dolomite on the southeast have been thrust upward along the fault plane against the Clinch sandstone, the Clinton shale or basal beds of the Cayuga dolomite on the northwest. The stratigraphic displacement along the fault ranges from about 4900 to 5600 feet, but the movement along the fault is believed to be several times this amount. Only a few miles outside the district in either direction, the Silurian beds are entirely cut out by the fault and dolomites of the Knox group lie against Ordovician beds. Where this occurs, Wallen Ridge disappears or becomes much lower because of the absence of the resistant Clinch sandstone, which normally forms its crest.

The Wallen Valley fault plane is partly exposed near the road along Sulphur Hollow 0.4 mile east of the junction with the Mulberry Creek road. At this locality the fault plane dips 35° to the southeast. Fine-crystalline dolomite in the upper part of the Maynardville limestone above the fault overlies sandstone near the top of the Clinch below the fault. The beds above and below the fault are nearly parallel with the fault plane. At several other places where the position of the fault plane is approximately known, it seems to dip at about 30°, but in one locality it has a dip of only 17°. The nearly rectilinear trace of the fault across country, with only minor deviations due to topography indicates that the steeper dips are more representative of the general attitude of the fault plane.

STATIONARY BLOCK UNDERNEATH CUMBERLAND OVERTHRUST BLOCK

The stationary block is composed of rocks that lie beneath the Cumberland overthrust block and also beneath the fault slices enclosed by upper and lower fault planes of the Pine Mountain overthrust fault. Where the overriding block and the slices have



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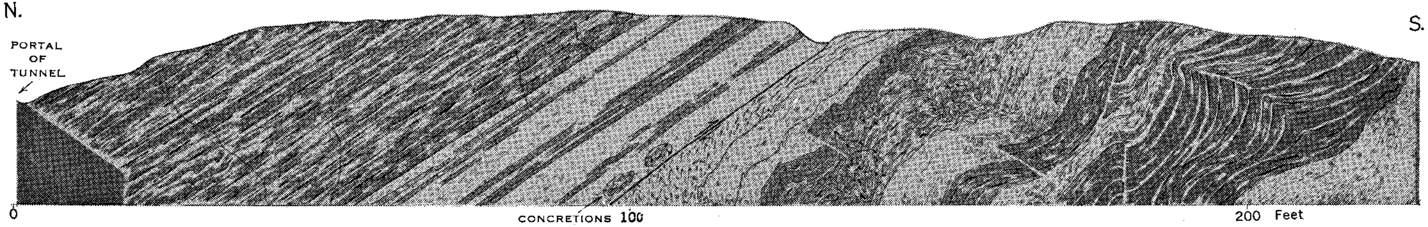
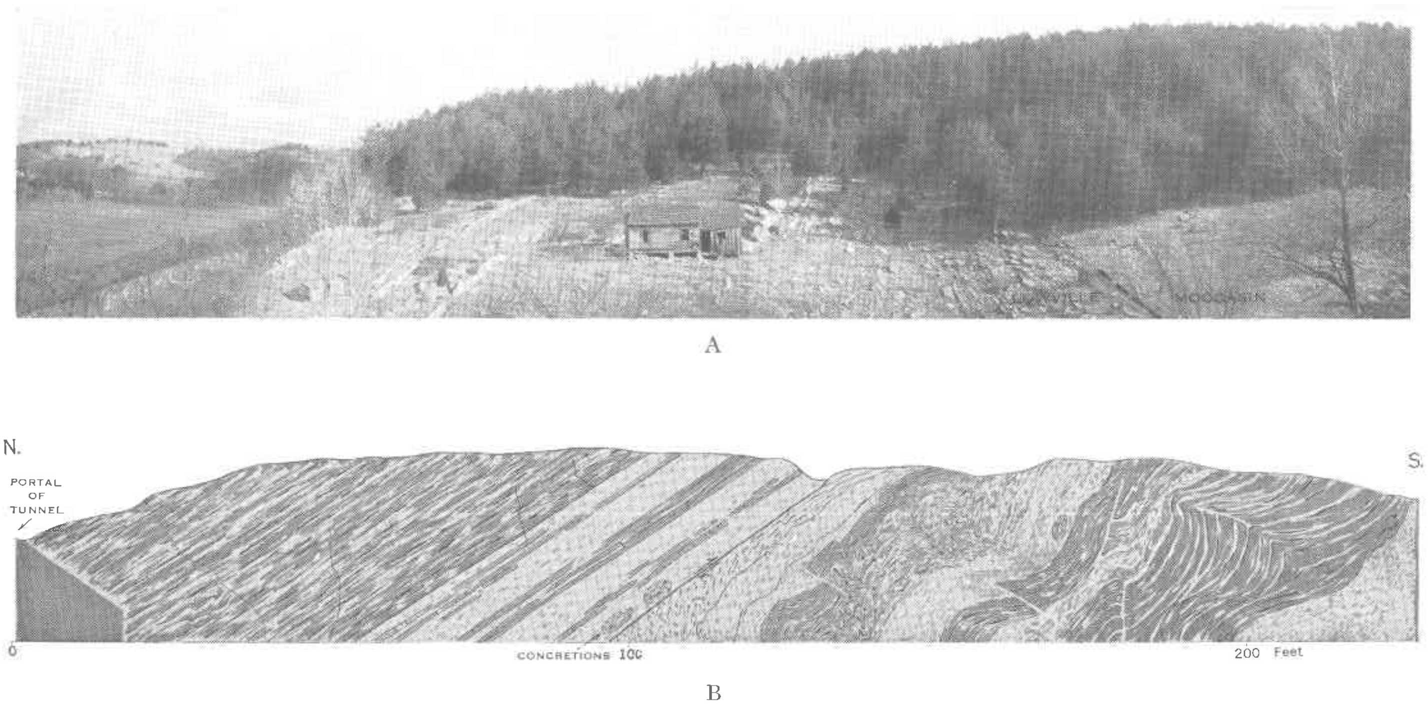
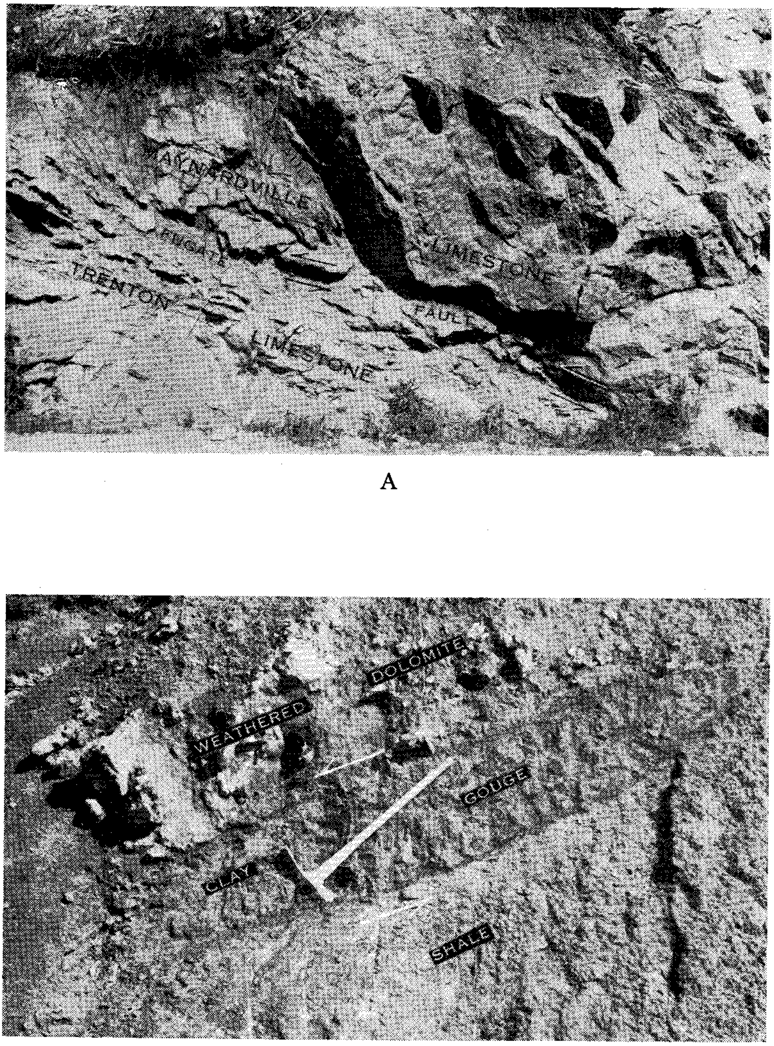


B

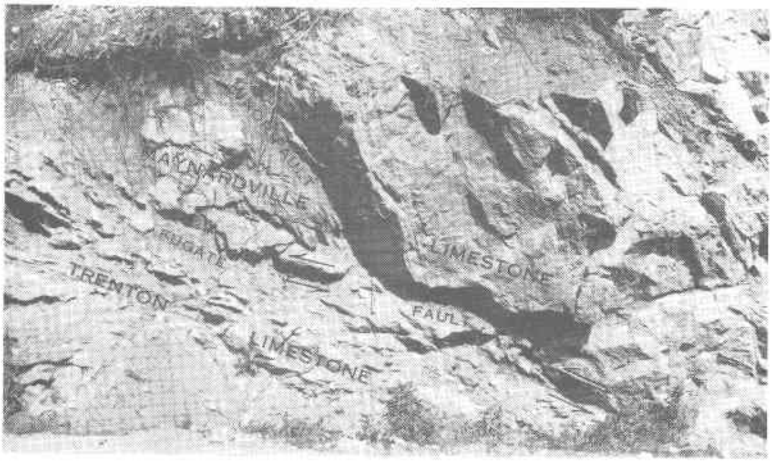
A, Panoramic view showing typical outcrops of the platy member of the Lowville limestone to left and in center, and of the lower part of the Moccasin limestone in right quarter of picture. B, Sketch of reverse fault in Brallier shale upthrust to the south. In cut at mouth of Hagan tunnel. By Ansel M. Miller.



A, Panoramic view showing typical outcrops of the platy member of the Lowville limestone to left and in center, and of the lower part of the Moccasin limestone in right quarter of picture. B, Sketch of reverse fault in Brallier shale upthrust to the south. In cut at mouth of Hagan tunnel. By Ansel M. Miller.



A, Fugate fault along the Fourmile Creek road at the south end of the Fourmile fenster. B, Fugate fault opposite Dean Store in the Dean fenster.



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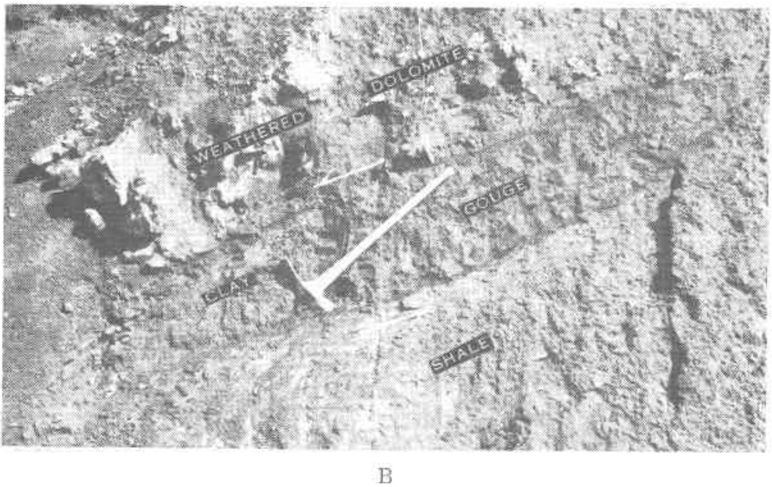


B

A, Fugate fault along the Fourmile Creek road at the south end of the Fourmile fenster. B, Fugate fault opposite Dean Store in the Dean fenster.

been eroded, the stationary block is exposed in a series of fensters, which are shown on Plates 1 and 2. The Pine Mountain overthrust fault exposed in the Rose Hill district appears to be continuous beneath the Middlesboro syncline and comes to the surface on the northwest side of Pine Mountain in Kentucky. Likewise, the rocks of the stationary block revealed in the fensters are believed to be continuous with the rocks northwest of Pine Mountain, without any major dislocations beneath the Cumberland Mountain monocline and Middlesboro syncline. These relations are shown in the structure section (Pl. 5B). The geology of the stationary block in the fenster area of the Rose Hill district is shown in Plate 40C as it would appear if the rocks of the Cumberland overthrust block and of the intermediate slices could be stripped away.

FUGATE FAULT

The Fugate fault, the lower branch of the Pine Mountain overthrust fault, partly encloses the Fourmile, Sugarcamp and Dean fensters (Pl. 2). In places around each of them, however, the plane of the Fugate fault merges with the plane of the Chestnut Ridge fault and the single overthrust plane beyond the junction has been mapped as the Pine Mountain fault. The Fugate fault is the only bounding fault for the small Brooks fenster and for the unnamed tiny fenster between Edds Hollow and Low Hollow. Along the Fugate fault the Fugate slice, which is described on p. 246, has moved in a northwest direction over the stationary block beneath. Even near the fault plane the limestones, shales and sandstones of the stationary block are very little disturbed as the result of the overthrusting, but the overlying dolomites of the Fugate slice are commonly highly brecciated.

The Fugate fault is excellently exposed in a road cut at the south edge of the Fourmile fenster, 1000 feet south of the Lemons No. 1 well. Here a sliver of Trenton rock has been broken from a concealed belt of Trenton limestone in the stationary block 0.2 mile to the southeast and has been dragged along the fault plane to the position of the present outcrop of the fault. As a result massive Maynardville limestone above the fault lies on thin-bedded Trenton limestone, as shown in the photograph (Pl. 37A), but a few dozen feet to the left of the photograph the Trenton rock of the fault sliver overlies gently dipping beds of the Sequatchie formation which is the top formation of the stationary block at this point. The steeply inclined surface in heavy shadow in the photograph represents a slip surface along which a small amount of movement has taken place within the Maynardville.

A second good exposure of the Fugate fault, quite different in appearance, is in a road cut almost opposite the Dean Store near the head of Low Hollow (Pl. 37B). At this point weathered, brecciated, cherty dolomite belonging to the undifferentiated Longview, Kingsport and Mascot dolomites overlies contorted thin-bedded shale of the Hagan member of the Clinch sandstone. A zone of clay gouge, about 17 inches thick, marks the fault plane, and appears in the photograph as a slightly darker and structureless belt inclining gently from the lower left to the upper right of the picture. In the middle of the picture the zone of clay gouge extends from the lower tip of the mattock blade to the upper tip of the handle.

Many near-exposures of the Fugate fault can be found in the woods around the margins of the fensters. The rocks close to the fault are surprisingly fresh and well exposed. Furthermore a contrast in resistance between heavy-bedded dolomites above the fault and weaker limestones or shales beneath has commonly resulted in undercutting of the resistant beds with resultant numerous outcrops just above the fault.

The Fugate fault plane can be exactly located at many places in the area and can be located within a few score feet at many other places. Enough data of this type are available so that it has been possible to draw a structure contour map of the fault plane (Pl. 38A). The line bounding the area of the Fugate fault on Plate 38A represents the junction of the upper and lower branches of the Pine Mountain overthrust and hence encloses the area of the Fugate slice. The location shown for this line of junction is based on control points around three sides of the Fugate slice, but on the southeast side where the overthrust rocks conceal both fault planes, the position of their line of junction is not known. In contouring the fault plane solid lines have been drawn for the areas where the fault lies beneath the surface and dashed lines for the areas where the rocks which formerly enclosed the fault have been eroded. The change from solid to dashed contours thus takes place at the outcrop of the fault plane. Only parts of the Fourmile, Dean and Sugarcamp fensters are shown because the remainder of these fensters are rimmed by the Pine Mountain fault.

The plane of the Fugate fault, as shown by the contours and in the profiles, is far from an even or flat surface. The 50-foot contour interval that has been used fails to bring out some of the abrupt changes in amount or direction of dip of the fault plane which may be seen in the field. Throughout most of the area the fault plane is gently dipping and its line of outcrop swings around the hills and the heads of the valleys. In several places, however, the fault line turns abruptly and cuts straight up a hill nearly at right angles to its usual course. Examples of this can be seen in the region of the fault sliver of Lowville limestone at the southeast corner of the Fourmile fenster (Pl. 2) and near the area of Mosheim limestone at the southeast corner of the Dean fenster.

Several lines of evidence, which will be discussed in the section on origin of the structural features, indicate that the Fugate fault has been deformed after the movement on the fault ceased but while movement on the upper or Chestnut Ridge branch of the overthrust was still going on. Hence, the fault surface, as it now exists, is much more undulatory than it was at the time of movement, although some of the irregularities are believed to have been initial.

WILSON FAULT

The Wilson fault encloses the Wilson fenster and is also exposed at the north end of the Martin Creek fenster (Pl. 2). Like the Fugate fault, the Wilson fault is the lower branch of the Pine Mountain overthrust fault. The limits of the area underlain by the Wilson fault are incompletely known; the fault may extend farther to the north than the map (Pl. 38A) indicates, before it merges with the upper branch (Chestnut Ridge fault) of the Pine Mountain overthrust fault.

The outcrop of the Wilson fault is somewhat obscure because in most places dolomite of the Chances Branch dolomite member of the Maynardville limestone (Cambrian) is thrust over Cayuga dolomite (Silurian) which is very similar in appearance to that of the Chances Branch. The fault is fairly well exposed, however, in the woods just above the road at the north end of the Martin Creek fenster and also in gullies on the north side of the Wilson fenster.

The Wilson fault plane slopes gently and rather evenly to the north as shown by the contour map of the fault plane (Pl. 38A). It is more regular than the Fugate fault plane. Evidence, which is discussed in the section on the Wilson slice, indicates that the main overthrust movement took place along the Wilson branch of the overthrust and that the upper or Chestnut Ridge fault plane was the subsidiary branch of the Pine Mountain overthrust in this area.

INNER FENSTERS

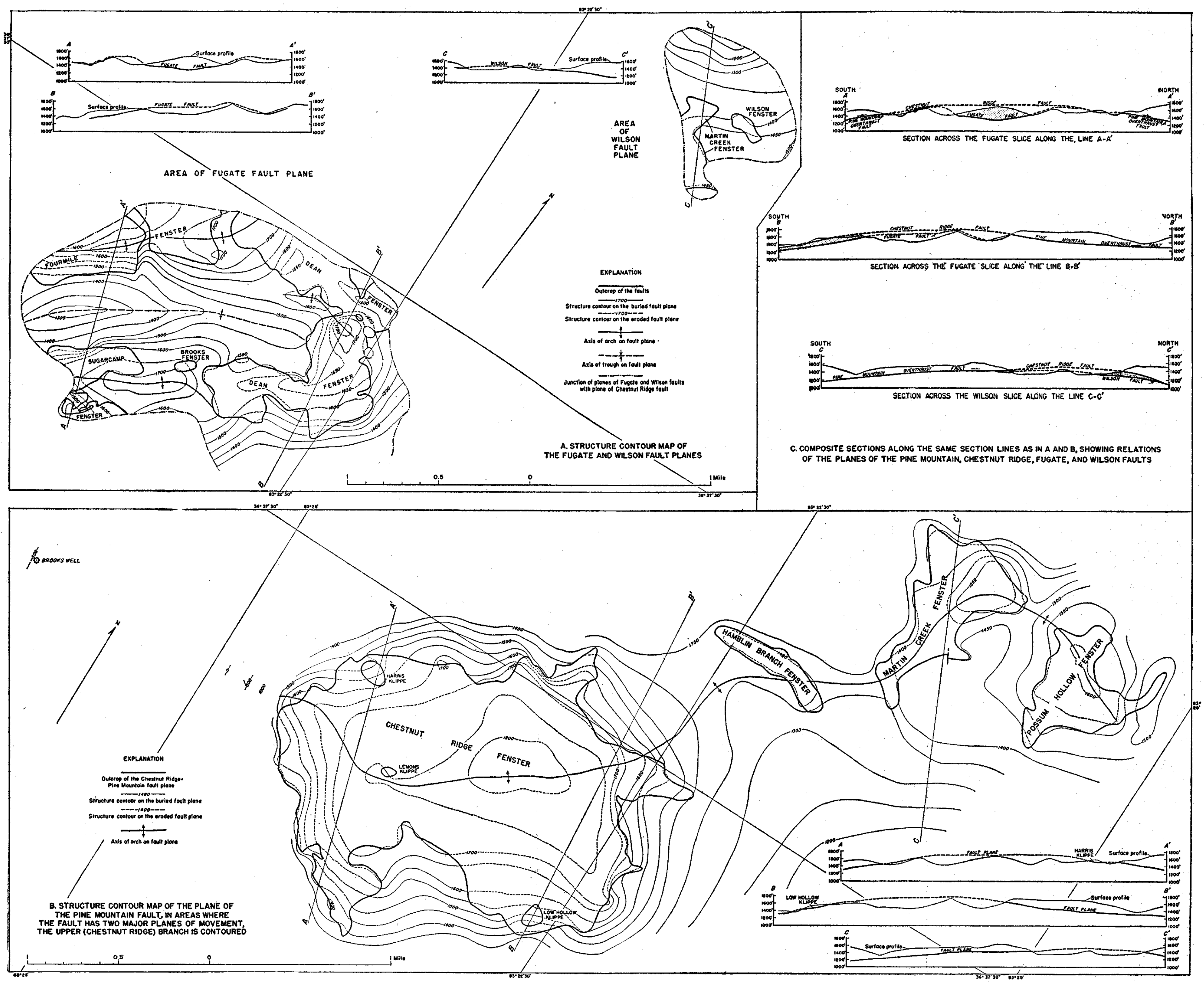
In the parts of the fenster area where two branches of the Pine Mountain overthrust fault are found, rocks of Ordovician or Silurian age in the stationary block are exposed beneath a fault slice consisting of older Ordovician and Cambrian beds. The bounding fault for the fensters or parts of fensters below such fault slices is the Fugate fault in the western part of the area and the Wilson fault in the eastern part. In the parts of the fenster area where there is a single plane of overthrusting, the Ordovician and Silurian rocks of the stationary block lie beneath Cambrian rocks of the overriding block. Many of the fensters are bounded around part of their periphery by the Fugate or Wilson fault and around the rest by the Pine Mountain fault. Fensters that are bounded by the Fugate or Wilson fault, and (or) by the Pine Mountain fault are called inner fensters. Those bounded wholly or partly by the Chestnut Ridge fault are called outer fensters. The inner fensters of the district are the Fourmile fenster, Sugarcamp fensters, Brooks fenster, Dean fenster, Hamblin Branch fenster, Inner Martin Creek fenster, Wilson fenster, Possum Hollow fenster, and a tiny unnamed fenster south of the Dean fenster.

FOURMILE FENSTER

The Fourmile fenster is the westernmost of the inner fensters. It lies 3 miles southeast of Ewing on the headwaters of Fourmile Creek, from which it is named. The overthrust relations are better shown in this fenster than in any other and its geologic interest is further enhanced by its being the site of the fifteen successful oil wells (Jan. 20, 1947) and also of the largest iron-ore mines.

The fenster is roughly rectangular in shape, about a mile long from northeast to southwest and half a mile wide. It is nearly cut in two, however, by a tongue of overthrust rocks that caps a long northwest-trending ridge. The narrow tongue of the Clinton shale which connects the two parts of the fenster is covered by stream alluvium and the Clinton does not crop out in the gap between the hills of Maynardville limestone on either side. The bottom of the valley in the gap is only a few feet below the overthrust plane.

The Fourmile fenster is bounded on its east and south sides by



Maps and structure sections of the principal planes of movement of the Pine Mountain overthrust fault.

the Fugate fault, the lower branch of the Pine Mountain overthrust, and on its west and north sides by the Pine Mountain overthrust. The junction of the two branches (Fugate and Chestnut Ridge faults) of the overthrust is not well exposed at the northeast or southwest edges of the fenster, but the relations can be seen clearly where the two faults come together on either side of the Harris klippe. South of the junction the Maynardville limestone of the overthrust sheet lies on the Longview, Kingsport, and Mascot dolomites of the Fugate slice, which in turn lies on the Clinton shale. North of the junction the Maynardville limestone lies directly on the Clinton shale. A view of the fenster showing ledges of the Maynardville limestone overlying the Clinton shale, which forms smooth cultivated slopes, is reproduced as Figure 14. The fault line in the sketch and in many other places around the fenster is almost exactly marked by the woodland line. The Maynardville limestone dips gently to the northwest and is little deformed except in a zone, 10 to 20 feet thick, immediately above the overthrust. The Longview, Kingsport and Mascot dolomites of the Fugate slice are much gnarled and brecciated for considerable distances above the Fugate fault plane, and even the Maynardville limestone of the Fugate slice at the southern end of the fenster is much more folded and faulted than it is where it overlies the Pine Mountain fault. The Maynardville limestone overlying the Fugate fault is well exposed, especially along the Fourmile Creek road where the photograph (Pl. 37A) of the Fugate fault was taken, but the Longview, Kingsport and Mascot dolomites have only scattered outcrops near the fault, though they do produce an abundant and unmistakable float of white, blocky chert.

Where the rim of the Fourmile fenster is formed by the Pine Mountain fault, its position is largely controlled by the topography. The outcrop of the fault swings up the valleys and around the ends of the hills, thus indicating a flat or gently inclined fault plane, which has only gradual changes of dip or direction. Along the southern rim of the fenster where the Fugate fault is the bounding fault, the fault trace runs in places along the base of the steep hill, as it does, for example, along the south side of the hollow in which the Lemons No. 1 well was drilled, but elsewhere it cuts nearly straight uphill, as for example, at the southeast corner of the fenster. South of the iron-ore mine hollow the fenster rim fault is peculiarly located on the crest of a ridge. Here the fault plane dips steeply to the south and underlies the rocks that form the south slope of the ridge.

Three fault slivers have been dragged along the plane of the overthrust and left in such positions that they now crop out along the edge of the Fourmile fenster. One sliver composed of Trenton limestone is exposed along the road between the Sequatchie formation below and the Maynardville limestone above (Pl. 37A). The second

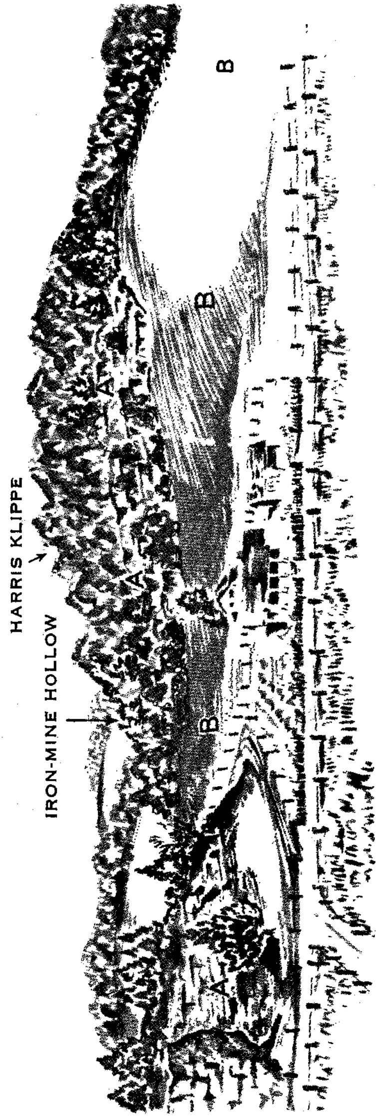


FIGURE 14.—Sketch of the north part of the Fourmile fenster looking east toward the Harris klippe. A, Maynardville limestone (Upper Cambrian). B, Clinton shale (Silurian). By Ansel M. Miller.

sliver is composed of Reedsville shale, and the third is of Lowville limestone. The source and significance of these slivers are discussed in a later section of the report.

The exposed formations of the stationary block in the Fourmile fenster are the Sequatchie formation, the Clinch sandstone, and the Clinton shale. Both the Hagan and Poor Valley Ridge members of the Clinch sandstone were mapped. The Sequatchie and the Clinton form basinlike lowlands surrounded on all sides by higher hills; but the Clinch sandstone is responsible for the long spur east of the Fugate oil wells and it also causes the narrowing of the valley of Fourmile Creek near the wells. Hence, the western part of the Fourmile fenster consists of two topographic basins separated by a ridge through which Fourmile Creek flows in a watergap.

The formations of the stationary block in the southern and central part of the fenster dip northward, gently at the south and more steeply in the central part. In the northern part of the fenster, however, small folds exist and dips are variable. The Clinton shale contains beds and lenses of hematitic iron ore which were worked extensively about 1907. Most of the iron pits lie in the hollow in the northeastern part of the fenster (Fig. 14) but two lie west of Fourmile Creek. In the hollow the mine pits are scattered over a broad area of the valley floor and the south wall of the valley. The exposures indicate that the general attitude of the iron-ore beds is nearly flat or slightly synclinal, though many small folds are present which cause the dips to vary greatly in amount and direction. Two beds of iron-ore were mined, which lie several feet apart near the base of the formation. The economic geology of these deposits is discussed in the section on iron ore.

SUGARCAMP FENSTERS

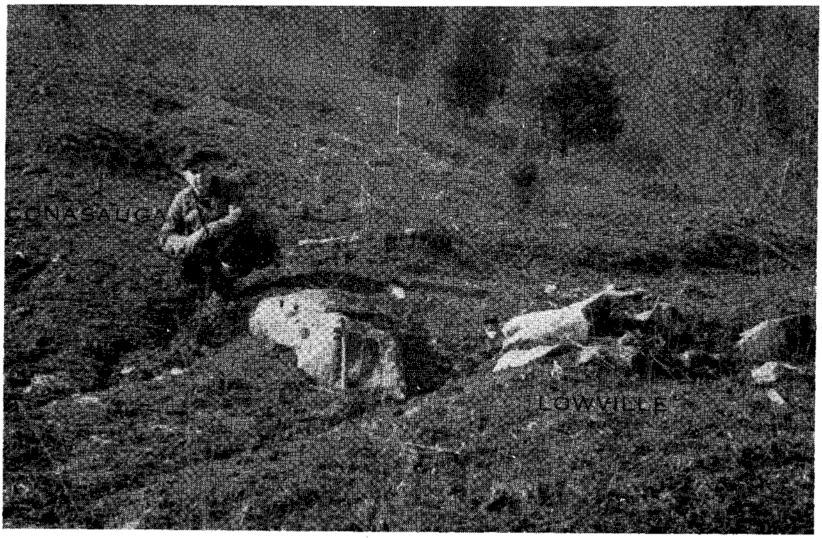
The Sugarcamp fensters are especially significant because they expose formations that are older and lie farther southeast than those in any other fenster of the Rose Hill district, and also because they reveal structural complexities that are not seen elsewhere in the district. The Sugarcamp fensters are a group of three fensters that are barely separated from one another by narrow bands of the overthrust rocks. The three form an integral whole, with closely related rocks and structural features. The name is taken from the deep sinkhole valley known as Sugarcamp Hollow in the southernmost fenster.

The Sugarcamp fensters lie almost entirely in woods, which are traversed by only a few lanes and trails. Erosion has barely breached the overthrust fault plane over a considerable part of the area of the fensters, and the development of the major features of the present topography has been controlled largely by the rocks above the overthrusts rather than by the exposed rocks of the stationary block.

The Fugate fault, below the Fugate slice, bounds the northern and eastern parts of the Sugarcamp fensters, and the Pine Mountain fault rims the fensters along most of their southern and southwestern sides. In most of the southeastern part of the fensters the rocks above the Pine Mountain fault are ribbon limestones of the Low Hollow member of the Maynardville limestone, but a narrow belt of the Conasauga shale lies between the fault and the Maynardville along the southern side of the fenster. An unusually interesting exposure along this part of the Pine Mountain fault is illustrated in Plate 39A. The hammer rests on a block of dolomite belonging to the Chances Branch member of the Maynardville, which has been dragged along the fault plane to its present position. The man crouches on weathered outcrops and soil of Conasauga shale above the fault and the outcropping ledges to the right of the picture are of lower Lowville limestone below the fault.

In the central and northern parts of the fensters where the Fugate fault is the bounding fault, the rocks of the Fugate slice above the fault consist primarily of fine-crystalline dolomites of the Chances Branch member of the Maynardville limestone. Along the northwest edge of the fenster, however, masses of Conasauga shale and of the Low Hollow limestone member of the Maynardville overlie the fault in places. Three long narrow bands of Chances Branch dolomite which form a part of the Fugate slice, stretch across areas of Lowville limestone within the fensters. Two of these bands are continuous from one side of the Lowville outcrop area to the other, but the third has a small gap in it. The two continuous bands of overthrust rocks of the Fugate slice divide the area underlain by rocks of the stationary block into three parts forming three separate but closely related fensters (Pl. 2, Section AA′). For convenience of reference these will be called the northern, central and southern Sugarcamp fensters.

The formations of the stationary block in the Sugarcamp fensters are the Murfreesboro, Mosheim, Lenoir, Lowville, Moccasin and Eggleston limestones. They are in general arranged in order with the oldest formations on the south and the youngest on the north, but



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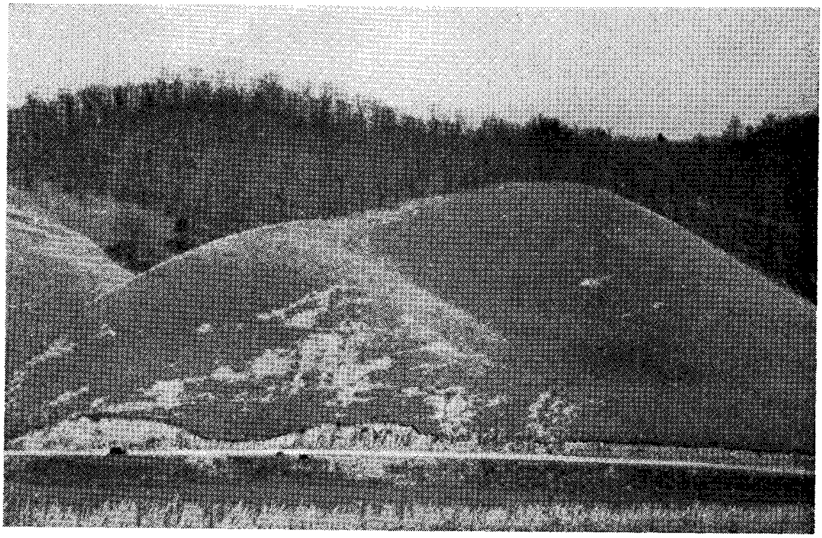
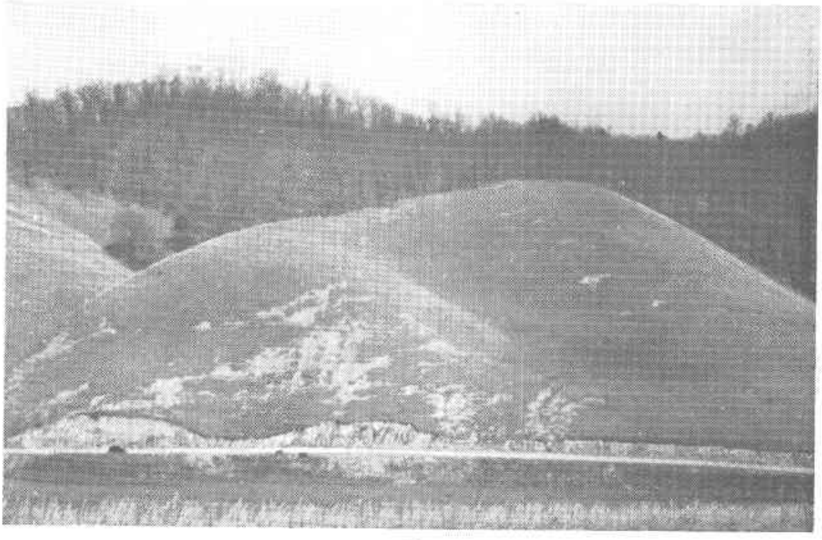


B

A, Block of dolomite of the Maynardville limestone behind the hammer, lying along the Pine Mountain fault between bedrock ledges of Lowville limestone to the right and Conasauga shale beneath the man. South rim of Sugarcamp fensters. B, View eastward across the Pine Mountain section of the Dean fenster at Low Hollow. The Fugate branch of the Pine Mountain overthrust follows the woodland line very closely.

A



B

A, Block of dolomite of the Maynardville limestone behind the hammer, lying along the Pine Mountain fault between bedrock ledges of Lowville limestone to the right and Conasauga shale beneath the man. South rim of Sugarcamp fensters. B, View eastward across the Pine Mountain section of the Dean fenster at Low Hollow. The Fugate branch of the Pine Mountain overthrust follows the woodland line very closely.

complications both of folding and of faulting disrupt the symmetry of this orderly arrangement, and make the internal structure quite complex. At the south side of the southern Sugarcamp fenster, the rocks consist of gently dipping Murfreesboro and Mosheim limestones, with a little Lenoir limestone preserved at one place just beneath the Pine Mountain fault. A gentle arching of these rocks combined with the effect of the topography causes the Murfreesboro to crop out in the bottom of Sugarcamp Hollow and the Mosheim to lie a short distance up the slopes on either side of the hollow.

In the southern half of the Sugarcamp fensters a thin slice of Lowville limestone originally belonging to the stationary block has moved a short distance northwestward with the overriding block. This slice is named the Sugarcamp slice and is shown by a pattern of gray closely spaced diagonal lines on Plate 2. The plane along which the movement occurred is named the Sugarcamp fault and is interpreted as a nearly flat overthrust, which represents the lowermost plane of slippage in the Pine Mountain fault zone. The Sugarcamp fault crops out at the crest of the spur in the northern Sugarcamp fenster, but the thin slice of Lowville limestone above the Sugarcamp fault has been breached by erosion in the southern Sugarcamp fenster, exposing the stationary rocks beneath the slice. Inasmuch as the small unnamed fenster thus formed lies within the southern Sugarcamp fenster, which in turn lies within the Chestnut Ridge fenster previously described, there is in this region a fenster within a fenster within a fenster. This set of compound fensters has been formed as the result of erosion through three different layers of overthrust rocks. These interpretations are shown in the Structure Section AA′ of Plate 2.

The Lowville rocks of the overthrust slice northwest of the innermost fenster dip steeply to the northwest or are overturned so that they dip southeast because of frictional drag along the Sugarcamp fault plane close beneath. In general, however, the beds lie in fairly regular order, with younger beds cropping out northward up the hill. Near the crest of the spur a small fault within the upper Lowville is probably connected downward with the Sugarcamp fault, which lies close beneath. Where the Sugarcamp fault comes to the surface at the crest of the spur upper Lowville limestone above the fault lies on the Hardy Creek member [upper member] of the Moccasin limestone below the fault. One anomalous small oval area of the Lowville and Moccasin limestones 500 feet farther north (Pl. 2) is probably an isolated remnant or klippe of the Sugarcamp fault slice.

The Moccasin limestone in the northern Sugarcamp fenster has been folded into an asymmetric anticline. Along the axis of the anticline buff-weathering argillaceous limestones of the lower Moccasin crop out, and on the gentle south flank and steep north flank of the anticline, the chert-bearing platy and siliceous limestones of the Hardy Creek member of the Moccasin are at the surface. The Eggleston limestone in normal position above the Hardy Creek, forms a belt along the northwest edge of the fenster. The lower and middle members of the Eggleston are excellently exposed along the ravine near the west end of the belt, and the chert bed beneath the lower big bentonite (R7) is prominent in a few places.

DEAN FENSTER

The Dean fenster takes its name from Dean School and Dean Store, both of which are near the edge of the fenster. It is the largest of the inner fensters, spreading out in a rough horseshoe shape over parts of four valleys, and including some moderately high ridges which separate the valleys. The valleys are Blackberry Hollow, Dry Branch Hollow, Low Hollow, and Edds Hollow. The ridges are unnamed.

At the northeast, the Dean fenster is barely separated from the Fourmile fenster by a divide, which is capped by undifferentiated Longview, Kingsport and Mascot dolomites of Lower Ordovician age. One may stand on the divide near Dean School and look down into the Blackberry Hollow section of Dean fenster which has been eroded on Clinton shale of Silurian age, then walk 100 feet westward and look down into the iron-mine hollow of Fourmile fenster, also eroded on Clinton shale. The continuation of the Clinton rocks underneath the dolomite along the divide is emphasized by the presence of iron mines, which worked nearly identical Clinton ore beds in the fensters on opposite sides of the divide. A panoramic view taken from this divide looking down into the Blackberry Hollow part of the Dean fenster is shown in Plate 7A.

Around most of its margin the Dean fenster is bounded by the Fugate fault. Rocks of the Fugate slice thus overlie the formations of the stationary block exposed in the fenster. Along the northern and northeastern sides of the fenster, however, only one plane of overthrusting, the Pine Mountain fault, is present and rocks of the overthrust block, principally Maynardville limestone, lie directly on the formations within the fenster.

The merging of the Fugate and Chestnut Ridge fault planes to form the Pine Mountain fault is exposed on the steep slopes north of Dean school. It can also be seen on the northeast side of Low Hollow, where the fault relations are very complex (Pl. 42) and on the northwest side of Dry Branch (Pl. 34B). The Fugate fault is excellently exposed near Dean Store in the road cut which was previously described (Pl. 37B). The Pine Mountain fault is well exposed in the woods at a number of places and has an unusually fine exposure at the northern tip of the fenster along a trail that winds past a house up a small ravine on the east side of Blackberry Hollow. At this place ribbon limestone of the Low Hollow member of the Maynardville (Cambrian) lies directly on Cayuga dolomite (Silurian) with no gouge and little weathering along the contact.

In most places the margin of the Dean fenster is clearly marked by the contrast between abundant outcropping ledges of massive dolomite or limestone above the overthrust fault and smooth slopes with only small outcrops of shale or thin-bedded limestone below the fault. Because of this contrast in character of outcrop, the areas of overthrust rocks are almost all wooded and the fenster areas are largely cultivated or are in pasture. This is well illustrated in the photograph (Pl. 39B) which was taken looking northeastward across Low Hollow. The smooth slopes in the foreground are of Reedsville shale and Trenton limestone within the fenster. The bounding fault follows the woodland line almost exactly, and abundant ledges of massive dolomite and limestone crop out in the woods above the fault.

Two areas of unusual complexity are present on the rim of the Dean fenster. In the area on the northeast side of Low Hollow, mentioned above, slices of numerous formations in fault relations with one another lie between the rocks of the stationary block and the Maynardville limestone of the overthrust block. The geology in this vicinity is shown on Plate 42 and is described in detail in the section on the Fugate slice. In the other complex area which is near the north tip of Blackberry Hollow, the plane of the Pine Mountain overthrust fault is very irregular, and along it are exposed four slivers of the Trenton and Eggleston limestones.

The formations of the stationary block inside the fenster are arranged in orderly sequence from the Trenton limestone in Low Hollow to the Cayuga dolomite in Blackberry Hollow. The Clinch sandstone, here as in Fourmile fenster, forms a prominent though short ridge. The high point of this ridge at 1750 feet gives the minimum elevation for the former position of the overthrust fault plane in this part of the fenster. The dips within the fenster are nearly flat in the area of Trenton limestone in Low Hollow, but they steepen abruptly along a line of flexure near the Trenton-Reedsville contact. The dips are more or less uniformly to the northwest at angles of 10° to 25° in the belts of the Reedsville, Sequatchie, and Clinch formations, but the Clinton shale dips at low angles in various directions. In Blackberry Hollow a gentle dome with a nearly east-west axis is suggested by outward dips of the Clinton shale from the center of the hollow, and by a line of iron mines and small, unmapped prospect holes which swings around the south, east, and northeast sides of the hollow.

In Edds Hollow nearly the whole of the Trenton limestone is present in an orderly sequence of steep northward-dipping beds extending from the contact with the Reedsville shale to a point near the center of the fenster. Here an anticlinal axis is crossed, south of which the beds dip steeply to the south. About 200 feet south of the anticlinal axis, an overthrust fault is encountered along which overturned beds of Trenton limestone have been thrust northward over the steeply-dipping but upright Trenton limestone of the south limb of the anticline. This is believed to be the same overthrust fault that is exposed in the Sugarcamp fensters and that was there named the Sugarcamp fault (p. 233). Its presumed location beneath the overthrust rocks separating the Dean and Sugarcamp fensters is shown on the map of the stationary block (Pl. 40C). From the Sugarcamp fault on southward, all the exposed beds of the stationary block in Edds Hollow are overturned, and because of this the Eggleston limestone overlies the Trenton limestone near the south edge of the fenster.

An unnamed fenster only 200 feet in longest dimension lies just south of the Dean fenster in Edds Hollow. It is due largely to the formation of a deep sinkhole at this point. The fenster is surrounded by Chepultepec dolomite and contains a few outcropping ledges of Trenton limestone in the sinkhole.

BROOKS FENSTER

The Brooks fenster lies between the Sugarcamp and Dean fensters near the Brooks cemetery, from which it takes its name. It is about 650 feet long and 300 feet wide. It has no distinctive topographic expression and the outcrops by which its limits are defined are scattered and inconspicuous. It is bounded by the Fugate fault above which are dolomites of the Copper Ridge dolomite and the Chances Branch member of the Maynardville limestone. The Trenton limestone, the only exposed formation of the stationary block, is best revealed in the bottom of the sinkhole at the northeast end of the fenster, but a few small outcrops and a little float in the fields to the southwest show that the Trenton is also present on the hillslope above the sinkhole.

HAMBLIN BRANCH FENSTER

The Hamblin Branch fenster lies at the bottom of the steep-walled valley of Hamblin Branch, a tributary of Martin Creek, about midway between the Dean and the Martin Creek fensters. Hamblin Branch has a flat floodplain, which is somewhat wider within the fenster than it is upstream or downstream. The fenster is bounded around its entire periphery by the Pine Mountain fault, along which ribbon limestone of the Low Hollow member of the Maynardville limestone has been overthrust upon the rocks of the stationary block inside the fenster. On the valley walls above the floodplain outcrops are fairly numerous so that the position of the Pine Mountain fault is well marked except where it is buried beneath alluvium at either end of the fenster. Around most of the fenster the fault trace lies about 30 or 40 feet above the valley floor.

Shale and platy sandstone near the top of the Clinton shale are the predominant bedrock formation of the stationary block inside the fenster. The dips are variable in direction but all are at low angles and the general attitude is that of nearly flat-lying beds. Around the east end of the fenster the lower part of the Cayuga dolomite normally overlies the Clinton shale directly beneath the fault. The basal sandy beds of the Cayuga are conspicuous and are overlain by limestone containing *Coenites,* the most abundant and characteristic fossil of the Cayuga. Only a few beds of dolomite, which make up the middle and upper parts of the Cayuga, are preserved above the limestone and beneath the fault. At the northeast side of the fenster a sliver of an Ordovician limestone lies along the fault between the Cayuga dolomite below and the Maynardville limestone above. In its western and middle parts the sliver seems to be made up almost entirely of limestone belonging in the upper part of the Trenton. At the eastern end of the sliver, however, shale is interbedded with the limestone, and a *Rafinesquina* collected from these beds was identified as *Rafinesquina fracta,* a species characteristic of the Reedsville shale in the Rose Hill district. The interbedded shale and limestone, therefore, probably belong in the Reedsville shale, and are in normal contact with the Trenton limestone in the western part of the sliver. This fault sliver, which is 1600 feet long and in places 40 feet thick, is the longest and largest one associated with the overthrust faults around any of the inner fensters. An excellent section across the fault sliver is exposed in a gully just below the road at the east end of the Hamblin Branch fenster. It shows shale and sandstone of the Clinton, sandstone and limestone of the Cayuga, and limestone and shale of the Reedsville exposed in that order as the gully is ascended; big ledges of Maynardville limestone occur just across the road from the top of the gully.

INNER MARTIN CREEK FENSTER

The Inner Martin Creek fenster, very similar in many respects to the Hamblin Branch fenster, lies along the bottom of the valley of Martin Creek. The overthrust fault bounding it does not rise more than a few score feet above the flat valley floor (Pl. 2). Because the valley floor is covered with alluvium, bedrock in the valley is exposed only in a few places in the stream channel. Both here and at Hamblin Branch the overthrust fault plane is very nearly flat. With only a little more downcutting of the valleys it is easy to picture the Hamblin Branch and Martin Creek fensters being extended downstream until they join at Edds Mill, forming a single long V-shaped fenster.

The geology of the Inner Martin Creek fenster is unusually simple and clear except near its northern end. In the central and southern parts of the fenster the Pine Mountain fault forms the boundary of the fenster, above which are ribbon limestones of the lower part of the Maynardville limestone. These beds are broken by numerous reverse faults, too small to map, which cause the limestone in most places to dip southeast. Except for these small faults the Maynardville is little disturbed and the ribbon banding of the limestone is clear and distinct only a few feet above the fault plane. The Pine Mountain fault plane is excellently exposed along the road at the south end of the fenster and is shown in the photograph (Pl. 41A). Massive beds of Maynardville limestone, above the hammer in the photograph, overlie somewhat broken and contorted beds of Cayuga dolomite, but with no gouge and very little brecciation at the contact. A few score feet to the left of the photograph a small cave has been formed in the limestone just above the fault, but the fault plane just misses being exposed in the cave. Along the road to the right of the photograph several small reverse faults in the Maynardville are excellently exhibited.

Around the northern end of the Martin Creek fenster the Pine Mountain overthrust had two major planes of movement. The lower of these is the Wilson fault named from its exposure around the Wilson fenster in Wilson Hollow, and the upper is the Chestnut Ridge fault. The area bounded by the Pine Mountain and Wilson faults encloses the Inner Martin Creek fenster, whereas the area bounded by the Pine Mountain and Chestnut Ridge faults encloses the Outer Martin Creek fenster. The Outer Martin Creek fenster, described on page 249, includes the Inner Martin Creek fenster, the Wilson fenster and the exposed rocks of the Wilson slice (Pl. 1). The line of junction between the Wilson and Chestnut Ridge faults is fairly well exposed on the east side of the inner fenster, but on the west side its location is imperfectly known because it cuts across cultivated fields in which there are almost no outcrops.

Along the Wilson fault bounding the north end of the fenster, dolomite of the Chances Branch member of the Maynardville limestone has been thrust over Cayuga dolomite. The two dolomites are very similar, but may be distinguished from each other in most places. Locally, however, they are so nearly identical that the position of the Wilson fault is recognized with the greatest difficulty, as at the locality, previously cited, along the west bank of Martin Creek at the north end of the fenster.

The rocks of the stationary block within the Martin Creek fenster are Cayuga dolomite and the upper part of the Clinton shale. Although there are in places low undulatory folds, the general attitude of the beds is horizontal. This is especially well shown by the belt of the Cayuga dolomite which is at nearly the same elevation around the entire fenster. The overthrust fault lies from 10 to 50 feet above the base of the Cayuga, except at one spot where it cuts down into the Clinton shale for a very short distance.

The Clinton shale which underlies the flat valley floor is nonresistant and has few outcrops, but more massive sandstones at the top of the Clinton crop out on the valley walls just below the ledges of the Cayuga dolomite. The contact between the two formations is well shown along the road near the south end of the fenster (Pl. 27B).

WILSON FENSTER

The Wilson fenster, which is separated from the Inner Martin Creek fenster by a belt of overthrust rocks about 400 feet wide (Pl. 2), lies in the bottom of Wilson Hollow where the downcutting stream has breached the Wilson fault and exposed the Cayuga dolomite and a very small area of fine-grained platy sandstone beds at the top of the Clinton shale. The rocks overlying the Wilson fault are part of the Wilson slice and are considerably faulted and contorted. They consist dominantly of dolomite of the Chances Branch dolomite member of the Maynardville, but limestone of the Low Hollow limestone member of the formation is also present around the rim of the fenster. The Low Hollow limestone member was not mapped separately because its extent is very small, and the faults that bring it into contact with the Chances Branch dolomite member are also small.

Within the fenster the Cayuga dolomite is the principal rock exposed. The Wilson fault transacts the formation diagonally, for there are 69 feet of Cayuga dolomite beneath the fault on the south side of the fenster and only 18 feet on the north side. Along the Wilson fault on both sides of the fenster there are from 1 to 5 feet of black carbonaceous shale lying above the Cayuga dolomite and below the Maynardville limestone. These beds are believed to be Brallier shale of Upper Devonian age, because no carbonaceous shale occurs anywhere in formations older than the Brallier and because in the Rose Hill district the Brallier is the next formation above the Cayuga dolomite of Silurian age. The two belts of Brallier are much too narrow to be shown on the scale of the fenster map (Pl. 2).

POSSUM HOLLOW FENSTER

In 1923, Charles Butts visited Possum Hollow to examine a reported occurrence of oil in that region. He immediately recognized the overthrust relations in Possum Hollow, and he described both the fenster and the oil occurrence within it in a press release of the U. S. Geological Survey.[214] The other three fensters that

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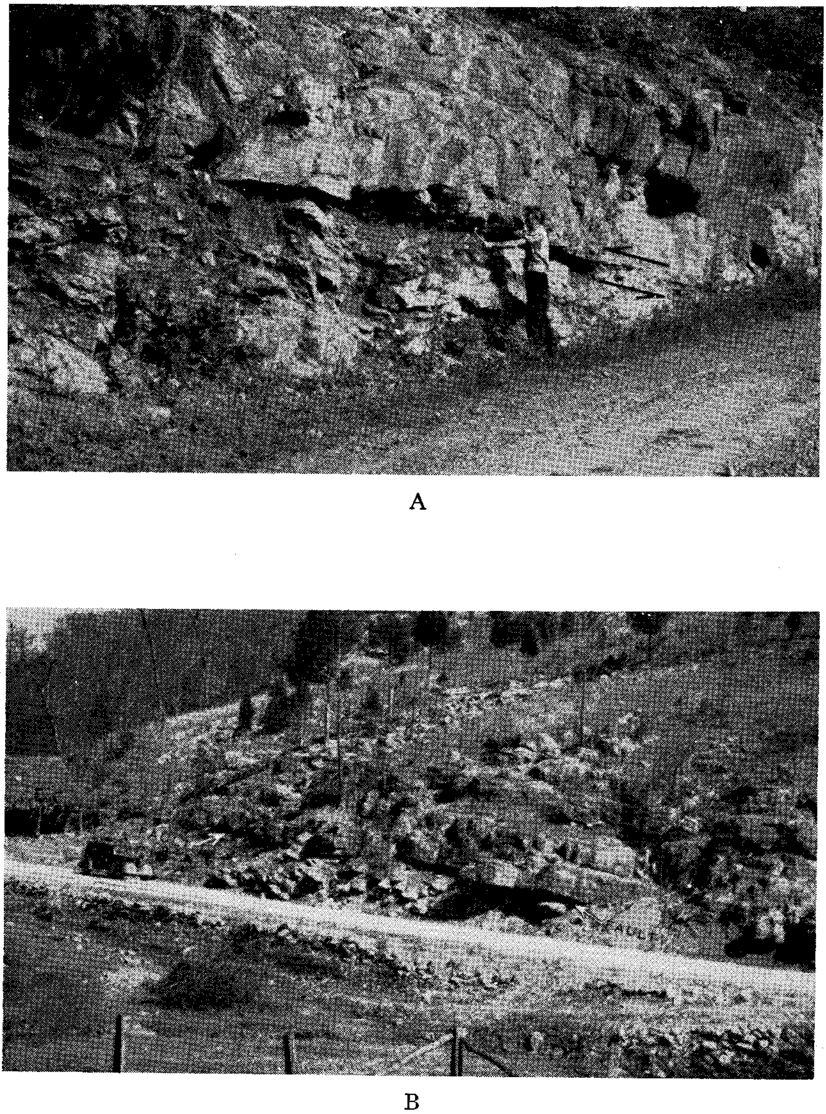
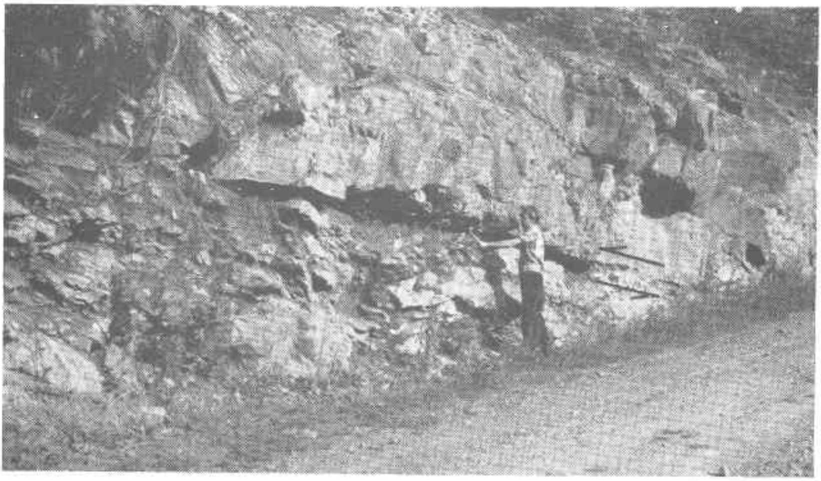
[214] Butts, Charles, Oil in Lee County, Virginia: U. S. Dept. of Interior, Geol. Survey, Press Release, 3 pp., July 3, 1923.



A, Pine Mountain overthrust fault at the south end of the Martin Creek fenster. B, Chestnut Ridge fault along the Low Hollow road south of the Dean fenster.



A

B

A, Pine Mountain overthrust fault at the south end of the Martin Creek fenster. B, Chestnut Ridge fault along the Low Hollow road south of the Dean fenster.

were known up to the time of the present investigation were discovered by Butts several years later. Although a few oil shows and a little production have been reported from wells in Possum Hollow the total production as the result of drilling eight wells in this fenster has probably not exceeded 200 barrels. The locations of the wells are shown on Plate 2.

The Possum Hollow fenster lies in an amphitheaterlike valley, roughly triangular in shape, which is partly bisected by a spur of the enclosing upland (Pl. 2). Steep walls rise on all sides of the fenster except at the outlet of the valley. The trace of the Pine Mountain overthrust lies about halfway up these slopes around most of the fenster. The Maynardville limestone, which overlies the fault, crops out as heavy ledges in a few places, but around much of the fenster outcrops of the overthrust rocks are few and small. In this respect the Possum Hollow fenster differs from the other fensters, which are largely surrounded by prominent ledges of the overthrust rocks. Within the Possum Hollow fenster the Cayuga dolomite and the upper part of the Clinton shale are the only formations exposed. Prominent outcrops are confined to the areas of the Cayuga dolomite, but float and small outcrops of the Clinton shale are visible on most of the slopes, especially those that have been gullied.

In the Possum Hollow region the overthrusting has been confined to one plane of movement, the Pine Mountain fault. Several springs lie along the fault plane, because the limestone and dolomite above the fault plane are very pervious owing to the formation of solution channels whereas the Clinton shale beneath the fault is very impervious.

Around much of the fenster, ribbon or mottled limestone of the Low Hollow member of the Maynardville limestone overlies the fault, but in the northeast tip of the fenster and in several other places the fault cuts higher, so that fine-crystalline dolomite of the Chances Branch member of the Maynardville is there in contact with the rocks below the fault. Where dolomite of the Chances Branch member lies on the Cayuga dolomite below the fault, some difficulty is encountered in distinguishing the two, but nowhere in Possum Hollow is the location of the fault as obscure as it is under similar circumstances in the Martin Creek fenster.

The beds within the fenster are undulatory, with all the measured dips less than 30°. In general, the rocks of the Clinton shale dip outward from the general region of the spur on which the

Holcomb well was drilled (Pl. 2). This rather obscure dome in the rocks of the stationary block is made more apparent by the appearance of Cayuga dolomite in the eastern and southern tips of the Possum Hollow fenster and in the Wilson fenster at lower elevations than the Clinton rocks on the spur in the Possum Hollow fenster. Whether the structure is closed on the north, thus making a complete dome, is not known, for the rocks of the stationary block are entirely concealed beneath the overthrust rocks in this direction.

COMPOSITE GEOLOGIC PATTERN OF THE STATIONARY BLOCK

The rocks of the stationary block can be seen through the fensters in so many places that the overall pattern of the block can be pieced together for the immediate region in which the fensters occur. Beyond the fensters the only source of reliable data on the geology beneath the overthrust is from deep drilling. There has as yet been too little drilling outside the fenster area to furnish a basis for extending the geologic mapping of the stationary block much beyond the fenster area.

Using the information gained from the fensters a map has been drawn (Pl. 40C), showing the geology of the stationary block as it would appear if all the overthrust rocks were stripped away. The known geology within the fensters is shown in solid lines and the interpretation of the geology beneath the covered areas is represented by dashed lines. The somewhat anomalous appearance of the eastern part of the map results from the fact that the rather thin but extensive layer of nearly flat-lying Cayuga dolomite directly beneath the overthrust has been eroded in parts of the Hamblin Branch, Martin Creek, Wilson, and Possum Hollow fensters. If there had been no erosion of rocks of the stationary block the Cayuga dolomite would have been shown covering the entire Martin Creek and Wilson fensters and the eastern third of the Hamblin Branch fenster. In the western half of Plate 40C, the beds in general dip to the north. They are steepest in the Trenton belt; they stand at moderate angles in the belts of the Reedsville, Sequatchie and Clinch formations; and their dips become gentle and variable in direction in the Clinton and Cayuga belts. In the southwestern part of the map the anticline that was mapped in the Moccasin limestone in the Sugarcamp fensters is probably continuous with the anticline in the Trenton rocks in the Dean fenster. If this interpretation is correct the anticline plunges eastward. In both fensters the south limb of the anticline is largely concealed beneath rocks that have been thrust westward along the Sugarcamp fault plane. As previously described this fault encloses a fenster of its own, where the thin slice of rocks above it has been eroded in the southern Sugarcamp fenster. Just south of this there is a gentle dome (Pl. 40C) in the Murfreesboro, Mosheim and Lenoir limestones. Most of the dome has been delineated from evidence in the southern Sugarcamp fenster, but its southern closure is hypothetical.

Evidence of a theoretical nature, which will be discussed later, suggests that to the north of the area shown in Plate 40C the top formation of the stationary block continues to be the Cayuga dolomite or the upper part of the Clinton shale, with perhaps a little Brallier shale in places directly beneath the fault plane. To the south older and older formations down to the Maynardville limestone are believed to abut beneath the fault plane. From the behavior of the rocks exposed in the fensters, one may surmise that these belts of older rocks are not much folded or faulted, and that they also dip to the north. These interpretations have controlled the representation of the concealed parts of the stationary block in the structure sections of Plate 2.

THE FAULT SLICES AND THE OUTER FENSTERS

CHESTNUT RIDGE-PINE MOUNTAIN FAULT PLANE

The two faults, Fugate and Wilson faults, that form the lower branches of the Pine Mountain overthrust fault have already been described. The corresponding upper branch of this overthrust fault is the Chestnut Ridge fault.

The composite sections of Plate 38C show the relation of the Pine Mountain fault plane to its two branches. The structure contour map of the Chestnut Ridge fault plane (Pl. 38B) has been extended to include the Pine Mountain fault in areas where overthrusting was along only one plane of movement. A much greater regularity is immediately apparent in the Chestnut Ridge-Pine Mountain fault surface than in the Fugate fault. In the eastern part of the fenster area the Chestnut Ridge-Pine Mountain fault plane dips gently to the northwest and southeast from an anticlinal axis which is sinuous and which passes through the three eastern fensters. In the western half of the area the fault surface is arched up to form a symmetrical dome, which is nearly flat on top and which has steep dips on all sides. In this same region the underlying Fugate fault plane (Pl. 38A) was folded into a series of anticlines and synclines.

The only place where the Chestnut Ridge-Pine Mountain fault surface has abrupt changes of amount or direction of dip is on the northwest side of Blackberry Hollow (Pl. 2). Here on the crest of a spur the Pine Mountain fault plane changes abruptly from a nearly horizontal attitude to one of steep inclination and as abruptly changes back again at an elevation about 150 feet lower. A prominent zone of brecciation does continue horizontally into the area of Copper Ridge dolomite of the overthrust sheet at the top of this monoclinal fold in the fault surface. The zone becomes very indistinct to the northeast, however, and it may not actually rejoin the main fault at the tip of the Dean fenster as has been suggested on the map (Pl. 2). The Maynardville-Copper Ridge contact, which crosses this brecciated zone, is displaced very little if at all, so that the zone cannot be considered the upper or Chestnut Ridge branch of the Pine Mountain overthrust. At this locality the Pine Mountain fault has only one plane of major displacement which gradually cuts upward from the base of the Maynardville limestone into the Copper Ridge dolomite of the overthrust sheet and abruptly cuts back downward again. Movement along this sinous fault plane was less free than normal, as is shown clearly by the zone of intense brecciation mentioned above, and by the presence of four different fault slivers of the Trenton and Eggleston limestones.

Although the Chestnut Ridge fault is in many places closely delimited by outcrops, the actual fault contact is exposed at only a few places. One of the best of these exposures is along the Low Hollow road and is shown in Plate 41B. In the photograph the fault plane lies just beneath the prominent ledge which inclines gently from above the automobile almost to road level at the right hand edge of the picture. Ribbon limestone near the base of the Low Hollow member of the Maynardville limestone, above the fault, lies on somewhat brecciated and contorted ledges of dolomite of the Chances Branch member of the Maynardville. The dolomite of the Chances Branch makes up only a thin fault sliver along the fault plane, however, and nearly vertical beds of the undifferentiated Longview, Kingsport, and Mascot dolomites crop out in the left foreground of the picture. Faint slickensides on the under surface of the overhanging ledge in the picture seemed to strike N. 22° E. This is about 50° from the

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AND DEVELOPMENT
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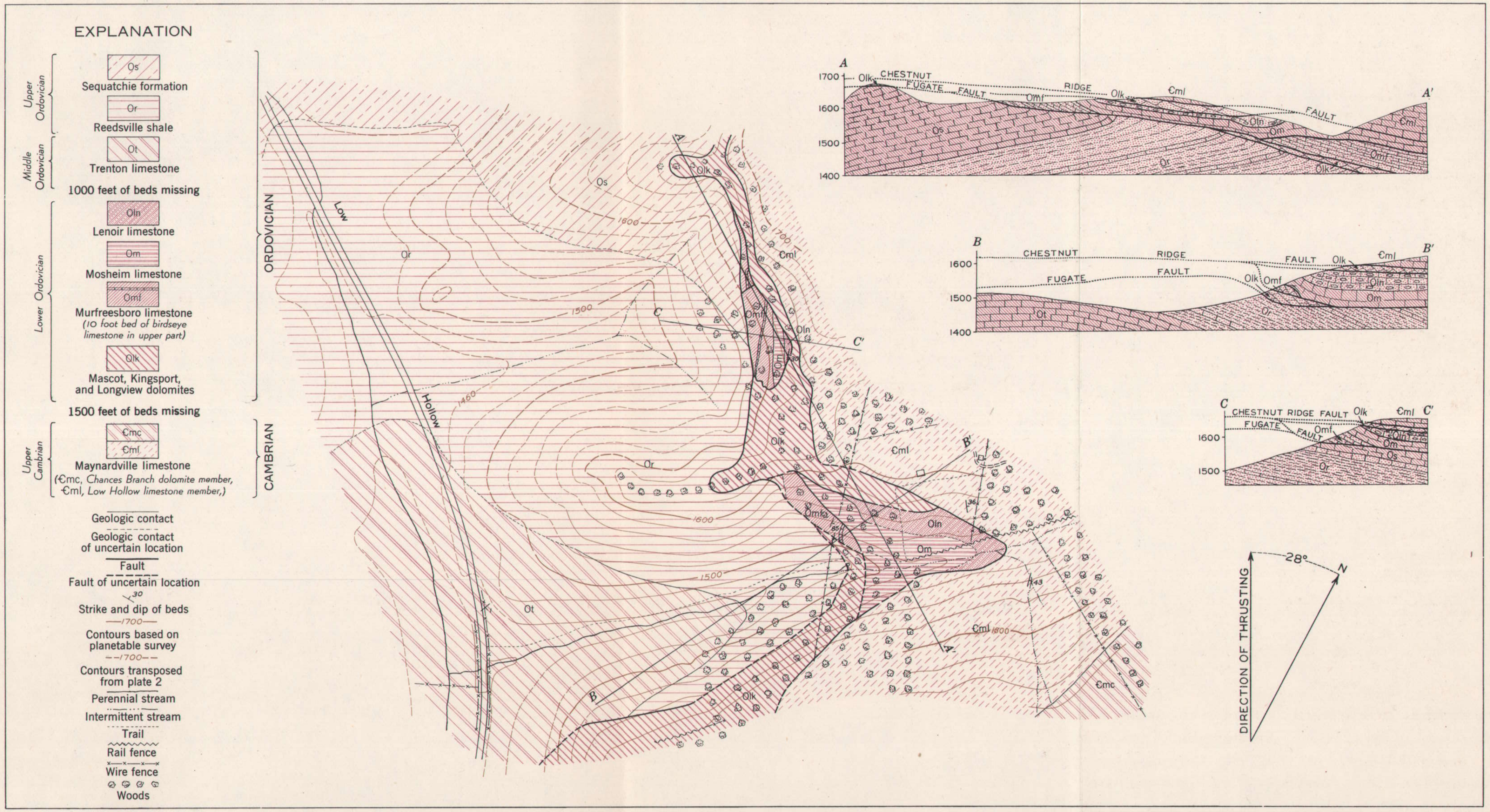
GEOLOGICAL SURVEY
U. S. DEPARTMENT OF INTERIOR

BULLETIN 71 PLATE 42



PLANE-TABLE MAP AND SECTIONS OF THE FUGATE SLICE ALONG THE SOUTHEAST EDGE OF THE DEAN FENSTER

100 0 100 500 1000 Feet

Contour interval 20 feet
Datum is mean sea level

direction of movement of the overthrust masses that has been deduced from the regional geological relations. Some local condition, probably involving rotation of the sliver of the Chances Branch dolomite beneath the fault, has caused the final relative movement along the fault plane at this point to be in a direction quite at variance with the general direction of regional overthrusting.

Throughout the whole fenster area the rocks immediately overlying the Chestnut Ridge-Pine Mountain fault plane are almost everywhere ribbon limestones near the base of the Maynardville limestone. This is apparent in the western part of Plate 2, where the Low Hollow limestone and Chances Branch dolomite members of the Maynardville have been mapped separately. It is also true in the eastern part of the region where the Maynardville has not been subdivided. The overthrust plane rather consistently developed at or near the contact between the Maynardville limestone and the Conasauga shale, and thus lies between two formations that have a great contrast in competency. The Conasauga shale undoubtedly also served as a lubricant to facilitate movement along the fault plane in the early stages of overthrusting. Later when the Maynardville limestone at the base of the overriding block was being shoved across formations other than the Conasauga, the fault plane was already so regular and smooth that movement continued easily and the rocks of the overthrust sheet were little contorted during movement.

In a few places the Chestnut Ridge-Pine Mountain fault plane cuts upward into dolomites of the Chances Branch member of the Maynardville limestone or still higher into the Copper Ridge dolomite. This is true east of the Low Hollow klippe and also at the north end of the Martin Creek fenster. These dolomites, which are more brittle than the Low Hollow limestone, are commonly much more brecciated near the fault plane. In the Bales quarry along Martin Creek, shown in the photograph (Pl. 43A), the Chestnut Ridge fault is both overlain and underlain by brittle dolomites. Massive beds of dark-colored somewhat brecciated lower Copper Ridge dolomite above the fault lie on a highly brecciated, contorted and faulted mass of intermingled Chances Branch dolomite and Copper Ridge dolomite below the fault. In the photograph the overlying beds have been thrust from left to right.

CHESTNUT RIDGE FENSTER

In the western part of the fenster area, the outcrop of the Chestnut Ridge-Pine Mountain fault plane encloses a large area in which rocks of all formations from the Maynardville to the Clinton are exposed by erosion of the overthrust sheet. This large fenster, the Chestnut Ridge fenster, encloses the inner fensters, which lie in the western part of the area (Fourmile, Sugarcamp, Brooks, and Dean fensters), and it also encloses the exposed parts of the Fugate slice. The interrelations of these elements is best seen in Plate 1, where the geology of the fenster area has been generalized.

Where only one plane of overthrusting, the Pine Mountain fault, exists, the Chestnut Ridge fenster has a common border with the inner fensters it encloses. This is true along the north and west sides of the Fourmile fenster, around the southern end and parts of the western sides of the Sugarcamp fensters, and around parts of the northern and eastern sides of the Dean fenster. In these areas the rocks beneath the bounding fault, Pine Mountain fault, are the Ordovician and Silurian formations of the inner fensters. Elsewhere the borders of inner and outer fensters are separate and the rocks below the bounding Chestnut Ridge fault belong to the Fugate slice and consist mainly of the Maynardville limestone and the dolomitic formations of the Knox group. The Chestnut Ridge fenster also encloses three klippen of the overthrust sheet, namely the Harris, Lemons and Low Hollow klippen which have been described previously in the section on the overthrust block.

FUGATE SLICE

The Fugate slice, which lies between the Chestnut Ridge and Fugate faults, is made up of rocks that have been thrust over the formations of the inner fensters and have in turn been overridden by the rocks of the overthrust block. In Plate 40B the exposed rocks of the Fugate slice are shown, together with the known or inferred limits of the slice. The edge of the slice is quite accurately known except along the south side where it is completely concealed by the overthrust block. The slice thickens and thins, due principally to the undulations in the Fugate fault surface beneath it. This is shown in the composite sections AA′ and BB′ of Plate 38C, which were constructed by superimposing the corresponding sections showing the Fugate fault (Pl. 38A) and the Chestnut Ridge-Pine Mountain fault (Pl. 38B). The slice ranges from a few feet thick near its edges to nearly 400 feet thick in its thickest part.

In the area exposed within the Chestnut Ridge fenster, the Fugate slice is made up of roughly parallel belts of Maynardville limestone and of the formations of the Knox group. These belts are commonly in fault contact with one another except near the southeastern corner of the Chestnut Ridge fenster. The two members of the Maynardville limestone have not been mapped separately in most of the Fugate slice because the Maynardville is too much faulted and exposures are too few to make it practicable.

Complex structures characterize the Fugate slice and make it very easy to distinguish rocks belonging to the slice from those of the overthrust block above it, although the same formation may be present above and below the fault that separates them. The rocks of the slice are commonly steeply dipping, and are gnarled, brecciated and sheared for a considerable distance away from the overthrust, whereas the rocks of the overthrust block are nearly flat-lying and are deformed only within a zone a few feet thick above the overthrust fault plane. The steep dips alone are in most places enough to distinguish rocks belonging to the Fugate slice, for in very few places do rocks of either the overthrust block or of the stationary block dip more than 30°.

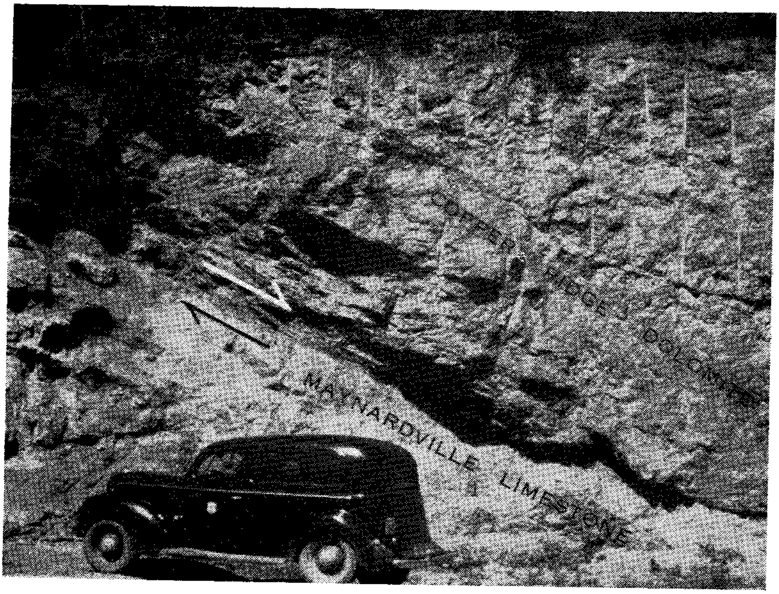
In a small quarry just north of Dean School and also in the Bales quarry shown in Plate 43A, intense brecciation of dolomite of the Fugate slice is beautifully exhibited. In both quarries the exposed brecciated rocks lie close below the Chestnut Ridge fault plane but brecciation of dolomites of the slice is in places known to extend several score feet away from the major fault planes. Flowage of rocks of the Fugate slice, under the stresses to which the slice was subjected, is confined largely to the limestones and hence to the areas of lower Maynardville. Flowage combined with faulting of Maynardville limestone can be seen in the quarry along the Fourmile road a few dozen feet south of the southern end of the Fourmile fenster.

Because of a scarcity of outcrops in much of the Fugate slice, the dolomitic formations of the Knox group are distinguished from one another with extreme difficulty. The problem is further complicated by a plethora of faults, of which only the most important have been shown on Plate 2. Within the Fugate slice most of the major faults are low-angle faults which have been upthrust on the southeast. The largest of them is the Lemons fault, which cuts from northeast to southwest across the central part of the Chestnut Ridge fenster. Along it the Copper Ridge dolomite on the southeast has been thrust northwestward over the undifferentiated Longview, Kingsport and Mascot dolomites. The fault is known to pass downward and join the Fugate fault below because a small sliver of Lowville limestone

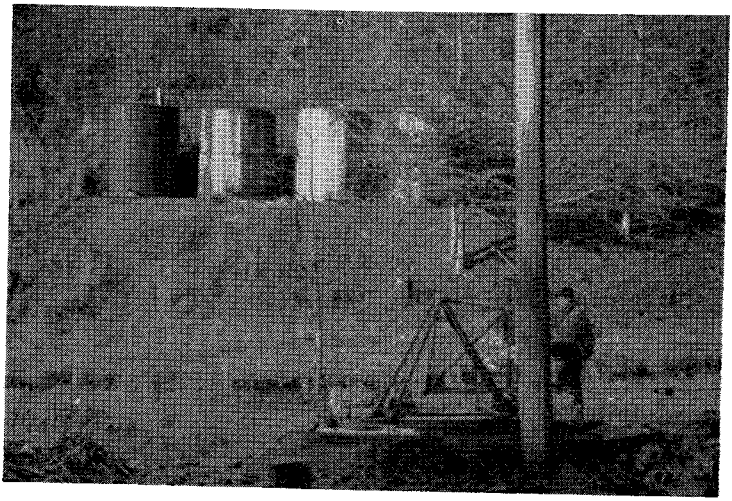
(Pl. 2) has been left along the Lemons fault and it could only have reached this position by having been dragged along the Fugate fault plane and then upwards along the Lemons fault plane.

On the west, north, and south sides of the Brooks fenster, the Low Hollow limestone and Chances Branch dolomite members of the Maynardville and the lower member of the Copper Ridge dolomite are intimately faulted together. Since the Fugate slice in this region is only 20 to 50 feet thick, it is not surprising that it should be much shattered and faulted. A coherent interpretation of these faults is difficult, however, because the faults are not exposed but have had to be inferred from the pattern of the rock outcrops combined with evidence given by the dip of the beds where this could be deciphered. The faults on opposite sides of the area of Copper Ridge dolomite that surrounds the Brooks fenster join eastward and seem to represent the same fault plane. Hence, the fault appears to be a flat overthrust, along which an area of the limestone and dolomite of the Maynardville has been thrust over the Copper Ridge dolomite. The interpretation of the other mapped faults that cut the Fugate slice is shown by the symbols that have been placed along the faults on Plate 2.

The most complex part of the Fugate slice is along the east edge of the Dean fenster in Low Hollow. Here a long thin belt of much faulted limestone and dolomite of the Lenoir, Mosheim, Murfreesboro limestones and the Mascot dolomite lies between rocks of the stationary block and of the overthrust block. A planetable map (Pl. 42) was made of this area in order to work out the relations of the fault slices to one another. It is particularly interesting to note in the sections of Plate 42 that fault slivers of the Longview, Kingsport and Mascot dolomites both underlie and overlie the sliver of Murfreesboro, Mosheim and Lenoir limestones. The lower sliver of dolomite must first have been dragged forward beneath the overthrust block and left in its present position. Later the sliver of the limestones was slid forward over it, and still later the top sliver of dolomite moved forward with the overriding block and was left behind on top of the limestone slice. The triangular wedge of the Longview, Kingsport and Mascot dolomites in normal contact with Murfreesboro limestone and in fault contact with the projection of dolomite near the center of the map is an integral part of the limestone sliver. The dolomites in the fault slivers were originally derived from sources farther to the southeast than the limestones, but all the rocks of these slivers were probably faulted from the top of the stationary block at the same time, and carried forward as part of the large relatively coherent



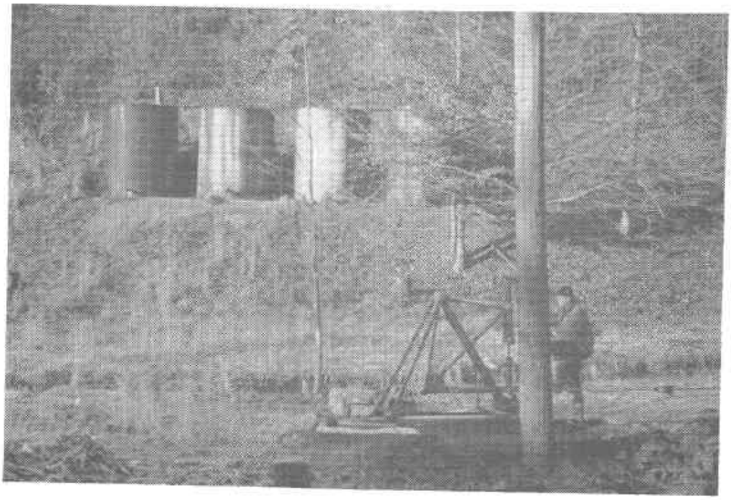
A



B

A, Chestnut Ridge fault in the Bales Quarry. B, Pump and storage tanks at B. C. Fugate No. 1 well.

A



B

A, Chestnut Ridge fault in the Bales Quarry. B, Pump and storage tanks at B. C. Fugate No. 1 well.

Fugate slice. After the Fugate slice moved to its probable present position subsequent overriding by the overthrust block sheared thin slivers from it and slid and rotated them farther forward.

On the south side of Dry Branch another small sliver of Mosheim limestone (shown on Plate 2) lies along the overthrust fault about 200 yards north of the area shown in Plate 42. It was almost surely a part of the larger limestone sliver in Low Hollow, which was torn loose and dragged a little farther along the fault before it finally stopped.

OUTER MARTIN CREEK FENSTER

The Outer Martin Creek fenster is bounded in part by the Pine Mountain fault plane and in part by the Chestnut Ridge branch of the Pine Mountain fault. In the southern part of the fenster the Pine Mountain fault forms the common border of the Outer and Inner Martin Creek fensters. Farther north, however, the outcrop of the Chestnut Ridge fault encloses not only the northern part of the Inner Martin Creek fenster, but also the Wilson fenster and the exposed rocks of the Wilson slice (Pl. 1). The Outer Martin Creek fenster needs no special description as the inner fensters it encloses have previously been described and the part of the Wilson slice exposed within it is described in the succeeding section.

WILSON SLICE

The Wilson slice includes the rocks in the eastern part of the fenster area that lie between the Chestnut Ridge fault above and the Wilson fault below. The exposed part of the slice surrounds the Wilson fenster and partly encloses the north end of the Inner Martin Creek fenster. Much of the Wilson slice is concealed beneath the overthrust block and the presumed original size and shape of the slice shown on the map (Pl. 40B) may be considerably in error. In its exposed part the Wilson slice averages about 150 feet in thickness (Pl. 38C, Section CC′).

Dolomite of the Chances Branch member of the Maynardville limestone makes up most of the Wilson slice but a little limestone of the Low Hollow member, which has not been mapped separately, is faulted in with the Chances Branch dolomite, and some Copper Ridge dolomite is also included. In most of the slice the rocks are complexly faulted and in many places they are very highly brecciated.

This is especially true of the rocks within 20 to 50 feet of the Chestnut Ridge fault (Pl. 43A).

Throughout most of the forward movement of the overthrust the rocks of the Wilson slice were a part of the overthrust block. Shortly before the end of thrusting, the Wilson slice broke loose and stopped as the overthrust mass moved forward. The forward movement of the overthrust block, after the separation of the Wilson slice from it, was not great, probably not more than a few thousand feet. The stresses developed during the overriding of the slice by the overthrust block were, however, great enough to produce the faulting and the brecciation visible in the rocks of the slice. The gouge left in the base of the overthrust block by the breaking off of this slice of Maynardville limestone and lowest Copper Ridge dolomite from it is partly visible at the north end of the Outer Martin Creek fenster, where beds above the base of the Copper Ridge dolomite overlie the Chestnut Ridge fault. As the fault is followed southward around the rim of the fenster gradually it cuts downward to its normal position near the base of the Maynardville limestone.

BROOKS SLICE

In the Brooks well, which is located in the area of Conasauga shale in the western part of the district, the drill penetrated the Pine Mountain overthrust at a depth of 1920 feet and passed from shale of the Rome formation (Cambrian) into Clinton shale (Silurian) (Pl. 1, Section CC′). At 2002 feet, however, the drill crossed another fault, going from Clinton shale into Cayuga dolomite. From that point downward all formations were in order and a complete section of Clinton shale was drilled in its normal position beneath the Cayuga dolomite. The 82 feet of Clinton, lying between shale of the Rome formation above, and Cayuga dolomite below, seems to represent a fault slice similar to those previously described. It is here named the Brooks slice. No idea of the horizontal dimensions of the Brooks slice can be gained at present as the Brooks well is the only well in this vicinity that has yet crossed the overthrust.

Judging from the behavior of the formations exposed in the fensters two miles to the east, the dips in the stationary block at the Brooks well are probably also to the northwest. The Clinton shale should therefore lie directly beneath a single Pine Mountain overthrust fault plane a short distance southeast of the Brooks well. If this interpretation is correct, the rocks of the Brooks slice, which include some Cayuga dolomite, must have broken loose from the top of the stationary block only a short distance to the southeast, probably less than a mile.

FAULT SLIVERS

In contrast with the fault slices, already described, there are numerous much smaller masses of rock that are also in fault contact on all sides with the enclosing formations. Almost all of these masses are made up of rocks of one formation that have moved as a unit during overthrusting and consequently have no internal structures of mappable size. These smaller fault masses are termed fault slivers.

The fault slivers are of two types: (1) those that have been broken from the stationary block, have been dragged forward as the overthrust block moved ahead, and have come to rest at some position along the fault plane northwest of their starting point, and (2) those that were originally part of the overthrust block or of one of the fault slices but have broken loose from the base of the overriding mass and been left behind. These latter now lie southeast of the rocks from which the sliver was broken although they are of course northwest of their original source before overthrusting. Fault slivers of the two types will be discussed separately.

Slivers from the stationary block.—Twelve slivers derived from the stationary block are exposed in the Rose Hill district, all but one of which lie along the rims of the inner fensters. Eleven of the twelve slivers are in the western half of the fenster area. This is expectable because the greater complexity of the faulting and the irregularities of the major fault planes in this region would have favored formation of fault slivers. In the eastern half of the area where the Pine Mountain fault plane is nearly flat and where almost undeformed rocks above the fault overrode almost undeformed rocks below, the only exposed fault sliver is the one on the north side of the Hamblin Branch fenster.

The present location and presumed original source of the fault slivers derived from the stationary blocks is shown in Plate 44. They have been carried forward distances ranging from about 0.2 mile to 1.7 miles. Trenton limestone makes up five of the slivers but the Reedsville, Eggleston, Lowville, Lenoir, Mosheim and Murfreesboro formations are also represented in various of the slivers. The three slivers of Murfreesboro, Lenoir and (or) Mosheim on the southeast side of the Dean fenster may not have come to their present position as isolated masses, but were probably broken from a concealed part of the Fugate slice (p. 248). They would thus have traveled as isolated slivers a much shorter distance than indicated, but the figures on Plate 44 represent the present distance of the slivers from the original source of the rocks.

Most of the slivers are exposed along outcrops of the faults for only a few hundred feet. Inasmuch as the slivers are seen in inclined or nearly vertical cross-section, and as most of each sliver is concealed or has been eroded, little idea of the original shape of the slivers can be gained from field studies. It seems logical that they should be fairly regular in shape, however, because highly irregular masses would probably not be broken from the stationary block, and if some were, various projecting parts would probably become separated from the main sliver in the course of being dragged along the overthrust. All the slivers are thin, and most of them have an average thickness of 10 to 20 feet between the top and bottom faults.

The only sliver derived from the stationary block that does not lie along the rim of an inner fenster is the small mass of Lowville limestone along the Lemons fault, which was mentioned in the discussion of the Fugate slice. When the Fugate slice was ruptured by the Lemons fault, this sliver had already been formed and had moved forward with the overlying Fugate slice along the Fugate fault plane. It was then carried forward together with the rocks above it, this time along the Lemons fault plane, and was left in its present position almost midway between the Fugate and Chestnut Ridge branches of the Pine Mountain overthrust.

A small fault sliver of dolomite of the lower Murfreesboro limestone and uppermost Mascot dolomite, not shown on Plate 44, lies on the undifferentiated Longview, Kingsport and Mascot dolomites of the Fugate slice 0.6 mile due east of Dean School (Pl. 2). This sliver seems not to have been derived directly from the stationary block, but rather from the faulted complex of rocks that is partly exposed on the east side of the Dean fenster in Low Hollow (Pl. 42). It thus represents a sliver from the trailing edge of the Fugate slice that has been dragged almost half a mile farther along the Chestnut Ridge fault plane and has been left on top of the main part of the Fugate slice.

Slivers from the overthrust masses.—Slivers that have broken from the base of masses of overriding rocks and have been left behind are associated with the Pine Mountain fault and with both of its branches, the Fugate and Chestnut Ridge faults. Those that have broken from the underside of the Fugate slice are difficult to recognize because the dolomites of the Fugate slice are so commonly faulted and brecciated near the Fugate fault that the significance of one or two additional faults enclosing a small slice is apt to be overlooked. Examples of slivers from the Fugate slice that have been recognized include: (1) the small isolated block of dolomite of the Maynardville limestone on the south side of the Sugarcamp fensters, pictured in Plate 39A. This block now lies along the Pine Mountain fault between Conasauga shale and Lowville limestone, but has almost certainly broken loose from the base of the Fugate slice which now lies a short distance to the northwest; (2) the small area of Maynardville limestone on the south edge of the Dean fenster in the bottom of Edds Hollow. This area seems to be isolated and to have broken loose from the larger area of Maynardville, part of which is now exposed on the opposite edge of the fenster 2000 feet to the north.

Slivers that have broken loose from the underside of the main overthrust block are more easily recognized. This is because the lowest rocks of the overthrust block are almost everywhere ribbon limestones near the base of the Maynardville limestone; hence small isolated areas of ribbon limestone of the Maynardville lying on top of other formations are almost sure to be fault slivers from the overthrust block. The ribbon limestone of the Maynardville is not very susceptible to small-scale faulting and brecciation, so that exposed faults enclosing a sliver of this rock are quite easily recognized.

The best example of one of these slivers is the area of Maynardville limestone that lies along the Chestnut Ridge fault in Low Hollow south of the Dean fenster. The northern part of this sliver, whose outcrop area is nearly oval in shape (Pl. 2), was mapped as Maynardville undivided because it is composed of a much-faulted jumble of rocks of both the Low Hollow limestone member and the Chances Branch dolomite member. The long narrow belt extending southwest along the Chestnut Ridge fault is entirely of Chances Branch dolomite, and was so mapped. It is this sliver that appears just below the Chestnut Ridge fault in the photograph (Pl. 41B). The spoon-shaped indentation in the base of the overthrust block formed as the result of breaking off of the fault sliver from it is partly visible northeast of the sliver. In this direction along the Chestnut Ridge fault, the fault plane cuts upward across the Maynardville limestone into the lower part of the Copper Ridge dolomite and then back down again to its normal position near the base of the Maynardville. Undoubtedly if the part of the sliver concealed beneath the overthrust block could be examined, it would contain some Copper Ridge dolomite in addition to the limestone and dolomite of the Maynardville.

POSITION OF THE PINE MOUNTAIN OVERTHRUST OUTSIDE THE FENSTER AREA

The major overthrust fault, which forms the fensters in the Rose Hill district, is not known to be exposed anywhere else southeast of its outcrop along Pine Mountain in Kentucky and Tennessee. Although deep wells have been drilled in various parts of the Cumberland overthrust block no records were kept on some of the older wells and only two wells are definitely known to have penetrated the fault. One of them is the Brooks well in the western part of the Rose Hill district, and the other is the Shown well one mile east of Jacksboro in Campbell County, Tennessee. The Shown well is so far from Rose Hill and so near the southwest edge of the Cumberland overthrust block that the data from it have little direct bearing on the geologic problems of the Rose Hill district, but they are important in a consideration of the oil possibilities of the Powell Valley anticline in Tennessee. It is interesting to note that the Shown well is only 4 miles northeast of the Jacksboro tear fault, which forms the southwest edge of the Cumberland block, yet it encountered the Pine Mountain overthrust fault at a depth of 3016 feet below the surface. The formation directly above the overthrust in this well is probably the Maynardville limestone and the formation below is the Sequatchie. Only one major plane of overthrusting was penetrated by the well.

In the Brooks well, which lies 2 miles west of the Fourmile fenster, 1920 feet of shale and sandstone (Conasauga and Rome) were drilled before the Pine Mountain fault was met. This entire thickness of Cambrian strata is older than any beds exposed at the surface in the fenster area. The fault plane has thus descended from 1500 feet above sea level to 480 feet below sea level in the two miles between the Fourmile fenster and the Brooks well (Pl.

1), and also has crosscut almost the full thickness of the Conasauga and Rome formations in its descent. From information gained in the Fugate No. 2 well and from knowledge of the behavior of the fault where it is exposed in the fenster region, the fault plane more likely descends abruptly, crosscuts the Conasauga and Rome just west of the Fourmile fenster and then flattens out near the base of the Rome rather than descending gradually and evenly between the Fourmile fenster and the Brooks well. This interpretation is shown in the Structure Section CC′ of Plate 1. It has also been suggested on the structure contour map of the Pine Mountain-Chestnut Ridge fault plane (Pl. 38B), although insufficient information is available to attempt careful contouring of the fault in this region. The change in direction of the axis of the Powell Valley anticline from northeast-southwest to east-west coincides in location with this postulated crosscutting by the Pine Mountain overthrust fault.

Five miles east of the Rose Hill district the Phipps well (Pl. 47), which started in the Cumberland overthrust block near the base of the Chepultepec dolomite, stopped at a depth of 855 feet in the Copper Ridge dolomite without having reached the Pine Mountain overthrust fault. No cuttings or written records of the Parkey well (southwest corner of Plate 1) or the McClure well (10 miles east of Rose Hill) have been found but from the verbal information that could be obtained, it seems probable that both these wells cut the Pine Mountain fault plane near the bottom of the holes (See pp. 294-296). In the Parkey well the fault is believed to be at a depth of about 2640 feet below the surface or 1175 feet below sea level and in the McClure well at 3300 feet below the surface or approximately 1800 feet below sea level. In the McClure well the overthrust fault is believed to lie at or near the base of the Maynardville limestone with the entire Knox group present in its normal position between the Maynardville limestone and the Ordovician limestones that are exposed at and near the well. This is the favored position for the Pine Mountain fault plane in the fenster area. At the Parkey well, however, the overthrust fault seems to be at a horizon about in the middle of the Knox group. This means that the fault has cut upward across the Rome, Conasauga and Maynardville formations and the lower half of the Knox group in the distance from the Brooks well (Pl. 1) to the Parkey well.

From the facts gleaned in the fenster area and at the Brooks well and from the interpretation of the scanty available information at the Phipps, McClure, and Parkey wells the following tentative conclusions can be drawn as to the position of the Pine Mountain overthrust fault in the parts of the Rose Hill district where it is concealed. East and southeast of the fenster area the base of the overthrust block is probably at or near the base of the Maynardville limestone, so that the depth of the overthrust beneath the surface can be roughly obtained by calculating the thickness of beds between the base of the Maynardville and the outcropping beds, and multiplying this by a factor determined by the regional dip. Along the axis of the Powell Valley anticline west of the fenster area the overthrust fault appears to lie near the base of the Rome about 2000 feet beneath the base of the Maynardville. It probably occupies this position also in the part of the district southwest of the fenster area. Somewhere northwest of the axis of the Powell Valley anticline the fault plane begins cutting upward across the lowest formations of the Cumberland overthrust block. The amount of crosscutting that takes place between the fensters of the Rose Hill district and Pine Mountain, Kentucky, is determined by the thickness of beds between the base of the Maynardville, which forms the base of the overthrust block in the fenster area, and the Mississippian black shales, which form the base of the overthrust block at the outcrop of the Pine Mountain fault in Kentucky. This amounts to nearly 6000 feet of beds.

INTERPRETATION OF THE REGIONAL STRUCTURE

MECHANISM OF OVERTHRUSTING

Localization of the overthrust fault plane.—Differences in rock resistance have been the controlling factor in the localization of planes of overthrust faulting. Rich[215] has applied this well-recognized concept to an interpretation of the Pine Mountain fault. The views expressed below on the reasons for the stratigraphic position of the fault are substantially the same as those advanced by Rich. The Cumberland block has been able to move forward as a unit along a nearly flat fault plane because it is in the main composed of competent formations capable of transmitting lateral stresses for long distances without buckling. The most competent of all the formations in the block is the thick and massive Lee formation

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[215] Rich, J. L., Mechanics of low-angle overthrust faulting as illustrated by Cumberland thrust block, Virginia, Kentucky, and Tennessee: Am. Assoc. Pet. Geol. Bull., vol. 18, no. 12, pp. 1584-1596, 1934.

of Pottsville age, which lies in the upper part of the block. The Lee formation has long since been eroded from the crest of the Powell Valley anticline but is still preserved in the Middlesboro syncline. Interbedded with the competent formations in the block there are, however, two relatively thin, very incompetent units, the Conasauga shale and the Upper Devonian and Lower Mississippian black shales (Chattanooga of early authors). The Conasauga lies directly beneath the massive limestones and dolomites of the Maynardville limestone and the Knox group, and the Devonian and Mississippian shales lie between the massive Cayuga dolomite (Silurian) and the thick Newman limestone (Mississippian). The relations of the competent and incompetent units of the Cumberland block are shown in Figure 15A. The two incompetent shale units have been the horizons most favorable

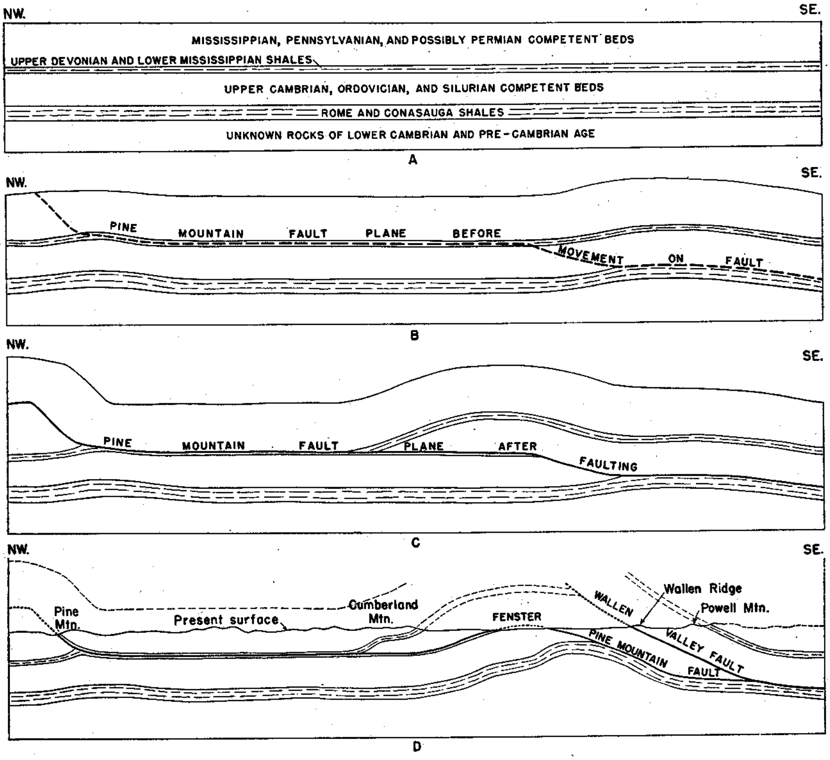

FIGURE 15.—Stages in the development of the Cumberland overthrust block. A, Competent and incompetent rock units before deformation. B, Gentle folding, and development of Pine Mountain fault plane. C, Overthrusting along the Pine Mountain fault. D, Development of the Wallen Valley fault, and folding of the Powell Valley anticline.

to movement and the Pine Mountain fault plane has consistently developed near their contacts with adjacent competent formations. It is curious and unexplained that in the Rose Hill area most of the incompetent Conasauga shale has been left behind in the stationary block while the competent Maynardville limestone and dolomites of the Knox group overrode it, whereas at Pine Mountain in Kentucky most of the incompetent "Chattanooga" shale lies above the fault plane and has moved forward with the overriding rocks. In both places, however, the shale unit controlled the position of the fault plane. The easy movement along the fault in the shale unit prevented the overriding block from being ruptured by other faults of the imbricate type, whereby the horizontal stresses would have been dissipated upward to the surface.

West of the fensters in the Rose Hill district the Pine Mountain fault plane has been shown to lie near the base of the Rome formation in the Brooks well (Pl. 1, Section CC′). The Rome is composed mainly of relatively incompetent interbedded shale and sandstone. The nature of the rocks that normally underlie the Rome is not known as they are not exposed at the surface and have not been penetrated by drilling for many miles in any direction. Along the eastern side of the Appalachian Valley the Rome lies on massive-bedded Shady dolomite, which may possibly be the underlying formation in the Rose Hill district also. At any rate there must be a strong contrast in competency between the lower Rome and the underlying rocks (Shady dolomite ?) that tends to localize the formation of fault planes near the contact between the two. This is clearly indicated by the fact that many of the major reverse and overthrust faults in the northwestern part of the Appalachian Valley have formed at or near the base of the Rome formation, and the Rome has been pushed northwestward over younger rocks.

Crosscutting of the overthrust fault plane.—Obviously an overthrust fault plane cannot develop limitlessly at the same stratigraphic horizon no matter how incompetent that horizon may be to resist shearing stresses. Somewhere there is a point where the resistance to faulting is less in some other direction than along the incompetent unit. This direction is almost always upward, with the result that the fault breaks across the competent beds above the incompetent unit. The point at which crosscutting begins is influenced by various factors, but apparently the most important are warps or folds, which cause the developing fault to follow an incompetent unit upward until it confronts a downward flexure where the fault can no longer follow the incompetent beds. Instead, the fault crosscuts the beds stratigraphically above the incompetent unit. Once the crosscutting has begun, many or most overthrust faults continue to break across the formations, competent and incompetent alike, till the surface is reached. Somewhere between the Rose Hill fensters and Pine Mountain, Kentucky, the Pine Mountain fault plane cuts from the top of the incompetent Conasauga shale upward across more than 6000 feet of competent beds, but unlike most overthrusts it then flattens out along another incompetent unit, the Devonian and Mississippian black shales. This course, including the crosscutting, resulted from the apparent absence of a sharp flexure preceding or accompanying the formation of the Pine Mountain fault plane. There was probably only a very gentle fold that deflected the growing fault upward across the competent beds above the Conasauga shale, but that did not prevent its flattening out again along another incompetent zone at a higher level. In the series of four sections depicting the development of the major structures of the Cumberland block (Fig. 15), Section B shows the initial development of the Pine Mountain fault plane according to this interpretation.

In the areas where the Pine Mountain overthrust fault developed parallel with the beds in one of the incompetent shale formations, there should apparently be little deformation of the overthrust block above the fault. Conversely where the fault plane cuts upward across the competent beds to a higher incompetent horizon a belt of weakness was probably formed in the overthrust block. Forward movement of the overriding block would be expected to produce warping or folding of the overriding block at the location of the crosscutting of the fault plane. The crosscutting in the section (Fig. 15B) has therefore been shown as occurring in the belt where the Cumberland Mountain monocline was to be formed later, for this belt represents the only deformed area between the Rose Hill district and Pine Mountain, Kentucky. The evidence from the Parkey well (p. 296) supports the view that the crosscutting of the Pine Mountain fault plane takes place beneath the Cumberland Mountain monocline.

Amount of displacement on the Pine Mountain overthrust fault.—Butts[216] calculated that the forward movement of the overthrust block in the region of the Rose Hill fenster was 7 miles. His figure was computed from measurements taken from the structure section that accompanied his report. As Butts pointed out, the amount of displacement can be determined by the distance between the broken edges of the same rock zone above and below the overthrust fault. The actual measurement that results from the application of this method depends of course on the interpretations that have been drawn into the section in those areas where factual control of the critical elements is scarce.

Our section across the Cumberland block (Pl. 5B) was drawn independently, yet it differs only slightly in its major features from the one Mr. Butts drew. Our measurement on Plate 5B of the displacement along the Pine Mountain fault was made by scaling the distance along the fault plane between (1) the edge of the Silurian rocks under Brush Mountain and (2) the edge of the same rocks in the vicinity of the Dean fenster. This distance is 5.8 miles. Although the interpretations in our section and in Butts' are not identical, the differences are not sufficiently great to account for the discrepancy of 1.2 miles between our measurements. His greater measurement arose from the inaccuracy of the topographic maps then available that lengthened by nearly a mile the distance between the fensters and Cumberland Mountain.

In the sections showing the structural history of the Cumberland block (Fig. 15), Section C has been constructed by moving the overthrust block forward a distance representing 5.8 miles along the fault plane shown in Section B.

FORMATION OF THE WALLEN VALLEY FAULT

Wentworth[217] believed that the formation of the Wallen Valley fault preceded that of the Pine Mountain fault, but did not discuss his reasons. We incline to the opposite view, although we have studied such a short stretch of the Wallen Valley fault that we advance this as a tentative conclusion only. We are, however, impressed by the fact that both the Pine Mountain and Wallen Valley fault planes lie at or near the base of the Maynardville

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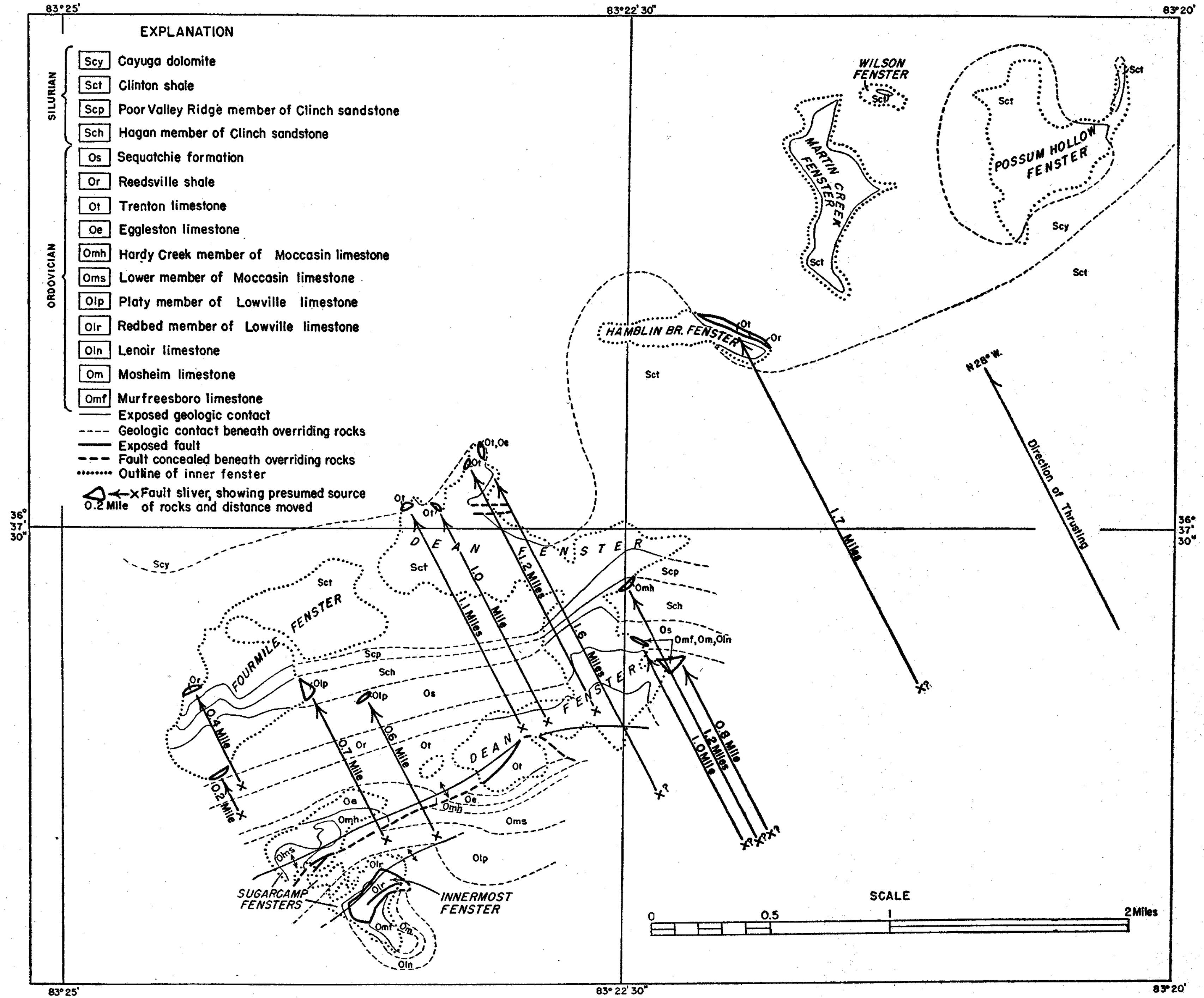
[216] Butts, Charles, Fensters in the Cumberland overthrust block in southwestern Virginia: Virginia Geol. Survey Bull. 28, pp. 8-9, 1927.

[217] Wentworth, C. K., Russell Fork fault of southwest Virginia: Jour. Geology, vol. 29, no. 4, pp. 351-369, 1921.



Geologic map of the stationary block beneath the Cumberland overthrust block, showing the location and presumed source of the fault slivers derived from it during overthrusting.

limestone in our area. This is necessitated if, after extensive forward movement of the Cumberland block accompanied by some folding, the resistance to further movement of the whole block became too great and the block ruptured nearer the source of the compression to form the Wallen Valley fault. If, on the other hand, the Wallen Valley fault formed first, the selection by both faults of the identical stratigraphic horizon on which to move becomes fortuitous rather than a necessary accompanying phenomenon. Furthermore we find it difficult to visualize the transmission of nearly horizontally directed stresses across a preformed Wallen Valley fault into the rocks of the Cumberland block northwest of the fault. Hence we believe that the Wallen Valley fault developed in the final stages of overthrusting along the Pine Mountain fault plane, and that the new plane of movement along the Wallen Valley fault relieved the stresses that had been pushing the Cumberland block forward along the Pine Mountain fault. We interpret the Wallen Valley fault as a fault of imbricate type that merges with the Pine Mountain fault at depth (Fig. 15D).

Faults of the imbricate type, such as the Wallen Valley fault, had gently to steeply dipping fault planes when they were first formed. These faults should not be termed overthrusts. The name *low-angle reverse faults* is here proposed for faults whose initial fault planes dipped between 10° and 45°, and *high-angle reverse faults* for those whose planes originally dipped more than 45°. The name *thrust fault* is undesirable, because of the unavoidable confusion as to whether the term is being used synonymously with *reverse fault* or with *overthrust.* It seems at times to have been used in order to avoid a more precisely understood name. In the classification here suggested, the Wallen Valley fault is classed as a low-angle reverse fault. Many other of the so-called overthrusts of the southern Appalachians seem to belong in this category.

A true overthrust fault, such as the Pine Mountain, Fugate, Wilson, and Chestnut Ridge faults of this report, has a nearly flat fault plane along most of its course at the time of faulting. The fault plane may be inclined at fairly steep angles where it breaks across competent formations, and especially where it breaks through to the surface. It may also later be tilted or folded, so that the fault plane as now observed dips steeply. In order to be classified as an *overthrust,* however, the original fault plane should over most of its area have been flat or only gently dipping.

FORMATION OF THE POWELL VALLEY ANTICLINE

The Powell Valley anticline was formed largely by folding subsequent to the overthrusting. This is indicated by the fact that the Pine Mountain overthrust fault plane is known to be arched near the fensters and by the probability that it is arched elsewhere into an anticline similar to, though not identical with, the anticline in the exposed rocks of the Cumberland overthrust block. The final step, therefore (Fig. 15D), in the development of the major structural features of the Cumberland block was the arching of the fault plane and the rocks of the Powell Valley to form the Powell Valley anticline. This arching probably accompanied movement along the newly formed Wallen Valley fault plane.

Rich[218] has interpreted the formation of the Powell Valley anticline as an accompanying phenomenon of the overthrusting. His diagrams illustrating the method of formation of the overthrust have been reproduced as Figure 16, A and B. After overthrusting was completed, he believes that the present structure of the region was attained by tilting the block shown in Figure 16B to the north, so that the diagonal line in the lower part of the diagram becomes the present horizontal. The present dip of the fault plane northward from the fenster area is accounted for by

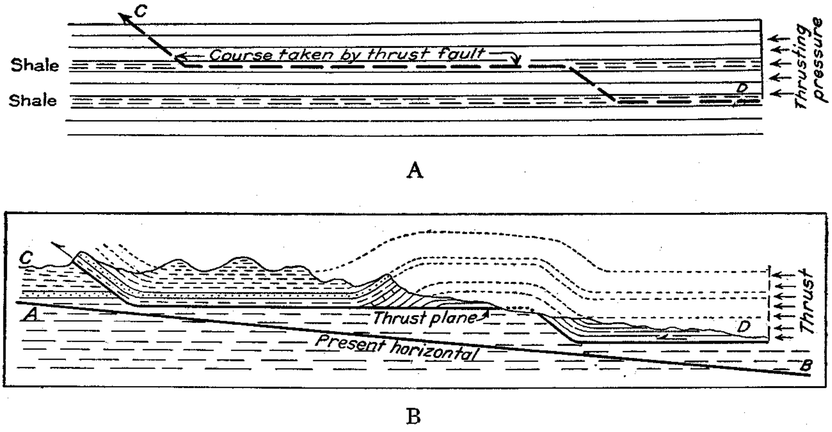


FIGURE 16.—Development of the Pine Mountain overthrust fault and the Powell Valley anticline, according to the interpretation of John L. Rich.

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[218] Rich, J. L., op. cit., pp. 1584-1596.

this tilting. The fault plane is known to dip northward 15° between the Fourmile fenster and the recently drilled George Yeary well. We believe that the dip of the fault plane becomes even greater nearer the Cumberland Mountain monocline. Even if the maximum northward dip of the fault plane were only 15°, a tilting of the entire block by this amount would impose a 15° northward dip on the formations of the flat-bottomed Middlesboro syncline. The floor of the Middlesboro syncline is, however, composed of practically horizontal beds, and has the aspect shown in Rich's diagram before tilting, not after tilting. Furthermore a tilting of the Cumberland block by as much as 15° to the north would have resulted in 29,000 feet of relative uplift of the south edge of the block with respect to the north edge.

DEVELOPMENT OF SECONDARY STRUCTURES ACCOMPANYING THE OVERTHRUSTING

Origin of dual planes of movement along the Pine Mountain fault.—As previously described the Pine Mountain overthrust fault has two branches in most of the fenster region. The two branches result from the formation of a second fracture after development of the original fault plane. In the western part of the fenster area there is great difficulty in determining the order of events, as may be seen by looking at the sections of Plate 2. If the upper or Chestnut Ridge branch was formed first and if the lower or Fugate branch was formed later then the Fugate slice must have been faulted loose from the stationary block to the southeast after the initial fault movement. If, on the other hand, the lower branch was the first to form then the Fugate slice was originally a part of the overthrust block from which it broke loose at the time of formation of the upper fault plane. There seems no sure way to determine which branch of the fault did form first. At one time, however, the overthrusting movement was along the Fugate fault southeast of the Lemons fault plane, followed the Lemons fault plane across the Fugate slice, and thence along the Chestnut Ridge fault plane northwest of the Lemons fault. This regime is required by the presence along the Lemons fault of the sliver of Lowville limestone (p. 252) enclosed by dolomite of the Knox group that belongs to the Fugate slice.

There must have been some rotation of parts of the Fugate slice to account for the anomalous strike of the belts of the Copper

Ridge and Chepultepec dolomites in the lower part of Edds Hollow (Pl. 2). Rotation suggests simultaneous movement on both the upper and lower branches of the overthrust. The movements have thus been so complex and varied that unscrambling the exact sequence of events is almost impossible. It is fairly certain, however, that final movement was along the Chestnut Ridge branch of the Pine Mountain overthrust fault. This is indicated by the fact that the Fugate fault plane is much the more irregular of the two, as though after movement on the Fugate fault had ceased, the fault plane had been warped and folded and the rocks of the Fugate slice deformed during the subsequent movement of the overriding block along the Chestnut Ridge fault plane.

In the eastern part of the fenster area the interrelations of the Wilson and Chestnut Ridge branches of the Pine Mountain overthrust are less complicated, as the Wilson slice is closely related to the overriding block from which it came. The thrusting was almost all along the lower or Wilson fault plane, which was the first to form. Near the end of thrusting a slice of Maynardville limestone and lower Copper Ridge dolomite was broken from the underside of the overthrust block along the Chestnut Ridge fault plane. The slice was then overridden for a short distance with the resultant brecciation and faulting of the rocks in the slice. Other smaller slices have been formed in the same manner, and still others are undoubtedly present but not exposed, as shown by the absence of the lower part of the Maynardville limestone and in some places of the entire Maynardville around the rims of the Chestnut Ridge and Martin Creek fensters.

Formation of the Cumberland Mountain monocline.—The Cumberland Mountain monocline is much more sharply folded than the Pine Mountain overthrust plane beneath it is believed to be folded (Pl. 5B). In places along the front of Cumberland Mountain the Lee formation dips even more steeply than it does along the line of section in Plate 5B. Furthermore reverse faults, upthrown on the northwest side, are common along the Cumberland Mountain monocline and are found nowhere else in the area. These faults show the tendency along the monocline for the rocks on the northwest to override those on the southeast. Stress of this type would develop normally during overthrusting as the moving block formed a monoclinal wrinkle, whereas folding of the monocline either before or after thrusting would not be expected to produce reverse faults upthrown on the northwest. The mechanism is related to underthrusting, whereby the Middlesboro basin part of the Cumberland block sheared upward along numerous high-angle faults as it was pushed ahead by the Powell Valley part of the block. The folding of the rocks of the overthrust block into the Cumberland Mountain monocline thus appears to have accompanied the overthrusting, but the dip of the beds in the monocline was later increased by the arching of the Powell Valley anticline.

DATE OF DEFORMATION

Evidence for dating the folding and faulting of the rocks is not available from within the Rose Hill district. The youngest folded and faulted rocks are of Devonian age and the oldest undeformed sediments are very recent unconsolidated gravels and alluvial deposits. However, from evidence elsewhere in the southern Appalachians it has been amply proved that folds and faults similar to those described in this report also affect Carboniferous rocks and that Triassic rocks are deformed in a very different manner. The major structures of the rocks in the Rose Hill district were thus surely produced in the interval between the deposition of youngest Carboniferous and oldest Triassic sediments. This is at or near the end of the Paleozoic era, and the paroxysm which produced the folds and faults of the Appalachian Mountains at that time is called the Appalachian Revolution.

GEOLOGIC HISTORY

GENERAL STATEMENT

The geologic record that may be deciphered from the rocks exposed at the earth's surface, spans nearly two billion years. In no one region does the evidence of the rocks tell the whole story, and in most regions the gaps in the record are much greater than are the parts for which evidence is preserved. By piecing together a partial record from one locality with partial records from others, gradually and laboriously a chronological story of the events of the geologic past is deciphered, and the story in one locality is fitted into its proper place in the continental and world-wide picture. Conversely the evidence learned from surrounding regions helps to fill in the gaps in the record in the more local areas. The compilation of geologic history even in a local region thus demands first, correct interpretations of the rocks, and second, correct correlations from region to region.

In the Rose Hill district only a small part of known geologic time is represented in the section of the rocks available for examination. Although the bedrock deposits of the district have a total thickness of nearly 8000 feet, they represent only one half of one of the five eras, or only about one tenth of known geologic time. The deformation by folding and faulting to produce the structural features, including the Pine Mountain overthrust fault and Powell Valley anticline, took place more than 100 million years after the deposition of the youngest rocks preserved in the district. After another long interval, the record of which is missing, the region was sculptured by erosion to produce the present landscape. The relative lengths of geologic time during which the processes of deposition, deformation, and sculpturing endured is shown in Figure 17. Ruled areas represent the time during which events that can be interpreted from a study of the surface geology and topography were occurring in the Rose Hill district. The chapter on stratigraphy of this report has been concerned with the first and largest of the ruled wedges; the chapter on structure deals with the results produced during the time represented by the second wedge; and the chapter on physiography has been concerned with the occurrences that have transpired during the relatively recent time represented by the third wedge. The blank areas represent geologic time for which no record of events was left, or else for which the records have been later buried or destroyed so that they are not now available for study. The general remarks that are made in the following section about geologic events that occurred during these long blank intervals are based on evidence from outside the Rose Hill district.

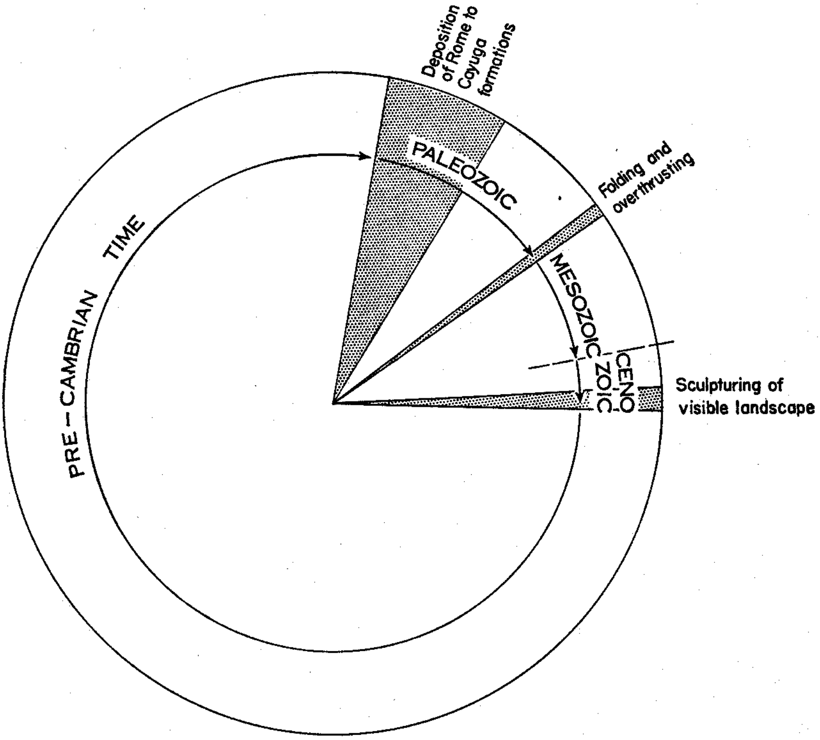


FIGURE 17.—Geologic time table showing the relative lengths of time involved in the deposition of the exposed rocks of the Rose Hill district, their folding and faulting, and their sculpturing to produce the present landscape. Length of time represented by the dial is two billion years.

PRE-CAMBRIAN HISTORY

The events that occurred during the three-fourths of geologic time covered by the pre-Cambrian can only be surmised. Pre-Cambrian rocks underlie the Rose Hill district, but at a depth which is nowhere less than 5,000 feet and is much greater in most of the district. The nearest pre-Cambrian rocks exposed at the surface are in the Blue Ridge province of eastern Tennessee 50 miles to the southeast. Here the rock record shows a very long and complex history, during which great thicknesses of sediments were deposited, vast igneous masses were intruded, and the whole rock sequence was folded, faulted, and metamorphosed. No evidence exists to deduce what changes may have taken place in the 50-mile interval between the Blue Ridge and the Rose Hill district, but probably the pre-Cambrian rocks beneath the district are the products of an equally complex sedimentary, igneous, and metamorphic history.

PALEOZOIC HISTORY

DEPOSITION OF THE ROCKS

At the close of pre-Cambrian time a mountain range was formed along the eastern seaboard of North America. Although it was subjected to the same processes of weathering and erosion, which gradually wear down the mountain ranges of today, it was reelevated from time to time throughout the Paleozoic era and thus formed a continuous barrier separating the eastern and central interior parts of the continent from the Atlantic Ocean. This persistent positive area has been named Appalachia or the Appalachian geanticline.

Early in Cambrian time a long trough developed parallel to Appalachia on its landward side. This trough or depression was a persistent negative area throughout most of the Paleozoic era. Though shut off from the Atlantic by Appalachia, the trough was repeatedly flooded by waters which advanced up the trough from the Caribbean and down the trough from the region of Newfoundland and Labrador. Throughout much of the early and middle parts of the Paleozoic there was a continuous seaway from one end of this trough to the other, and at times of most widespread submergence, the waters in this depression were also connected with seas that spread over the central interior of the continent. This trough has been named the Appalachian geosyncline. Though it was receiving great quantities of sediments from Appalachia, the floor of the trough was also settling so that a rather even balance was maintained. From time to time the trough was filled with sediments for short periods and the surface was above sea level, but renewed settling again admitted the sea waters and a new series of marine sediments was deposited in the trough. The Rose Hill district lies within the Appalachian geosyncline so that it has received an unusually complete sequence of Paleozoic sediments.

At the beginning of Cambrian time when Appalachia stood high above sea level, the streams eroding it spread gravel, sand, and mud westward over the lowland region of the Appalachian geosyncline. These partly continental and partly marine earliest Cambrian sediments reach a great thickness on the eastern side of the present Appalachian Valley and they are probably also present but somewhat thinner just above the basement crystalline rocks in the Rose Hill district. Somewhat later in the Lower Cambrian epoch, Appalachia was worn down so that it ceased to supply coarse clastic sediments westward. At this time a carbonate formation, the Shady dolomite, was deposited in the eastern part of the geosyncline. It is probably also present wholly or in part in the Rose Hill district, but it is now so deeply buried that it has not been exposed by erosion or penetrated by drilling.

Beginning late in the Lower Cambrian epoch and continuing into the Middle Cambrian, the first sediments were deposited whose nature can be directly observed in and near the Rose Hill area. These are the sandstones, shales, limestones and dolomites of the Rome formation. The rapid alternation of lithologic characters within the formation indicates unstable conditions in and near the geosyncline, with fine and coarse clastic sediments settling from the sea water much of the time, but with occasional periods in which clear seas prevailed and carbonates were precipitated. Numerous ripple marks indicate shallow water deposition and the red color of much of the sandstone and shale shows that there was abundant opportunity for oxidation of the iron in the muds and sands. This probably took place when the sands and muds were close to or even slightly above water level.

Similar conditions of sedimentation continued in the late Middle Cambrian epoch and early Upper Cambrian when the Conasauga shale was formed. The Conasauga seas were dominantly muddy, but there were numerous clear-water periods when a few inches of limestone were formed before the next incursion of muds. Trilobites flourished for the first time in the Cambrian seas of the southern Appalachians and many of the limy beds of the Conasauga contain abundant fragments of their shells.

Early in the Upper Cambrian epoch, Appalachia had been worn down almost to sea level so that the seas that followed were clear over a long period extending well into the Ordovician. During this interval a great thickness of carbonate sediments was precipitated not only in the Appalachian geosyncline but over much of the eastern interior. This sequence of dolomites and limestones is one of the most striking deposits of the Appalachians. From New York to Alabama the sediments are very similar lithologically. In New York they were first called the Beekmantown limestone, in New Jersey the Kittatinny limestone, and in eastern Tennessee the Knox dolomite. More recent careful studies have shown that there are differences within the sequence, both lithologic and faunal, by which formations such as the Maynardville, Copper Ridge, Chepultepec, Longview, Kingsport and Mascot of this report can be differentiated and mapped. There was, however, little variation in the conditions under which these formations were deposited even though the sequence spans the boundary between Cambrian and Ordovician time. In most parts of the world a break in the sedimentary record exists at the close of the Cambrian period. Perhaps the small unconformity noted in the upper Copper Ridge dolomite in the Rose Hill district does represent a very brief withdrawal of the sea at or near the close of Cambrian time, but the fact that this unconformity has not been reported anywhere else in the southern Appalachians suggests that only a small area was brought above sea level and that it was quickly submerged again.

In Lower Ordovician time there came the first widespread emergence of the Appalachian geosyncline since it was originally formed and flooded in the Lower Cambrian. The Rose Hill district was brought above sea level and the Mascot dolomite, the last formation to be deposited, was eroded to a depth of several hundred feet in places. On the uneven surface resulting from this erosion, the Murfreesboro sea advanced, forming first a basal conglomerate by reworking the weathered material on the old erosion surface, then depositing argillaceous dolomitic sediments in the lowest areas. Except for local incursions of small amounts of mud, the remainder of Murfreesboro time was one of very clear seas in which limestones of considerable purity were deposited. In the latter part of the Murfreesboro time, however, there was probably a withdrawal and readvance of the sea. Under the turbulent conditions of this advancing late Murfreesboro sea, shells of abundant brachiopods living in the shallow water were fragmented by wave action to form a sort of basal conglomerate.

The Mosheim sea which occupied the Appalachian trough immediately after the close of Murfreesboro sedimentation, was one of the clearest and quietest bodies of water of which we have any record, as shown by the massive-bedded, chemically pure limestone deposited in it. The water must have been relatively deep for an inland sea, because there are no evidences of wave or current action such as produce closely spaced bedding planes. The nearest land must have been far removed and low-lying because there are practically no muddy or sandy impurities in the limestone.

The sea withdrew at the end of Mosheim time, and in places, as at Walnut Hill School, the entire Mosheim deposit was eroded before the Lenoir seas advanced over the area. In the Lenoir seas, in addition to the precipitation of calcium carbonate, much silica in the seawater was also precipitated to form abundant chert nodules scattered over the sea floor. These, together with fragmental shell beds of the type mentioned in the Murfreesboro, form the most distinctive features of the Lenoir deposits. As far as can be discerned from evidence in the Rose Hill district, Lowville time followed Lenoir time without any interruption. Lowville deposits indicate considerable variation in the conditions of sedimentation. Zones of massive birdseye limestone of the Mosheim type indicate occasional periods of quiet water conditions. Thinner bedded limestones show that throughout most of Lowville time the water was relatively shallow, and the argillaceous limestones containing mud cracks must have been formed under tidal-flat conditions. The lower Moccasin sea also was shallow and somewhat muddy but the water cleared and deepened in late Moccasin time when the Hardy Creek member was deposited. In early and late Eggleston time muddy seas prevailed in which a calcareous siltstone was deposited. In middle Eggleston time, however, thin-bedded limestones of the Lowville type were laid down.

Starting in Murfreesboro time and continuing through the rest of the Ordovician, volcanoes located in Appalachia erupted periodically. Their ash falls were spread by the winds over broad areas. When the ash dropped in quiet seas it settled to the bottom to form uniform layers, later to be altered to bentonite.

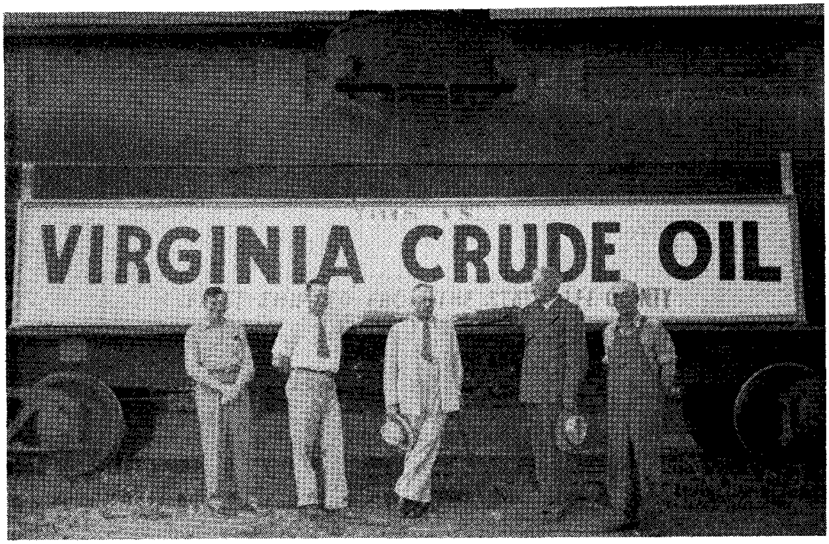
From the end of Conasauga time early in the Upper Cambrian epoch to the close of Eggleston time in the Middle Ordovician Appalachia was very low-lying, so that it supplied little sediment to the Appalachian geosyncline. Its shoreline lay so far to the southeast that the muds that were dumped into the sea by streams from Appalachia were not carried far enough seaward by currents to have much effect on the character of the deposits of the Rose Hill district.

By Trenton time, however, Appalachia was again beginning to rise and muds were washed into the inland sea in greater abundance. The muds, however, did not reach the Rose Hill region until Eden time. As a result Trenton deposits are still relatively pure limestone in the Rose Hill district, and the Reedsville shale is the first dominantly clastic formation of the Ordovician. The Sequatchie deposits, too, are muddy and they also contain red beds, but marine organisms lived in Sequatchie seas and were fossilized in its muds. Farther east and northeast the equivalent deposits are entirely red beds and have no fossils, so that they have been considered nonmarine.

At the close of Ordovician time there was a complete emergence of eastern North America. In eastern New York and southeastern Pennsylvania rocks in the Appalachian geosyncline were folded and metamorphosed, but in the southern Appalachians the interval between the Ordovician and Silurian systems was merely one of weathering and a little erosion of Ordovician deposits. During the interval, however, Appalachia was uplifted, hence the first Silurian deposits along the eastern edge of the geosyncline were continental conglomerates and sandstones. Once more the Rose Hill district was too far from Appalachia to feel the full effect of this incursion of coarse clastics. Instead, a sea spread over the area in which sandy and muddy beds were formed alternately as the waves and currents periodically carried silt or sand into the region to form the Clinch sandstone. The shoreline of this sea lay a few miles southeast of the Rose Hill district through most of Clinch time, but in middle Clinch time the sea temporarily retreated to or close to the northwest edge of the district, resulting in the deposition within the district of a few feet of beds containing clay galls and coarse conglomeratic pebbles.

Apparently the waters of the Clinton sea which followed were shallow, and embayments of the sea were from time to time almost entirely isolated. In them the concentration of iron in the water reached unusual percentages and resulted in the formation of iron-rich beds.

So far as known the Rose Hill district was emergent throughout Lockport time but was resubmerged in Cayuga time, resulting in the formation first of a basal sandstone and then of limestone and dolomite. At the close of the Silurian, the waters withdrew



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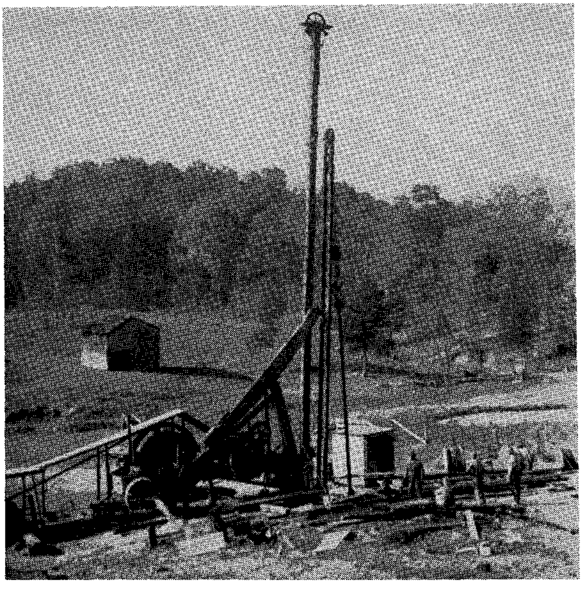
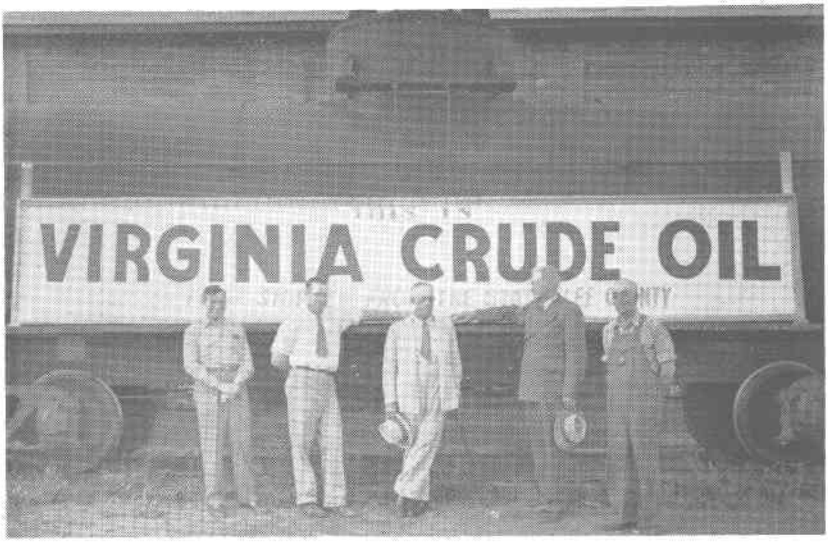


B

A, First shipment of oil from the Rose Hill oil field, May 24, 1943. From left to right: A. K. McInnes, Fred Seale, Byron Fugate, J. C. Sheaffer, Floyd Fitch. Photograph by Inmans photographers, Middlesboro, Ky. B, Cable-tool rig at the Brooks well, Lee County, Virginia, seating string of 6-inch casing at 3255 feet.



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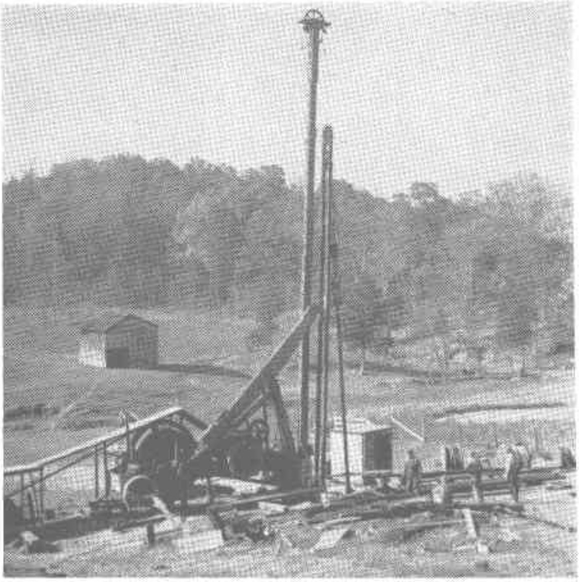

B

A, First shipment of oil from the Rose Hill oil field, May 24, 1943. From left to right: A. K. McInnes, Fred Seale, Byron Fugate, J. C. Sheaffer, Floyd Fitch. Photograph by Inmans photographers, Middlesboro, Ky. B, Cable-tool rig at the Brooks well, Lee County, Virginia, seating string of 6-inch casing at 3255 feet.

northward up the geosyncline and there were no deposits in the Rose Hill district throughout all of Lower and Middle Devonian. Not far to the northeast, however, formations of these ages are present. In late Devonian the seas returned and gray and black Brallier shales were laid down, of which only a few feet of the basal beds are preserved in the Rose Hill district.

The region continued to receive deposits through Mississippian and Pennsylvanian time, but these younger Paleozoic deposits have since been eroded from the area. From evidence nearby, however, it is known that a sea covered the region through much of the Mississippian and that in it there was deposited a thick sandstone and shale sequence, the Price formation, and then a thick limestone, the Newman limestone. Late in the Mississippian, however, the Appalachian geosyncline was once more brought above sea level. It remained low and swampy, however, and was covered with lush vegetation. Many tree ferns grew to great size. When they died their trunks fell into the stagnant swamp water and were prevented by the toxicity of the water from decaying completely. Thus great quantities of woody material slowly accumulated, later to be compacted and altered to valuable coal beds. Although there are numerous coal beds in the rocks of Pennsylvanian age and some in the rocks of upper Mississippian age, most of the sediments deposited at these times were sands and muds carried out from Appalachia by streams wandering across the great low-lying alluvial plains.

No sediments younger than the Pottsville, the oldest rocks of the Pennsylvanian, are preserved anywhere near the Rose Hill district, but younger Pennsylvanian and possibly even some Permian continental sediments may have been laid down over this region and since have been eroded.

DEFORMATION OF THE ROCKS

At or near the end of the Paleozoic the eastern United States was uplifted and was subjected to strong compressional stresses directed from the southeast. The sediments in the Appalachian geosyncline, which had accumulated to a thickness of at least 20,000 feet, were relatively incompetent. They buckled and folded, or broke and slipped under the stresses. In the Rose Hill region faulting has been much more prominent than folding in the deformation of the rocks. The upper layers were sheared loose from their foundations and pushed northwestward some six miles as part of a great overthrust block, which has been called the Cumberland block. The forward movement of the block was not always along one simple fault plane. In places slices or slivers were torn loose from the top of the stationary block and from the bottom of the moving block. Contemporaneously with the overthrusting the surface rocks were crumpled into a monocline, the Cumberland Mountain monocline. Eventually most of the horizontal compression in the Cumberland block was relieved by the formation of major faults nearer the source of the stress. The Wallen Valley fault, along which the movement was more than a mile, was one. After the faulting movements ceased the rocks of the Rose Hill district were warped into a gentle elongate anticline, the Powell Valley anticline. Before the conclusion of this period of intense deformation the rocks of the eastern United States had been faulted and folded into an imposing mountain range, the ancestral Appalachian Mountains.

MESOZOIC HISTORY

No record whatever has been left of the geologic events of the Mesozoic era in or anywhere near the Rose Hill district. The Mesozoic is presumed to have been a time of erosion during which the newly formed Appalachian Mountains were being worn down.

CENOZOIC HISTORY

Development of the Modern Landscape

Throughout the Cenozoic era, the Rose Hill district was continuously above sea level, but it was worn down to a rather low elevation in early or middle Tertiary time. This surface of low relief has been called the Schooley peneplain. The Appalachian Mountains may have been peneplaned previously, but little evidence remains to tell of their erosional history previous to Schooley time. The Schooley peneplain was very imperfectly developed near the Rose Hill district, for Cumberland Mountain and other mountains to the northwest stood out as monadnocks hundreds of feet above it.

The Schooley cycle was brought to a close by regional uplift and the streams cut down actively, eroding the weak formations to form lowlands and cutting narrow valleys across the more resistant rock belts. A standstill, probably in latest Tertiary time, permitted the development of a very local peneplain, the Harrisburg peneplain, on the belt of weak limestones along Powell River.

Since the close of the Harrisburg cycle erosion has been active in molding and shaping the major topographic features into the hills and valleys visible today.

ECONOMIC GEOLOGY

OIL AND GAS

GENERAL STATEMENT

The discovery of oil in the Rose Hill district on May 7, 1942 has resulted not only in the first significant production in the State of Virginia (Pl. 45A) but also the first production anywhere east of the Appalachian Plateaus. A few persons have carried on an almost continuous search for oil in the Rose Hill district since 1922, when the first well drilled in Possum Hollow produced a few barrels of oil from a depth of 300 feet. The B. C. Fugate No. 1 well, which obtained the first production of any significance, was the 11th well to be drilled in or near the Rose Hill district. Since completion of the discovery well 57 additional wells have been drilled of which 32 were producers. All wells in the district have been drilled with cable tools. A drilling rig of the type used on most of the recent wells is shown in Plate 45B. Table 11 is a chart summarizing the drilling history of the wells in Lee County.

In April 1947, the Rose Hill oil field was a fifteen well field, with a total production of about 600 barrels per day. On March 1, 1950 most of the early productive wells had gone dry, but new producers had been drilled. At that time total daily production was probably between 100 and 200 barrels.

Credit for the discovery of oil in Lee County is shared by many different men. Probably the most enthusiastic and persistent of all was C. A. Bales of Rose Hill, who was the moving spirit behind many of the early wells drilled in Possum Hollow. Several groups of men have drilled wells in the Fourmile fenster, but chief credit for the original discovery and for the early efforts in proving up the field belong to R. Y. Walker and Floyd Fitch. Among others, who have contributed financially or in time and energy toward the successful search for oil are: A. K. McInness, J. C. Sheaffer, Robert Fulkerson, Raymond Sliney, Fred Seal, Byron Fugate, J. C. Eisele, E. W. Whitney, F. M. Crockett, R. F. Spear, George W. Hindman, and Dr. Adam Stacy.

HISTORY OF DRILLING IN LEE COUNTY

WELLS IN POSSUM HOLLOW FENSTER

Gilbert Lee No. 1 well.—The Gilbert Lee No. 1, the first of the wells in the Possum Hollow fenster, was drilled in 1922 by a group of Rose Hill business men. It is located a few feet from the Possum Hollow road at the southwest corner of a shed (Pl. 2). The well started at an elevation of about 1420 feet in the upper part of the Clinton shale and bottomed at a depth of 303 feet in the upper part of the Clinch sandstone. Oil shows were reported at four horizons (see Pl. 46), and a gray sand 18 feet thick at the bottom of the hole is said to have supplied one-half to two-thirds of a bailer of oil each time the well was bailed. At 303 feet salt water was encountered which rose in the hole to 200 feet, flooding the oil sand. The higher shows in this well were in sands interbedded in the Clinton shale. The top of the Clinch sandstone is believed to lie at 259 feet and the show at the bottom of the hole was in a sand in the upper part of the Poor Valley Ridge member of the Clinch. The driller's log of the well is shown graphically in Plate 46. A description and analysis of the oil from the well is given in the section on grades of oil from the Rose Hill district.

Gilbert Lee No. 2 well.—The Gilbert Lee No. 2 well was drilled on a flat on the west side of Possum Hollow Creek about 500 feet north of Gilbert Lee No. 1 well and about 1420 feet above sea level. A few feet from the casing head is a concrete pier, on which part of an engine stands. The well was completed in 1924 at a depth of 1410 feet.

The well started in the upper part of the Clinton shale at a horizon probably 20 to 25 feet lower than the Gilbert Lee No. 1 well. We have examined an incomplete set of cuttings, which were obtained by Charles Butts. Enough cuttings were present to show without question that the well passed through the Clinch sandstone, Sequatchie formation, and Reedsville shale and bottomed about in the middle of the Trenton limestone (Pl. 46).

At 1225 feet about 70 feet below the top of the Trenton a show of oil was reported; this horizon was shot without appreciably increasing the flow. Another oil horizon occurred at the bottom of the hole. According to one of the local residents "This was pumped several times and each time got enough to fill thirteen 55-gallon drums, all the drums they had. There might have been more oil." Mr. Bales

TABLE 11.—*History of wells drilled in the Powell*

Number of well on Plate 1[1]	Name of well	Operator	Location	Date started	Date completed	Elevation of surface in feet	Formation at surface
Not on map	D. C. McClure No. 1.	Cedar Valley Oil Co.	4.1 miles west-southwest of Jonesville.	1910	1915	1370	Red bed member of Lowville limestone.
1	Gilbert Lee No. 1	L. E. Bales et al.	Possum Hollow fenster.	1922	1922	1420	Clinton shale
2	Gilbert Lee No. 2	L. E. Bales et al.	Possum Hollow fenster.	1924	1924	1420	Clinton shale
3	Lon Montgomery	Lon Montgomery ?	Possum Hollow fenster.	1925?	1925?	1455	Clinton shale
4	Billy Parkey No. 1.	Johnson, Head, and Gilmore.	Northwest corner of Rose Hill district.	1928 or 1929	1928 or 1929	1460	Trenton limestone.
5	Jack Asher	Jack Asher ?	Possum Hollow fenster.	1929?	1929?	1410	Clinton shale
6	W. B. Fulton	W. B. Fulton	Possum Hollow fenster.	1934	1934	1415	Clinton shale
7	Pritchard	?	Possum Hollow fenster.	1937	1937	1460	Clinton shale
8	Ingram	Ingram or Holcombe.	Possum Hollow fenster.	1938	1938	1570	Clinton shale
discov. [illegible]	B. C. Fugate No. 1.	Walker et al.	Fourmile fenster	1942	May 7, 1942	1447	Sequatchie formation.
10	B. C. Fugate No. 2.	Walker et al.	Fourmile fenster	1942	1943	1512	Clinch sandstone
11	B. C. Fugate No. 3.	Virginia Lee Oil Co.	Fourmile fenster	1943	1943	1451	Clinch sandstone
12	Bob Lemons No. 1	O. A. Larazola	Fourmile fenster	1939	1944	1445	Sequatchie formation.
13	Eli Brooks No. 1	Virginia Lee Oil Co.	Frog level	1943	1945	1452	Conasauga shale
14	Bob Lemons No. 2.	Fred Seal et al.	Fourmile fenster	Aug. 14, 1945	Oct. 10, 1945	1473	Sequatchie formation.
15	Bob Lemons No. 3.	Fred Seal et al.	Fourmile fenster	Oct. 30, 1945	Dec. 1945	1548	Clinch sandstone
Not on map	Charles Phipps No. 1.	Ellison et al.	Along U. S. 58, 7 miles west of Jonesville.	June 1944	1947	1585	Chepultepec dolomite.
16	Fugate Estate No. 1.	Rouge Oil Co.	Fourmile fenster	Feb. 15, 1946	May 5, 1946	1534	Clinch sandstone
17	B. C. Fugate 2-B	Rouge Oil Co.	Fourmile fenster	April 1946	May 27, 1946	1475	Sequatchie formation.
18	Fugate Estate No. 2.	Rouge Oil Co.	Fourmile fenster	May 17, 1946	June 24, 1946	1477	Clinton shale
19	Fugate Estate No. 3.	Rouge Oil Co.	Fourmile fenster	July 15, 1946	Aug. 27, 1946	1481	Clinton shale
20	Fugate Estate B-2.	Rouge Oil Co.	Fourmile fenster	Sept. 16, 1946	Dec. 3, 1946	1533	Clinton shale
21	Fugate Estate No. 4.	Rouge Oil Co.	Fourmile fenster	Oct. 15, 1946	Nov. 1946	1494	Clinton shale
22	Fugate Estate B-3	Rouge Oil Co.	Fourmile fenster	Dec. 4, 1946	Feb. 1947 ?	1539	Clinton shale
23	Gilbert Lee No. 3	Sheaffer et al.	Possum Hollow fenster.	1946	1946	1410	Clinton shale
24	L. E. Bales No. 1	Rouge Oil Co.	Fourmile fenster	Oct. 10, 1946	Nov. 11, 1946	1532	Clinton shale
25	Stacey Nelson No. 1.	Rouge Oil Co.	Fourmile fenster	Nov. 1946	?	1538	Clinton shale
26	G. C. Dean No. 1	Rouge Oil Co.	Fourmile fenster	1946 or 1947	1946 or 1947	1494	Clinton shale
27	Josh Dean No. 1	Rouge Oil Co.	Fourmile fenster	Nov. 3, 1946	Jan. 15, 1947	1516	Clinton shale

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Valley Section of Lee County up to March 1, 1950

Total depth[2] in feet	Formation at bottom	Elevation of Pine Mountain Over-thrust[3]	Elevation of top of Trenton limestone[4]	Depth to pays in feet	Depth to shows in feet (O–Oil) (G–Gas)	Remarks	Number of well on Plate 1[1]	
3300±	?	−1765?	Not reached	None	3000±–G	Dry hole. No records.	Not on map	A048LE
303	Clinch sandstone......	....	Not reached	None	300–G	Four shows reported between 71 feet and 300 feet. Best at 300 feet. Salt water at 303 feet	1	
1410	Trenton limestone.....	....	+265?	None	1225–O 1410–O	Very small production from Trenton.	2	A067LE
2400?	?	....	?	None	....	Dry hole. No records.	3	A054LE
2650?	?	−1185?	Not reached	None	....	Dry hole. No records. May have reached Pine Mountain fault at 2640 feet.	4	
900?	?	....	Not reached	None		Dry hole. No records.	5	A071LE
1498	Trenton limestone.....	....	?	None	....	Dry hole.	6	A64L
463	Clinch sandstone......	....	Not reached	None	....	Dry hole. Abandoned.	7	A53LE
1870	Trenton limestone ?...	....	?	None	....	Dry hole.	8	A58LE
1115	Trenton limestone.....	....	+737	1111	....	Produced about 8 bbls. per day for about 5 years.	9	A25LE
2003	Trenton limestone.....	....	−278	None	1813–O, G	Dry hole. Reedsville greatly overthickened in hole.	10	
1773	Eggleston limestone....	....	+646	805 1033	800–G 972–O	Produced about 3 bbls. per day for 3 or 4 years.	11	
3261	Mascot dolomite......	....	+835	None	1375–O 1405–O 1445–O	Dry hole. Shows in Moccasin limestone.	12	A056LE
4079	Eggleston limestone....	−468	−3005	None	2032–G	225,000 cu. ft. of gas in basal sandstone of Cayuga dolomite.	13	
1222	Trenton limestone.....	....	+578	1212	1055–O 1143–G	Small production from Trenton.	14	
1590	Moccasin limestone....	....	+610	None	1265–O, G	Dry hole.	15	
1902	Clinch sandstone......	+329	Not reached	None	....	Trenton not reached. Pine Mountain fault at depth of 1256 feet.	Not on map	
1609	Moccasin limestone....	....	+584	1608	1133–O 1158–O 1248–O 1277–O 1360–O	Produces from Hardy Creek member of Moccasin limestone. Only one of Fugate Estate wells still producing in December 1949.	16	
1908	Eggleston limestone....	....	Higher than +374	None	.... 716–O	Dry hole. No cuttings 0 feet to 1101 feet.	17	A43LE
1215	Trenton limestone.....	....	+567	1211	926–O	Produced for about a year. About a 20 bbl. well for first few months.	18	
1320	Trenton limestone.....	....	+466	1250 1303	1160–O, G	About a 50 bbl. well for several months. Dry by August 1947.	19	A027LE
1769	Eggleston limestone....	....	+513	1495 1760	....	Very small producer. Dry in August 1947.	20	
1526	Trenton limestone.....	....	+236	1525	1307–O ? 1394–O ?	60 bbl. well for several months. Dry in June 1947.	21	
2037	?	....	+392	?	....	Productive. Data not released.	22	
1869	Moccasin limestone....	....	?	None	....	Dry hole. No records.	23	A032E
1766+	?	....	+470	?	....	Productive. Data not released.	24	
1575	?	....	+538	?	....	Productive. Data not released.	25	
1766+	?	....	+196	?	....	Productive. Data not released.	26	A44LE
1806	?	....	+46	?	....	Productive. Data not released.	27	

TABLE 11.—*History of wells drilled in the Powell Valley*

Number of well on Plate 1[1]	Name of well	Operator	Location	Date started	Date completed	Elevation of surface in feet	Formation at surface
28	George S. Yeary No. 1.	E. R. Morris	North of Fourmile fenster.	Jan. 1947?	June 1947?	1691	Copper Ridge dolomite.
29	Charles Hobbs No. 1.	Rouge Oil Co.	Martin Creek fenster.	?	1947	1347	Clinton shale
30	Henly Sutton	Rouge Oil Co.	Frog level	Dec. 1946	1947	1509	Conasauga shale.
31	H. B. Nolan No. 1.	E. R. Morris	North of Martin Creek fenster.	May 20, 1947	July 1947	1376	Copper Ridge dolomite.
32	Joe Dean No. 1	Rouge Oil Co.	Fourmile fenster	Jan. 20, 1947	1947	1573	Clinton shale
33	Patton Ely No. 1	Stacy et al.	Northwest of Fourmile fenster.	Jan. 24, 1947	May 15, 1948	1552	Maynardville limestone.
34	Andy Ely No. 1	Rouge Oil Co.	Fourmile fenster	Jan. 27, 1947	April 22, 1947	1539	Clinton shale
35	W. S. Riley No. 1	Rouge Oil Co.	West of Martin Creek fenster.	Mar. 10, 1947	April 1947?	1500±	Copper Ridge dolomite.
36	R. L. Bales No. 1	Rouge Oil Co.	Martin Creek fenster.	April 7, 1947	June 1947	1348	Clinton shale
37	Joe Chadwell No. 1.	Rouge Oil Co.	North of Blackberry Hollow.	April 13, 1947	July 1947	1393	Maynardville limestone.
38	M. Davis No. 1	Robert Vorhees	1½ miles east of Possum Hollow fenster.	April 1947?	August 1947?	1620±	Chepultepec dolomite.
Not on map	Candy Cawood	Herbert Gardiner	East of Possum Hollow. Just east of map (Pl. 1).	April 1947?	April 1947?	1710	Chepultepec dolomite.
39	Cleve Dean No. 1	Rouge Oil Co.	North of Fourmile fenster.	April 1947	April 1947?	1698	Maynardville limestone.
40	W. T. Jenkins No. 1.	Rouge Oil Co.	North of Fourmile fenster.	April 1947?	April 1947	1711	Copper Ridge dolomite.
Not on map	Anthony Ely No. 1.	Robert R. Murray	On U. S. Highway 58 and Hardy Creek east of Hagan.	April 1947?	July 1947?	1330±	Chepultepec dolomite.
Not on map	M. H. Snodgrass No. 1.	C. E. Deaton	Powell River near Towell Ford.	April 1947	August 1947	1280±	Mascot dolomite.
41	O. Cavins No. 1	K. R. Wilson	2½ miles southeast of Possum Hollow fenster.	June 1947	Sept. 1947?	1525±	Mascot dolomite.
42	Gilbert Lee No. 1	American Trading Products Co.	Southwest of Possum Hollow.	June 7, 1947	August 1947	1395	Maynardville limestone.
43	Logan Snodgrass No. 1.	Rouge Oil Co.	Blackberry Hollow section of Dean fenster.	June 1947	August 1947	1467	Clinton shale
44	Owens No. 1	Fred Shaner et al.	Northeast of Martin Creek fenster.	July 1947	August 1947	1660±	Copper Ridge dolomite.
45	E. C. H. Rosenbaum No. 1.	K. R. Wilson	On Martin Creek east of Rose Hill.	June 1947	August 1947?	1440±	Kingsport dolomite or Mascot dolomite.
46	Sensebaugh Heirs No. 1.	K. R. Wilson	Dry Branch east of Dean fenster.	June 22, 1947	August 1947	1588	Maynardville limestone.
47	Glen Yeary No. 1	Dunnigan and Malloy.	Blackberry Hollow section of Dean fenster.	July 1947	August 1947	1614	Clinton shale
48	W. S. Riley No. 2	Rouge Oil Co.	West of Martin Creek fenster.	July 1947	Sept. 15, 1947	1524	Maynardville limestone.
49	Clarence Dean No. 1.	Ted Smith Oil Co.	Head of Low Hollow near Dean fenster.	July 12, 1947	Sept. 1947?	1515	Longview, Kingsport and Mascot dolomites undiff.

Section of Lee County up to March 1, 1950—*Continued*

Total depth[2] in feet	Formation at bottom	Elevation of Pine Mountain Overthrust[3]	Elevation of top of Trenton limestone[4]	Depth to pays in feet	Depth to shows in feet (O–Oil) (G–Gas)	Remarks	Number of well on Plate 1[1]
3034	?	+846	−559	None	Oil show in Eggleston ?	Dry hole.	28
?	?	....	+215	?	....	Productive from Trenton. Data not released.	29
2707	Sequatchie formation..	−361	Not reached	None	....	No gas reported in Cayuga dolomite. Trenton not reached.	30
2373	Moccasin limestone....	+1024	−283	None	....	Dry hole.	31
1574	?	....	+378	?	....	Productive. Data not released.	32
2900±	?	?	−183	None	1775–O 1885–O	Dry hole. A little oil and much salt water in Trenton.	33
2166	?	....	?	?	1285–O 1465–O 1800–O 2006–O 1995–G 2000–G	Produced 130 bbls. a day for about 2 months. Had settled to 33 bbls. by end of July.	34
355±	?	....	Not reached	....	....	Abandoned.	35
1867	Moccasin limestone....	....	+196	1463–71	1308–G 1754–G	Productive from Trenton. About a 15 bbl. well.	36 A049LE
2015	Eggleston limestone....	+1305	+5	None	....	Dry hole. A little gas in Sequatchie formation.	37
4405	Mascot dolomite......	+895±	−387	None	2536–O	Dry hole. Oil show just above base of Trenton.	38
150±	Copper Ridge dolomite.	....	Not reached	....	....	Abandoned.	Not on map A063LE
182?	Clinton shale.........	+1541	Not reached	....	....	Abandoned.	39
210?	Maynardville limestone ?	....	Not reached	....	....	Abandoned.	40 A38LE
2532	Moccasin limestone....	+687	−490	None	....	Dry hole. Gas, reported to be from Reedsville shale. Still blowing off 1 year later.	Not on map
1706	Copper Ridge dolomite.	Not reached	Not reached	None	None	Abandoned.	Not on map
2001	Chepultepec dolomite..	−322	Not present	None	....	Dry hole. Chepultepec dolomite at top of stationary block.	41
2108	?	?	?	None	439–O 1600–O	Dry hole. Deeper show shot and acidized.	42
1832	Eggleston or Moccasin limestone.	....	+409	None	?–O	Dry hole. Acidized unsuccessfully.	43
2325	Moccasin limestone....	?	?	None	1596–O 1603–O 2085–G	Dry hole.	44 A33LE
1456	Clinton shale..........	−2	Not reached	....	....	Abandoned.	45 A020LC
2002	?	?	?	....	....	Dry hole. Water at 1645 feet in Trenton.	46
2835	Lowville limestone ?	....	+297	1750?–O 2000?–O	1642?–O	Produced about 1200 bbls. from Trenton. Deepened to T.D. in Lowville by Stacy and Cardwell.	47
1840	?	?	+177	?	....	Initial production from Trenton 150 bbls. a day. Settled to 35 bbls. a day.	48
2085	?	?	?	None	....	Dry hole.	49 LE003

TABLE 11.—*History of wells drilled in the Powell Valley*

Number of well on Plate 1[1]	Name of well	Operator	Location	Date started	Date completed	Elevation of surface in feet	Formation at surface
50	B. C. Fugate No. 1.	H. and R. Oil Co....	South of Fourmile fenster.	August 9, 1947	Oct. 10, 1947	1450±	Conasauga shale.
51	Dewey Lee No. 1..	H. and R. Oil Co....	North of Hamblin Branch fenster.	Oct. 15, 1947	Nov. 20, 1947	1440±	Maynardville limestone.
52	Cleve Dean No. 2.	Rouge Oil Co........	Blackberry Hollow section of Dean fenster.	Oct. 8, 1947	Nov. 1947	1640±	Maynardville limestone.
53	Grant Smith No. 1.	H. and R. Oil Co....	East of Possum Hollow fenster.	Nov. 3, 1947	Feb. 1948	1615±	Copper Ridge dolomite.
54	Jim Ray No. 1....	Rouge Oil Co........	Martin Creek fenster.	Jan. 1948	March 1948	1350±	Clinton shale...
55	Clifford Yeary No. 1	H. and R. Oil Co....	South of Fourmile fenster.	Jan. 1948	June 1948?	1390±	Conasauga shale.
56	J. R. Osborn No. 1.	Rouge Oil Co........	Hamblin Branch fenster.	Dec. 1947	March 1948?	1340±	Clinton shale....
57	J. W. Campbell No. 1.	Rouge Oil Co........	North of Hamblin Branch fenster.	Feb. 1948?	March 1948	1410	Clinton shale....
58	Charles Marcum No. 1.	H. and R. Oil Co....	Hamblin Branch fenster.	Jan. 1948	March 1948	1365±	Clinton shale....
59	Beatty Heirs No. 1.	James Webb........	Martin Creek fenster.	June 17, 1948	1948	1330	Cayuga dolomite
60	Abney Heirs No. 1.	Cardwell and Stacy..	North of Hamblin Branch fenster.	June 1948	August 1948?	1430±	Maynardville limestone.
61	C. B. Hobbs No. 1.	H. and R. Oil Co. and Rouge Oil Co..	Martin Creek fenster.	May 1948	July 1948?	1430±	Cayuga dolomite
62	Jim Ray No. 2....	Rouge Oil Co........	Martin Creek fenster.	May 14, 1948	Nov. 1948	1330±	Clinton shale....
63	C. E. Hobbs No. 2.	Rouge Oil Co........	Martin Creek fenster.	May 17, 1948	July 1948	1400±	Clinton shale....
64	M. E. McCurry No. 1.	Rouge Oil Co........	West of Martin Creek fenster.	Sept. 13, 1948	Feb. 15, 1949	1380±	Maynardville limestone.
65	Lee Marcum No. 1.	?	South of Hamblin Branch fenster.	1949?	1949	1570	Maynardville limestone.
66	L. E. Bales No. 2..	Rouge Oil Co........	Northeast of Fourmile fenster.	Feb. 1949?	April 1949	1750±	Copper Ridge dolomite.
67	C. H. Frye No. 1..	Adam Stacy........	North of Hamblin Branch fenster	Sept. 1949?	Oct. 7, 1949	1510	Copper Ridge dolomite.
68	Alfred Shackleford No. 1.	Adam Stacy........	North of Hamblin Branch fenster.	Nov. 1949	Feb. 1950	1550	Copper Ridge dolomite.
69	Myrtle Campbell No. 1.	Rouge Oil Co........	North of Hamblin Branch fenster.	Jan. 5, 1950	Feb. 1950	1500±	Copper Ridge dolomite.
70	Sibbie Ramsey No. 1.	Adam Stacy........	North of Hamblin Branch fenster.	Nov. 1949	April 1950	1530±	Copper Ridge dolomite.

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[1] Wells not on Plate 1 are in Jonesville district to east of Rose Hill district.

[2] Since their original completion, some of the Rouge Company wells have been deepened. Final depths are not known to the writers.

[3] If well did not penetrate fault, column is blank. If well penetrated fault, but elevation of fault is not known to the writers, a question mark appears in the column.

[4] If well penetrated top of Trenton, but elevation of top of Trenton is not known to the writers, a question mark appears in the column. If Trenton is not present in the area the words "Not present" appear in the column.

Section of Lee County up to March 1, 1950—Continued

Total depth[2] in feet	Formation at bottom	Elevation of Pine Mountain Overthrust[3]	Elevation of top of Trenton limestone[4]	Depth to pays in feet	Depth to shows in feet (O–Oil) (G–Gas)	Remarks	Number of well on Plate 1[1]	
1494	Moccasin limestone....	+1008	+781	1479–O	789–O 811–O 1448–O	Very small producer. Pay in upper part of Moccasin limestone.	50	A18LE
2156	Moccasin limestone....	+1340?	+184	1502	460–O	Productive from Trenton. Came in as gusher. Show at 460 feet in Clinton.	51	
2300±	?	?	?	None	2296	Show of oil at 2296 feet, probably in Moccasin limestone. Acidized unsuccessfully.	52	A005LE
2188	Moccasin limestone....	+1288	+173	None	?	Dry hole. Small show in Trenton.	53	A61LE
?	?	....	?	?	....	Made 200 bbls. a day for several weeks. 35 bbls. a day 3 months later.	54	A017LE
3130?	Mosheim limestone....	+760	+287	None	....	~~Dry hole~~. Fault slice of Lowville(?) limestone from 630 feet to 1103 feet.	55	
?	?	....	?	?	....	Productive from Trenton after acidization.	56	A034LE
?	?	....	?	?	....	Small producer.	57	
1718?	?	....	?	?	1718–G	Small producer from Trenton. Dry in 3 months.	58	A055LE
?	?	....	?	None	....	Dry hole.	59	A012LE
1798	Trenton limestone.....	1095	−70±	1679	71–O 325–O 1224–O 1330–O 1509–O	Produced about 3200 bbls. from Trenton.	60	A031LE
1850	Trenton limestone.....	....	?	?	....	Productive from Trenton.	61	A 59LE
?	Moccasin limestone....	....	?	?	....	Productive from Trenton.	62	A007LE
2200+	Moccasin limestone....	....	?	?	....	Small production from Moccasin limestone.	63	
2318	Moccasin limestone....	?	?	1518?	....	Small producer from Trenton after acidization.	64	
?	?	?	?	None	....	Dry hole. No data on well. May not have reached Trenton.	65	A055LE
2252?	Moccasin limestone....	?	?	None	....	Dry hole. Acidized unsuccessfully.	66	
1695	Trenton limestone.....	1200±	0	1690	1600–O	Productive from Trenton.	67	
2780	Moccasin limestone....	965±	−225	None	939–O	Dry hole.	68	A029LE
1320?	?	?	?	?	....	Productive.	69	
2100±	Eggleston limestone....	?	?	1326	....	Productive from Reedsville shale.	70	?

of Rose Hill refined some of this oil by heating it in tanks and catching the distillate. Neither the quantity of crude oil nor the quality of the product resulting from this refining method was sufficient to make the venture financially successful, and the well was abandoned. A string of tools was lost in the bottom of the well and later another string is said to have been lost in an attempt to clean out the well. Some 6-inch and 10-inch casing was left in the hole.

Acetone tests of the cuttings from this well gave good color from samples at 1228 and 1237 feet, but only light color from the samples at 1410 feet where the only production was reported. Available evidence indicates that the beds penetrated by this well are nearly horizontal. Such oil as was present was probably in small fractures in the Trenton limestone.

Lon Montgomery well.—The Lon Montgomery well was drilled in 1924 or 1925 at a point almost in the middle of Possum Hollow near the west fork of Possum Hollow Creek and about 1455 feet above sea level (Pl. 2). The farm at that time was owned by Montgomery but was later bought by a Mr. Ingram. No cuttings and no drilling log of this well were kept, and only the sketchiest accounts of it have been obtained. It is said to have been about 2400 feet deep, and to have encountered one gas pocket but no oil. If the well was 2400 feet deep it should have bottomed near the base of the upper or platy member of the Lowville limestone, and it had certainly passed through both the Clinch sandstone and Trenton limestone in which shows were found and very minor production obtained in the two Gilbert Lee wells.

Jack Asher well.—The Jack Asher well is about 1410 feet above sea level in the bottom of Possum Hollow a few feet west of the creek and about a hundred yards south of the Gilbert Lee No. 1 well. It was drilled in 1928 or 1929. Here also no drilling records were kept. The well is said to be about 900 feet deep. It started in the upper part of the Clinton shale and should have been about in the middle of the Reedsville shale at 900 feet. Three sets of tools, presumably a drilling string and two sets of fishing tools, are said to have been lost in the well. No oil or gas was produced, but C. A. Bales is reported as stating that the well had some oil.

W. B. Fulton well.—The well drilled in 1933 and 1934 by W. B. Fulton of Gate City was the fourth to be located in Possum Hollow. Technically this well should be named the Gilbert Lee No. 3, but it has commonly been called the Fulton well. It was drilled on the side of the Possum Hollow road only a few feet east of the Gilbert Lee No. 1 well at the opposite end of a shed. The well started at an elevation of 1415 feet in the upper part of the Clinton shale. At a depth of only 40 feet a good show of oil was found and a 65-barrel tank was filled the first day. Drilling was continued, however, and at 300 feet a flow of salt water was met, which shut off the oil. This is the same water horizon reported in the Gilbert Lee No. 1 well. Although the well was continued to 1498 feet, no oil or gas of importance was found.

Lack of cuttings makes it impossible to determine exact positions of geologic contacts in this well, but a driller's log was preserved and has been interpreted graphically in Plate 46. The well undoubtedly penetrated most of the Clinton shale, all of the Clinch sandstone, the Sequatchie formation, and the Reedsville shale and bottomed a little above the middle of the Trenton limestone.

Pritchard well.—The Pritchard well was drilled in 1937 by the Mountain Empire Company. It was located in the Possum Hollow fenster on a steep slope on the east side of the road at an elevation of about 1460 feet. The pipe, including the casing head, was pulled and the location is now marked only by mud in the sludge pit.

Cuttings of the Pritchard well have been supplied to us by Mr. Gilbert Lee. The well is reported to have gone to 467 feet but the deepest cuttings in the set come from 453 feet. The well spudded in near the top of the Clinton shale only a few feet below the Pine Mountain overthrust fault. Maynardville limestone above the fault forms a small bluff a few dozen feet east of and above the well. The well penetrated a normal section as shown in Plate 46, and bottomed near the base of the Poor Valley Ridge member of the Clinch sandstone. No pays or shows were met anywhere in the well.

Ingram or Holcombe well.—The Ingram well, drilled in 1938, was the seventh well drilled in the Possum Hollow fenster. It is located on the crest of the spur that separates the two forks of the upper part of Possum Hollow. The well is 1570 feet above sea level and about 130 feet above the valley floor on which most of the earlier wells were spotted. Despite the recency of this well, little information could be obtained on the nature of the rocks penetrated. The well is said to be 1870 feet deep. It spudded in near the top of the Clinton shale and only a few feet below the Pine Mountain overthrust fault, which crosses the spur about 200 feet east of the well. The well is near the crest of a minor dome in the stationary block, as shown by the presence of Cayuga dolomite at lower elevations to the east and south in the Possum Hollow fenster, and to the west in the Wilson fenster. The dome is closed on the north by the northward dip of the rocks of the stationary block beneath the overthrust sheet. At 1400 feet a gas pocket was encountered which blew off for 2 or 3 days. Oil is reported to have been standing in the hole in 1942, but the horizon from which the oil comes is not known. If the rocks are in their proper order in the well, which seems reasonably certain, the gas horizon would have been about in the middle of the Trenton limestone, and the bottom of the well would have been near the base of the Eggleston limestone. There is no casing in the hole.

This is correctly shown as No. 21 on map (as No. 23 in chart)

Gilbert Lee No. 3 well.—This well was the eighth to be drilled in Possum Hollow. It is located on the north bank of Possum Hollow Creek 135 feet south of Gilbert Lee No. 2 well, and a slightly greater distance from the Gilbert Lee No. 1 well. The well was drilled by J. C. Sheaffer and associates in the summer or fall of 1946, and bottomed at 1869 feet. No data on the drilling history of this well have been obtained, but it is known to have been a dry hole.

WELLS IN FOURMILE FENSTER

B. C. Fugate No. 1 well.—The B. C. Fugate No. 1 well actually represents the second well started in the Fourmile fenster. The first well located in this fenster was the Lemons No. 1, which was drilled in 1939 to a depth of 1452 feet; it was deepened in 1944 to 3261 feet. Because the completion of the Lemons No. 1 well postdates the first three B. C. Fugate wells, it will be discussed after them.

The B. C. Fugate No. 1 well was drilled by R. Y. Walker of Baton Rouge, Louisiana. The well is located a few feet from the road in the narrows where Fourmile Creek cuts through the ridge of Clinch sandstone. At the time the well was drilled, the land was owned by G. W. Fugate, since deceased, but is now owned by B. C. Fugate. It spudded in at an elevation of 1447 feet in beds near the top of the Sequatchie formation which dip 21° to the northwest.

Cuttings of the well were saved but have since become scattered, and only a partial set was available for study. From these and the driller's log, the graphic log in Plate 46 has been constructed. The well reached the base of the Sequatchie formation at about 300 feet and the base of the Reedsville shale at about 710 feet. At 1108 feet, some 400 feet into the Trenton limestone, a little gas was encountered and on May 7, 1942 the well reached 1110 feet where the hole began filling with oil. Drilling was continued to 1115 feet. The well filled with oil to within 200 feet of the top in two days. The first day it pumped it produced 90 barrels, but fell to 56 barrels on the second day and to 30 on the third day. Some weeks later a 12-day pumping test was made, the results of which are shown below:

Pumping test on B. C. Fugate No. 1 well in June 1942

Date	*Hours Pumped*	*Number of Barrels*
June 5, 1942	3	20
" 6, "	5	20
" 7, "	5½	20
" 8, "	6⅔	15½
" 9, "	7½	10
" 10, "	7½	10
" 11, "	6	10
" 12, "	6	10
" 13, "	3½	10
" 14, "	5½	9
" 15, "	4½	9½
" 16, "	2¾	6⅔

The well was then shut in for nearly a year, during which time oil flowed out at the surface whenever the valve was opened. Daily pumping began in the spring of 1943 and the well quickly settled to a steady 8-barrel a day yield, which was obtained by pumping about an hour and 40 minutes once a day. When the well was pumped longer the fluid column in the well was lowered. After a day or two of heavy pumping production dropped below 8 barrels and recovered only when the time of pumping was shortened so that the fluid column could return to its former level. In June 1946 the B. C. Fugate No. 1 had been producing for three years at an average rate of 8 barrels a day with no signs of any decline in production. In these three years the well had produced about 7500 barrels of oil. The pump and storage tanks at the well are shown in Plate 43B. The pump is powered by a gas engine utilizing the small flow of gas from the well. The geology of the occurrence of the oil and also the grade of oil in the B. C. Fugate No. 1 well are discussed in later sections of the report.

B. C. Fugate No. 2 well.—The B. C. Fugate No. 2 well was drilled by R. Y. Walker in late 1942. It was the first offset to be drilled from the B. C. Fugate No. 1 producer. It is in the Fourmile fenster at an elevation of 1512 feet but it lies in the extreme western corner of the fenster only about a hundred feet from the outcrop of the Pine Mountain overthrust fault. Conasauga shale of Cambrian age lies above the fault, but the well started in the lower part of the Hagan member of the Clinch sandstone (Silurian) beneath the overthrust.

Although the B. C. Fugate No. 2 well was drilled only 1445 feet from the B. C. Fugate No. 1 well, and started within a few dozen feet of the same stratigraphic horizon, it encountered a very different geologic situation as it went down. The calcareous siltstones of the Sequatchie formation were reached at a depth of 115 feet and the Reedsville shale at 400 feet, which is quite normal. At 435 feet, however, a fault was crossed, and the drill went back into the Sequatchie. The drill then reached the Reedsville shale for the second time at a depth of 587 feet. The Reedsville shale is only 360 feet thick, yet the drill was in Reedsville from 587 to 1799 feet. In this distance slickensides show in the cuttings in several places, and a great deal of trouble was reported in the drilling because of steeply dipping beds. The Reedsville is thus tremendously overthickened in this well owing to faulting and probably also to folding. At 1528 feet there was a show of oil which came in at 7 barrels and later settled to 4 barrels. Drilling was continued, and the top of the Trenton limestone was reached at 1799 feet. At 1813 there was a small show of oil and gas directly beneath a horizon at which a mudflow occurred. The mudflow is believed to have been due to bentonite R13, (p. 127), which is only 2 inches thick where it has been seen at Hagan, but may be considerably thicker elsewhere. No additional shows were encountered in the well although nearly 200 feet of Trenton limestone were penetrated before drilling was stopped at 2003 feet. Evidence of faulting noted in the Trenton probably indicates that the 200 feet which was drilled represents a stratigraphic thickness considerably less than this. The possibilities for oil in this well were not completely tested, as the producing horizon in the B. C. Fugate No. 1 well was 400 feet below the top of the Trenton, or at least 200 feet deeper than the bottom of the hole in the B. C. Fugate No. 2.

After drilling stopped, the producing horizon at 1527-29 feet and the show beneath the bentonite at 1813 feet were both shot without improving the flow of oil. Then the 1527-29 foot horizon was acidized.

This seemed to have a plugging effect, for the reported production of 4 barrels a day ceased entirely after the acidizing. The well has 96 feet of 10-inch drive pipe and 357 feet of 8-inch casing.

The B. C. Fugate No. 2 well revealed some extremely important geology, which cannot be seen at the surface and which has not been duplicated in any other well. The information from this well forms the basis for many of the structural interpretations shown in later figures and discussed in the section on the occurrence of the oil.

B. C. Fugate No. 3 well.—Between the drilling of the B. C. Fugate No. 2 and the B. C. Fugate No. 3 wells, the Virginia Lee Company was formed, which included those interested in the first two Fugate wells and several additional men. Several of these men are residents of southwest Virginia, others are from outside the state. The Virginia Lee Company drilled the third well on the Fugate farm in the fall of 1943. It is located 565 feet north (downdip) from the B. C. Fugate No. 1 well, and is alongside Fourmile Creek about 500 feet west of the road at an elevation of 1451 feet.

The well started in the upper or Poor Valley Ridge member of the Clinch sandstone. In the immediate vicinity of the well the dip of the beds at the surface ranges from 11° to the northwest to 25° slightly east of north. The Fugate No. 3 well penetrated a normal sequence of formations (Pl. 46), though the thicknesses of formations in the well are somewhat greater than their true thicknesses due to moderately steep dips. The Trenton in particular is overthickened.

The well bottomed at a depth of 1773 feet very near the base of the Eggleston limestone. A show of gas was obtained at 800 feet just above the base of the Reedsville shale and a good show of oil at 805 feet in the very top of the Trenton limestone. Farther down in the Trenton a light show occurred at 972 feet and a good show at 1033 feet. Although the well was continued through the rest of the Trenton into the Eggleston no more shows were found. The good show at the top of the Trenton and the good show 200 feet deeper were both shot. Both horizons contribute to the production from this well, the lower one more than the upper. The well was hooked to the same engine that pumps the B. C. Fugate No. 1 well and it has been pumped daily since January 19, 1944. Right from the start it has averaged about 3½ barrels a day on 1½ hours of pumping. Total production up to June 1946 has been about 1700 barrels.

It should be noted that neither of the producing horizons in this well is the same as the producing horizon in B. C. Fugate No. 1 well, which lies about 400 feet below the top of the Trenton. Hence, the evidence opposes the presence of an oil pool confined within narrow limits to a particular stratigraphic zone in the Trenton limestone.

Lemons No. 1 well.—The Lemons No. 1 well was started in 1939 by O. A. Larazola and was drilled to a depth of 1445 feet. In 1944 it was cleaned out by Floyd Fitch and associates and deepened to 3261 feet, at which depth it was in the upper part of the Mascot dolomite. It thus reaches a deeper stratigraphic horizon in the stationary block beneath the Pine Mountain overthrust fault than any other well in the area.

The well is located near the south edge of the Fourmile fenster 486 feet southeast of B. C. Fugate No. 1 well and 77 feet east of the road at an elevation of 1438 feet. It started a little above the middle of the Sequatchie formation, which at the well dips about 16° to the northeast. The dips in this region are variable, however, probably because of the proximity of the Fugate overthrust fault, which formerly lay only about 30 feet above the rocks exposed at the well. Cuttings from top to bottom of this well have been examined by us. The well penetrated a normal sequence down through the lower part of the Sequatchie formation, Reedsville shale, Trenton limestone, and Eggleston limestone. A little gas was reported at 1125 feet near the base of the Trenton and also at 1250 and 1265 feet, the last mentioned directly below the lower of the two big bentonites in the Eggleston.

In the upper part of the Moccasin limestone oil shows were reported at 1375, 1405 and 1445 feet. None of the three shows seems to have been of sufficient magnitude to encourage Larazola to pump the well. The well was abandoned at 1445 feet in 1939. Later it filled with oil to within 160 feet of the top. When it was cleaned out in 1944 by Floyd Fitch, 40 barrels of oil were bailed. The well was then carried down through the lower Moccasin, Lowville, Lenoir, Mosheim, and Murfreesboro limestones into the Mascot dolomite. All formations in this part of the well are considerably thicker than their true thickness; this indicates that the dip of the beds is steeper in the lower half of the well than in the upper half. Several shows of gas and oil, indicated on the graphic log (Pl. 46), were met in the lower part of the Moccasin limestone and in the Lowville limestone. The largest gas show was a pocket at 1954 feet, which blew the tools back up the hole and blew off for 12 hours. This gas pocket lay directly beneath a bentonite, which has not been recognized elsewhere in the region. The stratigraphic horizon of the bentonite cannot be spotted exactly because of the absence of marker beds recognizable in well cuttings in this part of the section, and also because in the Lemons well the combined Moccasin and Lowville limestones occupy an interval 330 feet greater than their stratigraphic thickness. Red beds 100 feet below the bentonite are unquestionably in the redbed member of the Lowville, but which redbed or argillaceous zone they represent (see Pl. 20) is not apparent.

Contacts between the Lowville, Lenoir and Murfreesboro limestones cannot be drawn with assurance in the well, but the base of the Murfreesboro is marked approximately by a big bentonite, which is shown as R1 on Plate 26. Drilling was stopped at 3260 feet, about 82 feet below the top of the Mascot dolomite, because of persistent caving from this bentonite at the base of the Murfreesboro. No sandy horizons of any importance were found in the upper part of the Mascot, though there are a few sand grains in some of the cuttings.

The three best shows of oil were at 1444-53, 1509-16 and 1595-1606 feet, all in the Moccasin limestone. All three shows were shot. The first two failed to improve, but the third produces a little oil. Pumping tests indicate that this amounts to about three-quarters of a barrel a day. The well was drilled uncased and has stood open since drilling ceased.

The oil from this well has not been analyzed, but has a clear, amber color and resembles very closely the Trenton oil from the B. C. Fugate No. 1 well.

Lemons No. 2 well.—The Lemons No. 2 well was drilled in the late summer and early fall of 1945 by Floyd Fitch, Fred Seal and Raymond Sliney. Its location is at an elevation of 1473 feet 230 feet southeast of the B. C. Fugate No. 1 well and 319 feet north of Lemons No. 1 well. The well started near the top of the Sequatchie formation at almost the same stratigraphic horizon as the B. C. Fugate No. 1 well. The top of the Reedsville shale was reached at 280 feet and the top of the Trenton limestone at 795 feet. An oil show was encountered 260 feet below the top of the Trenton, a gas show 350 feet below the top, and a producing horizon at 1211-1214 feet, 416 feet below the top. Drilling continued to 1222 feet without finding additional producing beds. In the B. C. Fugate No. 1 well nearby the producing horizon was 400 feet below the top of the Trenton but was at a depth of 1110 feet. The variation in depth to the same horizon in the two wells is due to the fact that the thickness of the Reedsville shale in the B. C. Fugate No. 1 well is 70 feet greater than the true thickness of the

Reedsville whereas in the Lemons No. 2 well the thickness of the Reedsville is 175 feet greater than its true thickness.

When the producing horizon was penetrated in the Lemons No. 2 well, the hole filled with oil to within 200 feet of the surface in 3 days. After the initial head had been pumped off, the well settled to a daily production rate of about 7 barrels. By June, 1946 it had produced about 1800 barrels of oil. In July, 1946, the producing horizon was shot with deleterious results. Since that date production is reported to be at a rate of about 4 barrels per day. A little gas accompanies the oil, but there was no water anywhere in the well.

This well and all later wells in the Fourmile fenster were drilled after completion of our detailed studies of the Rose Hill district. It has not been possible to incorporate the data from these most recent wells into the illustrations of the geology of the oil field. Cuttings of the Lemons No. 2 and several other recent wells have been studied, however, and nothing was found which would materially alter the concepts set forth in the succeeding sections of this report.

Lemons No. 3 well.—Lemons No. 3 well was drilled in the fall of 1945 by Fitch, Seal, and Sliney immediately after the completion of Lemons No. 2. It was drilled 460 feet northeast of the Lemons No. 2 well just south of the crest of the Clinch ridge at an elevation of 1548 feet. The well started in the lower part of the Poor Valley Ridge member of the Clinch sandstone, reached the top of the Sequatchie formation at 89 feet, the top of the Reedsville shale at 473 feet and the top of the Trenton limestone at 938 feet. Both the Sequatchie and Reedsville are considerably thicker in the well than can be accounted for by correcting their stratigraphic thickness by the factor determined by the regional dip of the beds. The amount of overthickening is about 100 feet for the Sequatchie and nearly 125 feet for the Reedsville. Apparently the overthickening observed only in the Reedsville shale in the Lemons No. 2 well is distributed through both the Reedsville shale and Sequatchie formation in the Lemons No. 3.

In drilling the Trenton limestone, a show of oil accompanied by a little gas was encountered at 1265 feet. The oil show made about 10 gallons a day. No other shows were found, although drilling continued through the Trenton and Eggleston limestones. The base of the Trenton is at 1446 feet and the base of the Eggleston limestone at 1584 feet. The well was abandoned at 1590 feet in the top of the Moccasin limestone, and the casing was pulled. In the summer of

1946 the well was deepened, but we have not been able to obtain data as to the final depth reached. No producing horizons or important shows were encountered in the Moccasin limestone, and the well was abandoned for a second time.

Fugate Estate No. 1 well.—This well was drilled by the Rouge Oil Co. in the late winter of 1946 at a site on the north side of the ridge of Clinch sandstone. The well is 330 feet north-northwest of the Lemons No. 3 well and 368 feet east-southeast of the B. C. Fugate No. 3 well.

The well started at an elevation of 1534 feet in the upper part of Poor Valley Ridge member of the Clinch sandstone, reached the top of the Sequatchie formation at 241 feet, the top of the Reedsville shale at 497 feet and the top of the Trenton limestone at 947 feet. The Sequatchie formation occupies an interval in this well approximately equal to its stratigraphic thickness, but the Reedsville is as usual overthickened, here by about 100 feet. Shows of oil were reported in the Trenton at 1158 and 1277 feet, and shows of gas at 1133, 1248, and 1255 feet. None of these shows was promising and the operators were considering abandoning the well at 1488 feet, at which time it had reached a point 32 feet below the top of the Eggleston limestone. Eventually it was decided to drill a little deeper, and the well was completed at 1610 feet in the top of the Moccasin limestone 5 feet below the base of the Eggleston limestone. A producing horizon was penetrated near the bottom of the hole, but it is not clear from the drilling record, or subsequent history of the well whether the pay was in the top of the Moccasin limestone or the lower part of the Eggleston limestone. This is the first well in the region to obtain significant oil production from any formation other than the Trenton limestone. The well came in at 65 barrels a day, and ten months later had settled to a rate of about 18 barrels a day. If it remains at or near that figure it will prove to be more productive than any previous well in the field. The oil has not been analyzed but appears to be similar to if not identical with the oil produced from the Trenton in the other wells.

B. C. Fugate No. 2B well.—The B. C. Fugate No. 2B well was drilled in the spring of 1946, also by the Rouge Oil Co. It is on the land originally owned by G. W. Fugate but now belonging to Byron C. Fugate. The well was drilled 515 feet southwest of the B. C. Fugate No. 1 well, slightly less than halfway from this productive well to the dry B. C. Fugate No. 2 well. No cuttings were saved on the first 1100 feet of this well.

The well started at an elevation of 1468 feet in the upper part of the Sequatchie formation. It is known to have been in Trenton limestone at 1102 feet and to have bottomed at 1908 feet, in the Eggleston limestone. The upper part of the Eggleston is greatly overthickened showing very steep dips, probably accompanied by minor folding and faulting at the bottom of the hole. A show of gas was reported at 716 feet, but whether there were other oil and gas shows is not known. The well was a dry hole.

Recent wells in the Fourmile fenster.—Between May 1946 and April 1, 1950 ten wells were drilled in the Fourmile fenster by the Rouge Oil Company. All ten wells came in as producers, many of them with a larger daily yield than any wells completed previous to May 1946. Most of the data on these new wells have not been released for publication. However, the available information on the wells is given in Table 11 (p. 278), and the locations of the wells are shown on Plates 1 and 2.

All ten of the new wells are in the northern part of the Fourmille fenster. All start in the Clinton shale, and all eight completed wells are reported to obtain their production from the Trenton limestone.

Wells were spudding in at the rate of 1 or 2 a month in the spring of 1947. Two of these were near the north edge of the Fourmile fenster, but outside rather than inside of the fenster.

WELLS OUTSIDE THE FENSTERS

McClure well.—The first well to be drilled in Lee County was on the farm of D. C. McClure 10 miles east of Rose Hill and 6 miles east of the mapped area (Pl. 1). Its approximate location is shown on Figure 1. It was started in 1910 and drilled intermittently until 1915 when it was finally abandoned. No cuttings and no log of the well were kept by the drillers and reports of the depth of the hole vary from 3250 to 3400 feet.

The McClure well was drilled before the Cumberland overthrust block had been recognized by Wentworth,[219] and before the fensters of the Rose Hill region had been discovered by Butts.[220] There was thus no comprehension of the regional structure, and apparently there was also little appreciation of the local structures in the vicinity of the

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[219] Wentworth, C. K., Russell Fork fault of southwest Virginia: Jour. Geology, vol. 29, no. 4, pp. 351-369, 1921.

[220] Butts, Charles, Fensters in the Cumberland overthrust block in southwestern Virginia: Virginia Geol. Survey Bull. 28, 12 pp., 1927.

site chosen for drilling. The well was drilled on the south flank of the Powell Valley anticline. East of the Rose Hill district, however, another small anticline lies between the axis of the Powell Valley anticline and the Wallen Valley fault. Jonesville, the county seat of Lee County, is in the gentle flat-bottomed syncline between the two anticlines. These structures are shown on Butts'[221] Valley map of Virginia. The McClure well was spotted in a region of almost flat dips, on the edge of the flat-bottomed syncline. North of the well the beds dip southward off the crest of the Powell Valley anticline, but they are undulatory and in general horizontal for nearly half a mile south of the well.

The well started in the overthrust block at an elevation of about 1350 feet about 210 feet above the base of the redbed member of the Lowville limestone. It is believed to have reached the Pine Mountain overthrust fault near the bottom of the hole and to have penetrated a few feet into the stationary block. This opinion is based in part on the fact that the rocks are described by the man who drilled the well from 2400 feet to the bottom as having been entirely limestone or dolomite. If no fault had been encountered the drill should have penetrated all of the Knox group, which is uniformly dolomitic, and should have passed from the underlying Maynardville limestone into the Conasauga shale at about 3150 feet. Near the bottom of the hole, also, drilling troubles were encountered and the hole was shot in order to straighten it. After the shot, pieces of chert with abundant fossils "like snails" came up in the bailer. No chert with abundant snail-like fossils is expectable from formations in or anywhere near the Maynardville limestone. ? Gas was also reported in this part of the well "which would burn to the height of a man." In the Rose Hill district the Pine Mountain overthrust fault shows a marked preference for lying at or near the base of the Maynardville. The verbal evidence detailed above indicates that at about the expected depth of the base of the Maynardville, the driller encountered drilling troubles, a gas pocket and fossils unlike those in the Maynardville or Conasauga. ? The most logical explanation is that the Pine Mountain fault was penetrated at an approximate depth of 3150-3250 feet. The best guess as to the formation beneath the fault is that it was Trenton limestone which has numerous silicified gastropods especially in the upper part. An unsuccessful search was made at the well site for pieces of the fossiliferous chert.

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

The McClure well is known to have had 6-inch casing to 1800 feet, but there may have been additional casing. It is now partly plugged with concrete and filled with stones. The log is shown diagrammatically in Plate 46, but no data were available on which to base any interpretation of the rocks penetrated between the surface and the Pine Mountain overthrust.

Billy Parkey well.—The Billy Parkey well is located at the base of Poor Valley Ridge in the northwest corner of the district. It was drilled in 1928 and 1929 by J. H. Johnson, W. A. Head and J. A. Gilmore of Big Stone Gap, Virginia. No cuttings and no log of the well were kept, so that the valuable geologic information that might have been gained at this site is largely lost.

The well is situated in an area in which the rocks dip about 15° to the northwest. No anticlinal or synclinal structures lie anywhere in the vicinity. The well started at an elevation of about 1465 feet, 140 feet below the top of the Trenton limestone. It went to 2650 feet and was reported to have been in limestone or dolomite all the way to 2640 feet, below which an 8- to 10-foot bed of "fireclay" was penetrated. Below this lay a sand with a little oily gas. This was being tapped when a caving from the "fireclay bed" broke the rope and the tools were lost. Due to various difficulties the well was abandoned and the tools are still in the hole, as is casing to a depth of 1200 feet.

If formations were penetrated in their proper order the well should have been about in the middle of the Chepultepec dolomite at 2640 feet. No beds are known in the Chepultepec or for many hundreds of feet above or below it which would correspond with the description of "8 to 10 feet of fireclay". Coupled with the occurrence of gas and the drilling troubles at this same depth, this description sounds as though the Pine Mountain overthrust had been reached at 2640 feet and that below the fault the well entered beds that are probably the Upper Devonian or the Mississippian shales. It is not surprising that the Parkey well should apparently have met the Pine Mountain fault high above the base of the Maynardville limestone, because somewhere between the Rose Hill fensters and Pine Mountain, Kentucky, the Pine Mountain overthrust has to crosscut from the base of the Maynardville limestone upward into the Mississippian black shales. The presumed position of the Pine Mountain overthrust in the Parkey well has been shown in Plate 46.

Brooks gas well.—The Brooks well was drilled by D. E. McInnes, A. K. McInnes, A. R. Johnson, Charles Lamar and R. Y.

Walker in the summer and fall of 1943 and carried to a depth of 3255 feet, at which point it was in the Reedsville shale. In 1945 it was cleaned out by the Calapor Manufacturing Co. of New Orleans, Louisiana, and drilled through the Trenton limestone. It was completed at a depth of 4079 feet in the Eggleston limestone.

The well is located about 100 yards from the east fork of Lick Branch in the low flat region of Conasauga shale known as Frog Level (Pl. 1). Plate 45B shows the Brooks well site and the rig used in the 1945 drilling. When the photograph was taken a string of 6-inch casing was being seated at 3255 feet.

The well started at an elevation of 1452 feet in the middle of the Conasauga shale, with the expectation that the Pine Mountain overthrust fault would be met at a shallow depth and the potentially petroliferous rocks beneath the overthrust would be tested. Instead of that, 262 feet of Conasauga shale were drilled, and then 1658 feet of shale, sandstone, dolomite, and limestone belonging to the Rome formation (Pl. 46). These beds are not exposed anywhere in the Rose Hill district. In the Brooks well a major overthrust fault plane was finally crossed at a depth of 1920 feet. Beneath this overthrust 82 feet of lower Clinton shale were drilled (the Brooks slice), and then the well crossed a second major overthrust fault plane and entered the Cayuga dolomite. Formations of the stationary block were then drilled in the proper stratigraphic order from the Cayuga dolomite to the bottom of the hole in the Eggleston limestone. In the coarse basal sandstone of the Cayuga dolomite at 2029 to 2034 feet a gas horizon was encountered which gauged 225,000 cubic feet. The well was drilled as an open hole for the next 60 days, and the gas blew off continuously. At the end of that time it was shut in and after 2 hours it gauged 211,000 cubic feet. An analysis of the gas, which has been supplied by Mr. W. B. Maxwell of the United Fuel Gas Company, is given below:

Analysis of gas from Brooks well near Ewing, Lee County, Virginia (From W. B. Maxwell)

	Percent
Methane	89.2
Nitrogen	2.7
Ethane	5.1
Propane	1.8
Butane	0.8

B.T.U. saturated with water 1024.
B.T.U. dry 1042.

There was another small show of gas from the Clinch sandstone at 2430-35 feet and a slight show of oil in the Reedsville shale at 3132 feet. Drilling was discontinued at 3255 feet in 1943 because the hole was caving. When it was reopened in 1945 casing was set at 3255 feet and drilling continued through the Reedsville and Trenton almost to the base of the Eggleston. The Trenton, which was the horizon aimed for, had only one very light show of oil. The well was completed at 4079 feet and the casing pulled.

The Brooks well is especially important because it demonstrates possibilities for gas production, perhaps on a commercial scale, and because it shows that rocks deeply buried beneath the overthrust block may be as favorable for oil or gas accumulation as the rocks in the fenster areas. Exploration outside the fenster region will be more difficult and more expensive, however, because there the geology of the stationary block beneath the Pine Mountain overthrust must be worked out largely by deep drilling. The farther from the fenster area wildcat drilling sites are chosen, the more difficult it becomes to make reliable predictions on the depth to the Pine Mountain overthrust and the formations that will be found beneath the overthrust.

Phipps well.—The Phipps well, which was drilled in 1944 and 1946 by Clarence Ellison, is located 5 miles east of the main area mapped in this report (Pl. 1). The location of the well and the geology in the vicinity are shown in Plate 47. The well is in the middle of Chestnut Ridge about 700 feet southeast of U. S. Route 58, where the highway cuts from the Indian Creek lowland through Chestnut Ridge to the Powell River lowland. It started at an elevation of 1585 feet in rocks of the overthrust block about 1700 feet south of the axis of the Powell Valley anticline. The surface rock around the well is Chepultepec dolomite. Sinkholes are abundant in the region and the dolomite is deeply weathered so that a mantle of 70 feet of clay and sand was penetrated before bedrock was reached. The top of the Copper Ridge dolomite was reached at 190 feet.

The drillers had trouble with their equipment and with heavy flows of fresh water. After very slow progress over a period of several months, the well was closed down at a depth of 712 feet. In the winter of 1946 it was deepened to 855 feet, but then abandoned while still in the Copper Ridge dolomite. If the Pine Mountain overthrust is at or near the base of the Maynardville limestone here as it is in much of the fenster region, it would lie at a depth of about 1300 feet as suggested in Plate 46. There seems no chance for significant oil production at this site until the overthrust fault is passed, though experience elsewhere has shown that gas in small quantities can occur in the Cambrian dolomite above the overthrust fault. The log of the Phipps well, based on cuttings, is shown in Plate 46.

The above paragraphs were written and the graphic log of the Phipps well (Pl. 46) was drawn in early 1947. Later in 1947, drilling was resumed on the Phipps well and it was carried to a depth of 1902 feet. The Copper Ridge dolomite continued to 1032 feet, at which point a fault was encountered. Below the fault were 224 more feet of dolomite probably belonging to the Chepultepec dolomite. The Pine Mountain fault was penetrated at a depth of 1256 feet. The section beneath the Pine Mountain fault was normal, with 452 feet of Clinton shale, and 177 feet of sandstone and shale belonging to the Poor Valley Ridge member of the Clinch sandstone. The well was abandoned for the third time when it was 18 feet into the Hagan shale member of the Clinch sandstone.

WELLS IN PROGRESS, JANUARY, 1947

At the end of January, 1947, seven wells were being drilled. Two of them are in the Fourmile fenster, one in the Martin Creek fenster, and four outside the fenster area.

Wells in Fourmile fenster.—The Fugate Estate B3 and the Joe Dean well were being drilled in the Fourmile fenster by the Rouge Oil Co. in January 1947. The former is in the east-central part of the fenster and the latter in the northeastern part of the fenster. The location and elevations of these wells are given in Table 11.

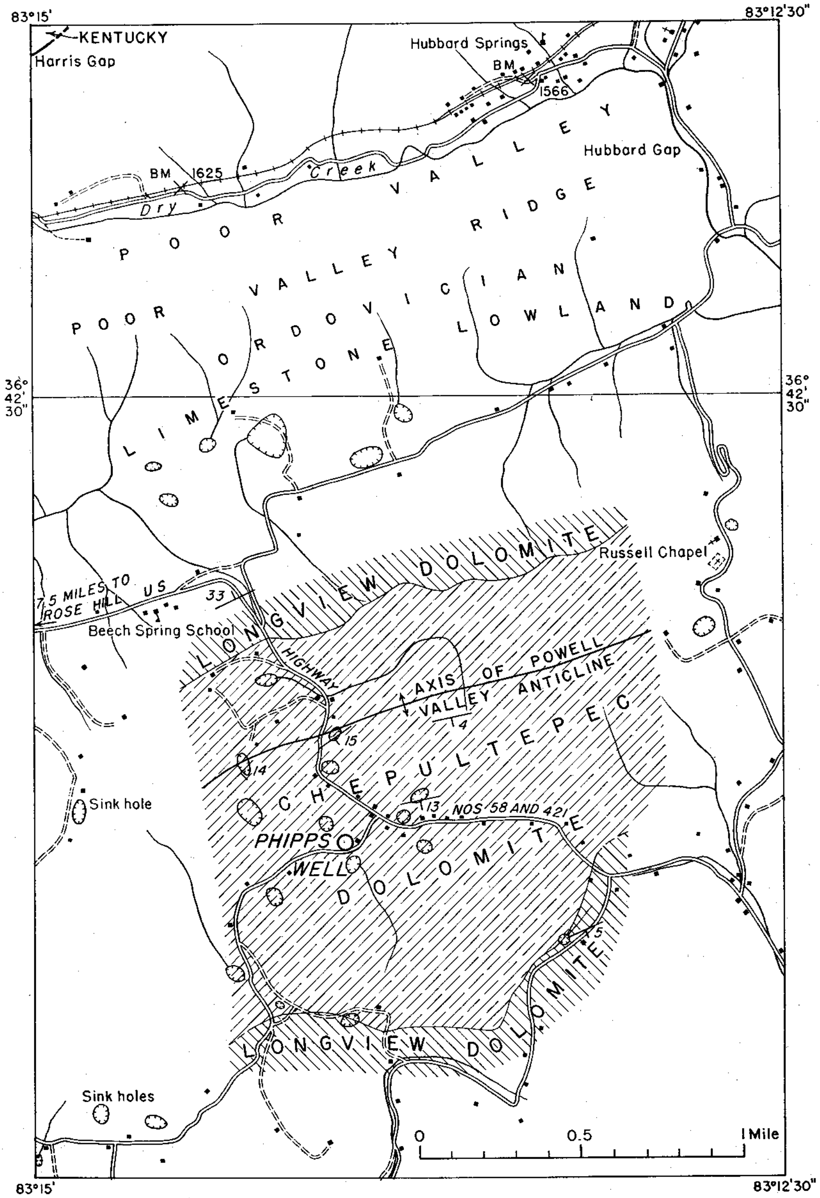
Well in Martin Creek fenster.—Up to January, 1947, all of the fenster wells were confined to the Possum Hollow and Fourmile fensters. In January, however, the Charles Hobbs well was started by the Rouge Oil Co. in the Martin Creek fenster, and drilling sites had been selected for wells in the Blackberry Hollow section of the Dean fenster and in the Hamblin Branch fenster.

The Hobbs well is in the northern part of the Martin Creek fenster just west of the main road. It spudded in on January 11th about 60 feet below the top of the Clinton shale. When visited by the senior author on January 15th, it was at a depth of about 150 feet, still in the Clinton. The dip of the beds of the stationary block in this vicinity is nearly horizontal, as shown by the Clinton-Cayuga contact, which lies at nearly the same elevation for considerable distances along both sides of the Martin Creek fenster.

Wells outside fensters.—At the end of January, 1947, four wells were being drilled outside of fensters. Two of them, the Patton Ely and George S. Yeary wells, are located northwest and north respectively of the Fourmile fenster. The Henly Sutton well is in the Frog Level region, about 1500 feet due north of the Brooks well, and the H. B. Nolan well is on Martin Creek about 3500 feet north of the north edge of the Outer Martin Creek fenster. Of these four wells, only the George S. Yeary well had progressed more than a few hundred feet when visited by the senior author in January, 1947. All four wells are listed in Table 11 (p. 278) and are shown on Plate 1. According to a report reaching us in late March, 1947, the Henly Sutton well was a dry hole, and the Nolan well was abandoned because of a crooked hole.

The George S. Yeary well is located 150 feet west of the Fourmile Creek road and about 3300 feet north of the north edge of the Fourmile fenster. It started about 350 feet below the top of the Copper Ridge dolomite. On January 20, it had reached a depth of 1225 feet and was in the upper part of the Clinch sandstone. The base of the Copper Ridge dolomite was at 666 feet, and the Pine Mountain overthrust fault was met at 845 feet. The beds directly above the fault are in the upper part of the Low Hollow limestone member of the Maynardville limestone; the beds directly below the fault are sandstones and sandy dolomites of the basal part of the Cayuga dolomite. However, between 845 feet and 888 feet the beds are somewhat jumbled. At least one small fault lies in this interval, resulting in the duplication of the Cayuga-Clinton contact. This contact was penetrated first at about 861 feet and again at 888 feet. Below 888 feet the beds are in normal order, and the top of the Clinch sandstone was reached at 1210 feet.

The George S. Yeary well gives an additional determination on the depth to the Pine Mountain overthrust fault outside the fenster area. It also demonstrates the presence of the sandstone at the base of the Cayuga dolomite beneath the fault at this location. This basal sandstone of the Cayuga is gas-bearing in the Brooks well, but no gas was reported at this horizon from the Yeary well. No doubt the steep dips and the faulting of the beds for 40 feet beneath the overthrust fault have permitted any gas in the sands of the Cayuga to escape.



Geologic map of the area near the Phipps well, Lee County, Virginia.

STRATIGRAPHIC HORIZONS OF THE OIL OCCURRENCE

Fourteen of the fifteen producing wells obtain their oil from the Trenton limestone, and the fifteenth (Fugate Estate No. 1) produces from the top of the Moccasin or the Eggleston limestone. The oil in the Trenton comes from at least three different horizons. The B. C. Fugate No. 3 well produces from the very top of the Trenton and also from a horizon about 230 feet deeper. The B. C. Fugate No. 1 and Lemons No. 2 wells on the other hand found no oil till 400 feet of the Trenton had been drilled, in spite of the fact that they are only about 600 feet from the B. C. Fugate No. 3 well. Obviously the oil is not confined to a single stratigraphic horizon. Information on producing horizons of the recent wells has not been released by the Rouge Oil Company, but the Company has indicated that all of them produce from the Trenton limestone.

The Trenton limestone is composed of coarse- to fine-crystalline, fossiliferous limestone containing partings and thin beds of gray to black shale. No beds have been seen in the Trenton at the surface that would be classified as sandstones. The Trenton has not been core-drilled in any of the wells in Lee County, so that porosity and permeability tests of the rock from the producing horizons could not be made. Fresh specimens of typical coarse-crystalline fossiliferous limestone from about the middle of the formation, and of fine-crystalline limestone from near the top of the formation were, however, collected at the surface and were tested for porosity and permeability. The effective porosity was 0.9 percent for the coarse-crystalline limestone and 1.2 percent for the fine-crystalline limestone. In both specimens permeability was negligible in both directions, parallel to the bedding and also across the bedding. None of these figures approach the porosity and permeability necessary for an "oil sand". The formation is not known to contain beds of any other lithologic character that would be appreciably more porous or pervious than the limestone. Hence, the space within the formation that is saturated with oil can hardly be original pore space.

Cuttings from the recent wells have not been available for study by us. We have, however, examined cuttings from the producing zones of the B. C. Fugate No. 1, B. C. Fugate No. 3, and Lemons No. 2 wells. Chemical analyses were made of 12 samples from the B. C. Fugate No. 1 and B. C. Fugate No. 3 wells, the results of which are shown in Table 12. Samples 1 and 2 came from zones not associated with any show or pay, and are included in the table to show the

TABLE 12.—*Chemical analyses of samples of well cuttings from the Trenton limestone*

Sample No.	Depth	Percent CaO	Calculated percent $CaCO_3$	Percent MgO	Calculated percent $MgCO_3$	Percent Insoluble	Percent Loss	Driller's description of sample
SAMPLES FROM B. C. FUGATE NO. 1 WELL								
1	1057′	49.40	88.16	1.63	3.41	8.20	0.23	No show
2	1075′	46.60	83.16	2.39	5.00	10.80	1.04	No show
3	1105′-1110′	43.00	76.74	1.74	3.64	17.90	1.72	Show of oil and a little gas at 1108′
4	1113′	19.60	34.98	2.25	4.71	54.80	5.51	Hole filled with oil at 1110′
5	1113′-1115′	39.90	71.21	1.76	3.68	23.60	1.51	Bottom of hole at 1115′
SAMPLES FROM B. C. FUGATE NO. 3 WELL								
6	897′-904′	45.40	81.02	2.21	4.62	13.70	0.66	
7	904′-911′	45.70	81.56	2.17	4.54	13.30	0.60	Small pay at 905′
8	1021′-1027′	50.40	89.94	1.48	3.10	6.90	0.06	
9	1027′-1032′	49.50	88.34	1.52	3.18	7.50	0.98	
10	1032′7″-1034′7″	49.30	87.98	1.92	4.02	4.10	3.90	Pay at 1032′-1034′
11	1034′7″-1037′	48.60	86.73	2.21	4.62	7.80	0.85	
12	1037′-1044′5″	52.20	93.16	1.45	3.03	3.70	0.11	

chemical composition of the Trenton at two horizons where it is nonproductive. Samples 3 to 12 came from zones at or near producing horizons in the wells.

The percentages of CaO and MgO in the analyses represent the amounts of these constituents in the soluble fraction of the sample only. On the assumption that all of the calcium and magnesium in the soluble fraction were present in the carbonate form, the percentages of calcium carbonate and magnesium carbonate were calculated. The increment not accounted for after totaling the percentages of calcium carbonate, magnesium carbonate and insolubles is reported as loss.

The analyses show clearly that the limestone has not been dolomitized, and hence that loss of volume due to dolomitization is not a factor in accounting for the porosity and permeability of the producing horizons in either well. The highest percentage of magnesium carbonate is in sample 2, one of the two samples remote from any reported pay or show. Samples at or near the pays have from 3.10 to 4.71 percent magnesium carbonate, which is lower than in the average limestone.

Samples at and near the pay in the B. C. Fugate No. 1 well and at and near the upper pay in the B. C. Fugate No. 3 well have higher percentages of insoluble material than the other samples. This is most pronounced in sample 4, which was labelled 1113 feet by the driller, but probably represents the interval from 1110 feet to 1113 feet and hence the pay. There is a slight increase in the percentage of insoluble material in sample 6, which lies just above the upper pay in B. C. Fugate No. 3 and in sample 7 which includes the upper pay, but sample 10 which includes the lower pay in this well has an unusually small amount of insoluble material. Some of the insoluble material in the analyzed samples is shale, which is common as partings and thin beds throughout the Trenton limestone. Sample 4, which has the highest percentage of insoluble material, contains more abundant chips of shale than do the other samples. Quite a few of the large chips of shale have one or more slickensided surfaces, indicating that slippage has occurred along the shaly beds and partings. Though quite numerous, the chips of shale in the sample do not seem sufficiently abundant to account for all the insoluble material shown by the chemical analysis. Furthermore the chemist reported that samples 4 and 5 ground harder than the other samples. In order to determine what other constituents might be present, thin sections of representative rock chips were made for each of samples 3, 4, 5, 6, and 7. Many of the chips in sample 4 proved to be medium-crystalline calcite and shale, but there were also numerous chips that consisted of minute, equidimensional, angular, quartz grains set in a matrix of crystalline calcite. The largest of the quartz grains were about 1/5 of a millimeter in diameter. In some of the chips quartz grains composed as much as half of the chip, but in others only a few quartz grains were scattered through the calcite. In no chip were the quartz grains uniformly in contact with each other, and none showed empty pore spaces between grains. In a few chips minor amounts of secondary quartz replaced calcite irregularly along planes of weakness. Sample 5 also contained a few chips having abundant quartz grains in a calcite matrix, and some chips having a few widely scattered quartz grains in calcite, but the proportion of chips composed entirely of calcite was much higher than in sample 4. Samples 3, 6, and 7 had some chips of calcite containing scattered quartz grains and small amounts of secondary quartz, but none containing abundant quartz grains.

The available data from chemical analysis and microscopic examination of cuttings from the producing horizon in the Trenton limestone may be summarized as follows. The openings occupied by the oil are not visible in the well cuttings. There is no evidence of dolomitization of the limestone at or near the producing horizons to account for the porosity. Two of the three producing zones studied contain some rock composed of abundant or scattered minute quartz grains in a calcite matrix. There are, however, no visible pore spaces between quartz grains. The quartzose rocks are not sandstones but are silty to fine-sandy limestones. The only sample from a producing horizon that consisted of sizable chips of rock showed several chips of shale having slickensided surfaces, thus indicating some slippage and movement of the rock.

Until the data and cuttings from the more recent productive wells become available for study, and until the Trenton limestone is cored and the cores from producing zones are tested and studied microscopically, final conclusions as to the nature of and causes for the porosity and permeability of the oil-bearing horizons in the Trenton are not possible. Our tentative conclusions, based on the information discussed above, are as follows:

1. The porosity and permeability of the oil-bearing horizons in the Trenton limestone are due to fracturing of the limestone during regional deformation of the rocks.

2. The fracture systems are interlocking, allowing migration of the oil along the fractures to the wells.
3. The fractures have probably been somewhat enlarged by solution, and the productive capacity of an oil-bearing zone may be directly related to the amount of solution that has occurred along the fractures. Inasmuch as the Trenton is not water-bearing in any of the wells for which drilling data are available, any solution that has occurred would have been by water that has since migrated elsewhere.
4. Limestones containing minute quartz grains seem to be more favorable for oil accumulation than non-quartzose limestones (a) because the quartzose limestones are more brittle and more susceptible to fracturing than the non-quartzose limestones, or (b) because the quartzose limestones are more susceptible to solution and the development of open channels along fractures, or (c) because of a combination of both of the above factors.

The top few feet of the Hardy Creek member of the Moccasin limestone seem to be the producing beds in the Fugate Estate No. 1 well, though some doubt exists whether the oil may not be coming from the overlying Eggleston limestone. The beds at the top of the Moccasin are well exposed in a section north of Chattels Station Church (Pl. 13). At this locality a unit, 13 feet thick, forms the top of the Moccasin limestone, and consists of interbedded cryptocrystalline, fine-crystalline, and medium-crystalline limestone, which is somewhat argillaceous and nodular and very fossiliferous in the upper part. These beds appear even more dense and impervious than the Trenton limestone, and are also not water-bearing where they have been drilled.

STRUCTURE NEAR THE OIL WELLS

The major structural features of the Rose Hill district have been described in the chapter on structure. The wells in and near the oil field are all drilled in rocks belonging to the stationary block, that is, rocks below both upper and lower branches of the Pine Mountain overthrust. The general structure of these rocks can be seen in the geologic sections of Plate 2, and in Map C of Plate 40, which is a geologic map showing how the rocks of the stationary block would appear if all the overthrust rocks could be stripped away. The oil in the Trenton limestone is believed to be in small fractures caused by structural deformation. It occurs in the upper edge of a broad anticline in the stationary block, which has been truncated by the Pine Mountain overthrust (Pl. 5B). The truncated anticline of the stationary block is surmounted by a broad anticline, the Powell Valley anticline of the overthrust block. It can not be too strongly emphasized that the structure contours shown on Plate 1 apply only to the Powell Valley anticline. The anticline in the stationary block cannot be accurately contoured until many wells are drilled outside the fensters. Local structures within the stationary block probably affect the occurrence of the oil, but the evidence that has become available to date does not justify conclusions as to which of the local structures are controlling or influencing factors.

In the Fourmile fenster where the early producing wells were drilled, the rocks dip to the north or northwest. At the surface the dips range from about 9° to 20°. Near the north edge of the Fourmile fenster the dips become gentle to nearly flat in the area of Clinton shale, and in the Sequatchie formation near the south edge of the fenster the dips are also nearly flat for a short distance. No anticline or monocline of any size can be deduced from these dips, however, for the geology exposed in the Sugarcamp fensters to the south requires that the dips to the northwest not only persist in the concealed rocks of the stationary block south of the Fourmile fenster, but that they become steeper. This is brought out clearly in the structure Section AA′ of Plate 2. Both the Reedsville shale and the Trenton limestone must abut beneath the Fugate branch of the Pine Mountain overthrust fault in the covered area between the Fourmile and Sugarcamp fensters, because the youngest formation exposed in the Sugarcamp fensters is the Eggleston limestone and the oldest exposed in the Fourmile fenster is the Sequatchie formation.

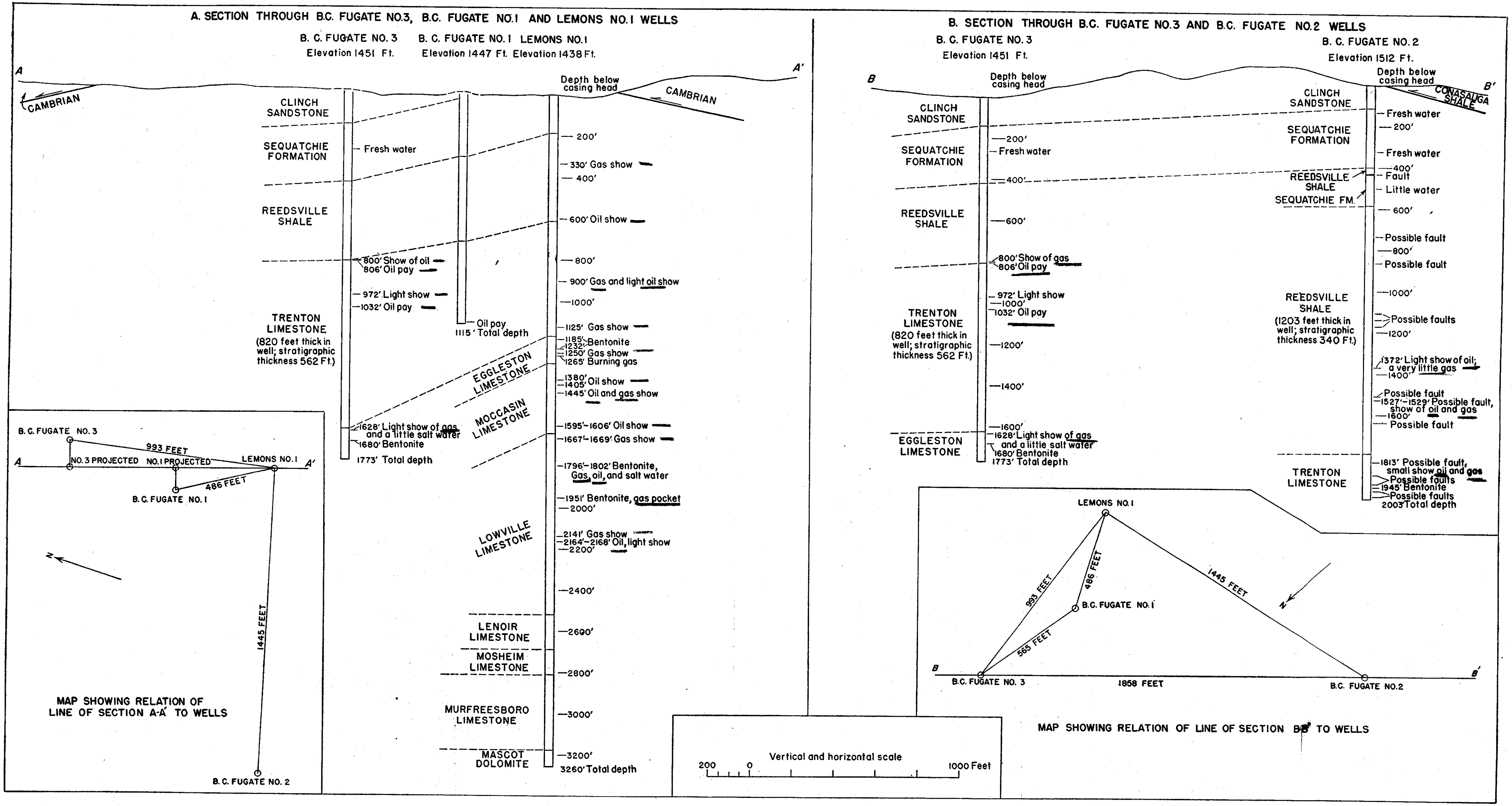
In order to get more detailed information on the structure in and near the oil field the logs of four wells (B. C. Fugate No. 1, 2, 3 and Lemons No. 1) were platted in their correct positions and to scale (Pl. 48). Section AA′ shows a northwest-southeast section through the Lemons No. 1, B. C. Fugate No. 1 and B. C. Fugate No. 3 wells. Uniform dips prevail in the upper parts of all three wells and the drilled thicknesses of the formations are only slightly greater than their true stratigraphic thicknesses. In B. C. Fugate No. 3 well, however, the Trenton limestone is 59 percent too thick. In the Lemons well the Trenton and Eggleston limestones have approximately their true thickness but all deeper formations are overthickened. Because of the difficulty in determining the contacts between the Moccasin, Lowville, Lenoir, Mosheim, and Murfreesboro limestones from well cuttings, it has not been possible to calculate the percentages of overthickening of individual formations in this part of the Lemons well, but the overthickening of the five formations combined is 25 percent. No evidence of faults was found in the B. C. Fugate No. 3 and Lemons No. 1 wells, hence the overthickening is believed to be due to a steepening of the dip of the beds.

Another line of section (Pl. 48, Section BB′) was taken in a northeast-southwest direction between the B. C. Fugate No. 3 and B. C. Fugate No. 2 wells. The section shows uniform dips from the B. C. Fugate No. 2 well to the B. C. Fugate No. 3 well in the upper parts of the wells, and the Sequatchie formation has approximately its correct stratigraphic thicknesses in both wells. Whereas in the B. C. Fugate No. 3 well the Trenton limestone, as previously noted, is somewhat overthickened, in the B. C. Fugate No. 2 the entire drilled section below a depth of 400 feet is highly abnormal. The Sequatchie-Reedsville contact is duplicated by a fault and after the Reedsville shale was entered for the second time, it was drilled continuously for 1203 feet. The formation is only 340 feet thick, so this represents an overthickening of 330 percent. One result of this overthickening of the Reedsville shale is that the Trenton limestone, which the operators expected to reach at about 800 feet, was actually found at 1790 feet. Both the cuttings and the drilling records indicate the presence of several faults within the Reedsville. The Trenton limestone also appeared to be fractured and faulted. This caused considerable drilling trouble, so the well was abandoned at 2003 feet after only 223 feet of Trenton had been drilled. Fractured and faulted Trenton limestone would seem to be more favorable for the accumulation of oil than undeformed Trenton, so it is unfortunate that the well was not continued through the Trenton to the Eggleston limestone.

The facts brought out by this analysis of the four wells may be interpreted in several different ways and still remain within the framework required by the well records. Three different interpretations were worked out graphically and are shown in block diagrams on Plate 50. Still other interpretations could also be made but they would probably be variations on or combinations of the three illustrated. A glance at the three blocks shows a strong similarity between them. Block 1 shows the simplest possible interpretation, in which all overthickening of formations is accounted for by the appropriate increase in the dip of the beds. The only fault shown is the one that is required by the duplication of the Sequatchie-Reedsville contact in the B. C. Fugate No. 2 well. According to this interpretation the occurrence of oil in the B. C. Fugate No. 3 well might be explained by the fracturing of Trenton limestone along the small monoclinal fold, but no reason for the localization of oil in the lower part of the Trenton in the B. C. Fugate No. 1 well is apparent. Block 2 is in general similar to Block 1 but the overthickening of the Reedsville shale in the B. C. Fugate No. 2 well is explained by a series of parallel faults rather than by folding. This seems to accord more closely with the drilling history of the well, but the net result is about the same as in Block 1. No good evidence exists for continuing these faults into the rocks penetrated by any of the other wells nor have any of the faults been noted at the surface. They have therefore been shown dying out to the east and being covered by the overthrust block to the west. The 25 percent overthickening of the pre-Eggleston formations in the Lemons well might be accounted for by extending one or more of these faults, but inasmuch as all pre-Eggleston formations appear to be overthickened in this well, a steepening of the dip of the beds seems a more logical explanation. The interpretation in Block 2 does not offer any additional reasons over Block 1 for the occurrence of oil in the B. C. Fugate No. 1 and No. 3 wells.

In Block No. 3 a hypothetical low-angle fault has been drawn connecting the lower producing horizon of the B. C. Fugate No. 3 well with a probable fault in the Reedsville shale at a depth of 330 feet in the Lemons well and with the known fault at the Reedsville-Sequatchie contact in the B. C. Fugate No. 2 well. The displacement on this possible fault could not be large, but it might be sufficient to account for the fracturing of the Trenton limestone in the B. C. Fugate No. 3 well and hence for the lower of the two producing horizons in this well.

The three interpretations shown in Plate 50 are not the only possible ones, for many other systems of small folds and faults might be drawn without violating the facts established by the surface geology and the well records. We believe, however, that the major framework of the structure must be essentially as shown in all three blocks. It is apparent that the major structure does



Sections through early wells in and near the Rose Hill oil field.

not supply any logical answer to the question why more oil occurs in the Trenton limestone in the B. C. Fugate No. 1 well than in the B. C. Fugate No. 3 well but none at all in the Lemons No. 1 well. One must conclude (1) that the fracturing which in places causes the Trenton limestone to be a reservoir rock is due to minor structural features of very limited areal influence or (2) that the strata of the Trenton limestone in the Fugate No. 1 and 3 wells are affected by some structure, such for example as a fault, that is so small in these two wells as to pass unnoticed, but that might nevertheless increase in magnitude away from the wells, or (3) that many brittle beds in the Trenton limestone are fractured over a fairly broad area. There is no water drive and little gas pressure in the oil field, so only minor diminution in degree of fracturing of the limestone would be necessary to render the limestone impervious.

Of the three possibilities suggested above, the third seems most reasonable in the light of present knowledge. Only when the records of the recent producing wells become available for study and when the limits of the field have been more definitely established by drilling, will it be possible to give a final answer to the problem of porosity and permeability.

The steep west dip from the Lemons No. 1 to B. C. Fugate No. 2 wells shown in the blocks of Plate 50 is not a purely local feature. As shown in the geologic section between the Lemons No. 1 well and the Brooks well (Pl. 1, Section CC′), the west dip continues until formations exposed in the Fourmile fenster are carried down nearly 3000 feet below their positions in the Lemons well. The known oil in the Trenton lies at the top of the monoclinal fold formed by this steep western dip of the beds. If the accumulation of oil has been controlled by fracturing of beds at the top of this monoclinal flexure, the possibilities for oil eastward along the strike from the B. C. Fugate No. 1 well would be poor. Recent producing wells drilled in the northeastern part of the Fourmile fenster more than half a mile west of the monoclinal flexure suggest, however, that the oil has migrated southward from beneath the Middlesboro syncline up the dip of the Trenton limestone to its present location rather than eastward up the dip of the monoclinal flexure described above. If any of the wells now drilling or proposed in the Dean, Hamblin Branch and Martin Creek fensters come in as sizable producers this interpretation will be strongly reinforced.

Recent discovery of oil that is probably in the Moccasin limestone in Fugate Estate No. 1 well, and the known occurrence of small amounts of oil in the Moccasin in the Lemons No. 1 well do not alter the hypotheses set forth above. They do, however, introduce additional problems requiring explanation. The Moccasin oil is so close to the Trenton oil and so similar to it, that the two probably had the same source. The most plausible explanation, though not necessarily the correct one, is that the oil accumulated in the fractured Trenton limestone, and migrated along a fault plane, such perhaps as the one shown in Block 3 (Pl. 50), across the highly impervious mudstones and bentonites of the Eggleston into fractured Moccasin limestone.

SOURCE OF THE OIL IN THE TRENTON AND MOCCASIN LIMESTONES

The oil being produced from the Trenton and Moccasin limestones in the Rose Hill field is believed to have had its source in the Trenton limestone. The Trenton seas were favorable to marine life, as indicated by the abundant shells of marine invertebrates now fossilized in Trenton rocks. Thus there could easily have been an abundance of organic material from which to form oil. Most of the Trenton limestones are dark colored due to included organic matter, and some of the brown and dark-gray limestones in the middle and upper parts of the formation have a strong petroliferous odor. In addition, joints coated with oily films, and vugs lined with asphalt have been found. Because the Trenton limestone is inherently dense and very impervious, the oil now thinly but very widely disseminated through the limestone must have been formed from organic matter trapped in the sediments at the time they were deposited. Its later accumulation in zones of fracture after the period of rock folding and faulting is then normal and expectable.

Too many unknown factors are involved in the problem to eliminate entirely the possibility that the oil now present in commercial accumulations in the Trenton limestone has migrated there from other source beds. The objections to such a hypothesis, however, are formidable. Some of these objections are considered below.

The most favorable source beds for the oil, other than the Trenton limestone, itself, are the black shales of the Upper Devonian and lower part of the Mississippian. In the Rose Hill district, however, these shales have been eliminated by overthrusting (Pls. 1 and 2) from the stationary block in which the oil occurs. Before erosion the black shales were present in the overthrust block about 5500 feet above the present location of the oil in the Trenton, but migration downward from these beds across all formations from the Cayuga dolomite to the Maynardville limestone and then across the Pine Mountain fault plane or planes into the stationary block beneath seems impossible. The black shales occur also beneath the Middlesboro syncline (Pl. 5B), where the Pine Mountain overthrust fault is believed to lie within them. Migration from this location might have taken place along the fault zone but after reaching the vicinity of the present oil field the oil would have had to migrate downward from the fault into the Trenton limestone. This also seems most improbable because it requires open channels from the present location of the oil upward to the fault plane, whereas the distribution of the oil as shown by the wells suggests that through channels or fractures do not continue upward to the fault. Furthermore, in migrating along the fault zone from the Middlesboro syncline, the oil would have had to pass over the edges of two formations far more porous and pervious and (or) more susceptible to fracturing than the Trenton limestone, that is, the Cayuga dolomite, and the Clinch sandstone.

Other formations in the region that might be source beds for the oil are the Copper Ridge dolomite and the Lenoir limestone. The lower 400 feet of the Copper Ridge is composed mainly of dark-colored coarse-crystalline dolomite, which has such a strong petroliferous odor that it has been called the "stinkstone." The oil is mostly disseminated as microscopic films around the crystals of dolomite, though some of it may be along cleavage planes within the crystals. In the photomicrograph (Pl. 11B) these films appear as thin black lines bounding the crystals.

The "stinkstone" is not local, but is characteristic of the lower part of the Copper Ridge dolomite over a broad area in southwest Virginia and east Tennessee. The organic material must have been imprisoned in the rock at the time the sediment was deposited, because it could hardly have been introduced so uniformly and so widely at a later date. The type of organic material that produced the oil is not known. Surprisingly, the Copper Ridge seas seem to have been generally unfavorable to marine organisms susceptible to fossilization, because fossils are extremely rare in the formation.

Specimens of the "stinkstone" were tested for porosity and permeability. The permeability proved to be negligible and the porosity only 0.5 percent parallel to the bedding and 0.9 percent across the bedding. Thus, although the rock is definitely petroleum-bearing, the petroleum may not have been available for abstraction and migration elsewhere. This same difficulty, however, is encountered in the case of the Trenton limestone, where the natural permeability and porosity are also very low. The Copper Ridge dolomite must thus be considered a possible though an improbable source bed for oil.

The lower 20 to 40 feet of beds in the Lenoir limestone are also characteristically dark-colored and in many places have a petroliferous odor when freshly broken. Most of the dark-colored beds are fine crystalline and dense, and sparingly fossiliferous, but some are coarse crystalline and are composed largely of fragmental fossils. This latter lithologic character is shown on the right side of the photomicrograph (Pl. 11F). Abstraction of disseminated petroleum from the fragmental type of Lenoir limestone would be difficult, but no more so than from the "stinkstone" of the Copper Ridge dolomite. On the other hand the fine-crystalline limestone of the Lenoir appears entirely too dense and impervious to be considered a possible source bed for petroleum that has escaped and migrated elsewhere.

The Copper Ridge dolomite is separated from the oil-bearing Trenton and upper Moccasin limestones by nearly 3000 feet of intervening beds, and the petroliferous beds of the Lenoir are separated from them by nearly 1000 feet of beds. Both intervals include one thick impervious unit, the argillaceous limestone of the lower Moccasin. Thus there seem to be great obstacles to consideration of either the Copper Ridge dolomite or the Lenoir limestone as the source beds for the oil that has accumulated in the Trenton and upper Moccasin limestones.

Although the Copper Ridge dolomite, Lenoir limestone, and the Devonian and Mississippian black shales are all possible source beds for oil, the available evidence favors the view that the oil in the Rose Hill pool came originally from the Trenton limestone.

SOURCE OF THE OIL AND GAS IN OTHER FORMATIONS

Shows of oil and gas have been found in several formations besides the Trenton and Moccasin limestones. A little oil was produced from the Clinch sandstone and sandstones in the lower part of the Clinton shale in Possum Hollow and light shows of oil have been found in the Lowville limestone and Reedsville shale. Considerable gas occurs in the basal sandstone of the Cayuga dolomite in the Brooks well and gas pockets and gas shows have been found in the Moccasin, Lowville and Eggleston limestones. In the Eggleston a little gas is commonly found beneath each of the two big bentonites, and many of the other pockets of gas found in the Eggleston, Moccasin and Lowville seem to have accumulated below thin beds of bentonite.

The source beds for these widespread oil and gas shows are unknown but possible source beds lie close at hand to account for most of them. Thus the underlying Lenoir limestone could have been the source for the Lowville shows. The description of oil from the Clinch sandstone in the Gilbert Lee No. 1 well (p. 314) indicates a darker-colored oil of lower gravity than the oil in the Trenton limestone. Hence this oil probably came from different source beds than the Trenton oil. The logical source beds close to the Clinch are the Devonian and Mississippian black shales. The gas in the basal sands of the Cayuga dolomite presumably had the same source as the oil in the Clinch sandstone. In both cases one must postulate downward or lateral migration from the black shales into sands of the Cayuga or Clinch beneath the Middlesboro syncline (Pl. 5B) and then lateral migration along the beds to the present location of the oil and gas.

GRADES OF OIL FROM THE ROSE HILL DISTRICT

The oil produced from the Rose Hill field is a clear, greenish-amber, high volatile oil with a paraffinic, wax-bearing base. Gravity is 44.4° A.P.I. Very little gas is associated with the oil, though enough is obtained at the casing head of the Fugate No. 1 well to run a gas engine which drives the pumps. In 1946 the O.P.A. price for Rose Hill oil at the refinery was \$3.69 per barrel which included a 75¢ per barrel subsidy. At the present time the oil is trucked from the storage tanks at the wells to Middlesboro, Kentucky. From there it goes by railroad to a refinery near Charleston, West Virginia.

A complete analysis of the oil from the B. C. Fugate No. 1 well by E. W. Saybolt & Company has been supplied by Floyd Fitch and is given on the following page.

TABLE 13.—*Analysis of oil from B. C. Fugate No. 1 well, Rose Hill oil field, September* 11, 1942

CHARACTERISTICS OF STILL CHARGE	DISTILLATION OF STILL CHARGE	
Gravity A.P.I. @ 60° F.—44.4°	I. B. P. 132F	45% @ 508F
Color—dark green	5% @ 184F	50% @ 541F
Flash Point—Below atmos. temp.	10% @ 228F	55% @ 572F
Fire Point—Below atmos. temp.	15% @ 272F	60% @ 606F
Vis. Say. Univ. @ 100° F. 38.0 Sec.	20% @ 312F	65% @ 640F
Pour. Point-Astm. D 97-39 5° F.	25% @ 357F	70% @ 672F
B. S. & W. Centrifuge—trace	30% @ 395F	75% @ 696F
Sulfur-Astm. D. 129-39 0.095%	35% @ 435F	80% @ 714F
	40% @ 469F	Cracked

Crude base.—Paraffinic, wax-bearing (*Bureau of Mines method of classifying crude oil according to "base"*).

Topping Operation

10,000 ML. charged to Saybolt laboratory still; gasoline obtained through atmospheric fractionating column; kerosene, gas oil, and light lube cuts obtained through fractionating column by vacuum; heavy lube distillate removed through side take-off of column by vacuum; barometric pressure maintained throughout at 759 mm. Hg.

The oil from the Moccasin limestone in the Fugate Estate No. 1 and Lemons No. 1 wells has not been analyzed but it appears to be almost identical to that from the Trenton limestone in the near-by wells.

An analysis of the oil from the Clinch sandstone in the Gilbert Lee No. 1 well was made in 1923 by Mr. E. T. Erickson of the U. S. Geological Survey.[222] Only a small quantity of this oil was obtained from the well before the oil horizon was flooded by salt water from a lower horizon. The oil was darker in color and lower in gravity than the Trenton and Moccasin oils of the Fourmile fenster. Mr. Erickson's complete description of the oil from the Clinch sandstone follows:

"The oil sample, about .115 cubic centimeters in volume, appeared low in viscosity, opaque to transmitted light, dark green by reflected light, and emitted a kerosene-like odor. Specific gravity 0.815 at 23°C. (equivalent to 41.8° Baumé or 42.1° A.P.I.). A slight quantity of water was noted in the bottom of the sample container."

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[222] Oil in Lee County, Virginia: Department of the Interior, Geol. Survey Press Release, 3 pp., July 3, 1923.

Tests on topping operation products. (Table 13—Continued)

GRADE	400E.P. Gasoline	525E.P. Kerosene	630E.P. Gas oil	Lube Dist.	Residue
Yields (approx.)	33.0%	16.0%	16.0%	24.4%	7.8%
Gravity A.P.I. @ 60°F.	63.0%	45.7	40.9	31.9	22.2
Flash Point—Degrees F.		178 TCC	285 PM	390 coc.	625 coc.
Fire Point—Degrees F.				460 coc.	710 coc.
Vis. Say. Univ. @ 100° F.			41 sec.		
Vis. Say. Univ. @ 130° F.				87 sec.	
Vis. Say. Univ. @ 210° F.				44 sec.	216.4 sec.
Viscocity Index				113	
Pour Point-ASTM. D 97-39			35°F.	95°F.	65°F.
Color	—30	—30	1 NPA		
Sulfur (Lamp) D 9034 T.	0.029%	0.052%			
Sulphur (Bomb) D 129-39.			0.085%	0.13%	0.24%
Doctor Test	Positive	Positive			
Corrosion 3 hrs. @ 122° F.	Corrosive	Corrosive			
Vapor Pressure Reid @ 100° F.	5.2%				
Octane No. ASTM. D 357-41 T.	27 (26.7)				
Plus 1 CC T.E.L.	41 (41.2)				
Plus 3 CC T.E.L.	55 (54.7)				
Diesel Index			78.9		
Aniline Point			193.08 F		
ASTM Distillation					
Initial Boiling Point @	120°F	426°F	550°F		
5% Recovered @	156	443	562		
10% Recovered @	172	448	566		
20% Recovered @	196	454	569		
30% Recovered @	220	458	572		
40% Recovered @	247	463	576		
50% Recovered @	272	468	580		
60% Recovered @	297	474	584		
70% Recovered @	319	480	590		
80% Recovered @	342	489	598		
90% Recovered @	364	501	611		
95% Recovered @	379	512	620		
End Point	402	524	631		
Recovery	98.5%	98.0%	98.5%		
Residue	1.0%	1.2%	1.3%		
Loss	0.5%	0.8%	0.2%		

Recapitulation

33.0%	400 E.P. Gasoline
16.0%	525 E.P. Kerosene
16.0%	630 E.P. Gas Oil
26.4%	Lube distillate
7.8%	Residue
0.8%	Loss
100.0%	

Test on lube fractions (Table 13—Continued)

	Cut #1	Cut #2	Cut #3	Cut #4	Cut #5	Cut #6	Cut #7	Cut #8	Cut #9
Yield	3%	3%	3%	3%	3%	3%	3%	3%	3%
Gravity API @ 60°F	37.2°	35.5°	34.5°	32.8°	29.5°	29.6°	31.9°	29.7°	28.5°
Flash Point	315°F	365°F	385°F	420°F	475°F	470°F	460°F	460°F	*415°F
Fire Point	370°F	425°F	460°F	490°F	545°F	540°F	550°F	550°F	555°F
Vis. Say. Univ.									
@ 100°F	52.0	64.3	83.1	......	......	......	......	......	......
@ 130°F	......	......	57.0	80.0	171.6	187.0	135.6	150.2	177.4
@ 210°F	33.8	35.6	38.2	43.2	52.8	60.6	49.8	51.0	58.6
Viscosity Index	103.5	104.9	115.5	123	120	117	81	72	113
Pour Point ASTM. D 97-39	60°F	75°F	80°F	95°F	100°F	105°F	105°F	105°F	105°F

*Slightly cracked.

"One hundred cubic centimeters of the oil sample gave the following results of distillation at atmospheric pressure by the Engler-Abbelohde method. The first drop of distillate appeared in the container at 34°C."

	Volume of distillate fractions (cubic centimeters)	Total volume (cubic centimeters)
34°C. - 100°C.	6.0	6.0
100 - 125	7.0	13.0
125 - 150	6.5	19.5
150 - 175	6.5	26.0
175 - 200	5.0	31.0
200 - 225	5.5	36.5
225 - 250	6.5	43.0
250 - 275	7.0	50.0
275 - 300	7.5	57.5
300 - 325	6.5	64.0
325 - 350	6.0	70.0
350 to near 375	27.0	97.0
Coke	2 grams	

"The oil is very similar to some oils from western Pennsylvania."

POSSIBILITIES FOR ADDITIONAL OIL PRODUCTION FROM LEE COUNTY

POSSIBILITY OF ENLARGING THE ROSE HILL FIELD

The limits of the productive area of the Rose Hill oil field have not yet been established, and it is not only possible, but probable, that additional producing wells can be drilled outside the area delimited by the 12 wells producing at the present time (Jan. 1947).

Dry holes have been drilled south (Lemons No. 1), west (B. C. Fugate Nos. 2 and 2B), and east (Lemons No. 2) of the discovery well (B. C. Fugate No. 1). To the south, the Lemons No. 1 well failed to obtain production in the Trenton limestone. Furthermore, the Trenton beds are known to abut beneath the Fugate branch of the Pine Mountain overthrust between the Fourmile and Sugarcamp fensters. Thus the Trenton limestone is not even present in the stationary block south of a strike line about half a mile south of the B. C. Fugate No. 1 well.

West and southwest of the B. C. Fugate No. 1 well both the B. C. Fugate No. 2 and B. C. Fugate No. 2B wells were dry. In this direction also, the dip of the Ordovician formations steepens abruptly along the sharp flexure shown in Section CC′ of Plate 1, and in Plate 50. There seems little chance that the Rose Hill oil pool would extend down the flank of this sharp monoclinal flexure west or northwest of the B. C. Fugate No. 1 well.

North and northeast of the B. C. Fugate No. 3 well, nine wells had been completed to January, 1947, all of which were productive. In this direction the dip of the beds at the surface becomes gentler and in the northern and northeastern parts of the Fourmile fenster the surface dip of the beds is nearly horizontal. The possibility seems good that the productive area of the oil field may be extended northward even beyond the edge of the Fourmile fenster. It can probably be extended also several hundred feet west of the line of producing wells and may also be extended an unknown but possibly a much greater distance to the east.

In summary, the limits of the productive area of the Rose Hill oil field are still unknown. Appreciable extension of the productive area in a southward direction is believed to be impossible; westward extension of more than a few hundred feet is believed to be improbable; eastward extension along the strike of the Clinton shale belt is believed to be the most favorable. A well now drilling north of the Fourmile fenster will show whether the oil follows the Trenton limestone northward down the steepening dip of the beds. If so, a large area north of the Fourmile fenster and possibly also north of the Dean, Hamblin Branch, Martin Creek and Possum Hollow fensters offers good possibilities for production.

POSSIBILITIES FOR GAS OR OIL PRODUCTION IN THE FROG LEVEL AREA

Outside the area of the producing oil wells in the Fourmile fenster, the only significant accumulation of oil or gas that has so far been found in Lee County is in the Brooks well in the Frog Level area, 2 miles west of the Fourmile fenster. The Brooks well was described and an analysis of the gas was given on pages 296-298. The gas occurs at a depth of 2030 feet in the coarse basal sandstone of the Cayuga dolomite only 30 feet below the lower branch of the Pine Mountain overthrust. At the fault red Clinton shale in a fault slice lies on the Cayuga dolomite, and is overlain by the Rome formation.

Clinton shale is also present in its normal stratigraphic position beneath the gas-bearing Cayuga sand. Here the thickness of the Clinton in the well is about the same as its stratigraphic thickness, as is also the thickness of the Trenton limestone near the bottom of the well. Between the Clinton and Trenton, however, the Reedsville shale is nearly 200 feet too thick, but this is believed to be due to squeezing and flowage of the incompetent beds of the Reedsville shale rather than to major changes of dip. The available evidence thus seems to indicate that the beds beneath the Pine Mountain overthrust at the Brooks well are horizontal or only gently dipping.

Because the gas-bearing beds of the stationary block in the Frog Level area are concealed beneath 2000 feet of overthrust rocks, and because the Brooks well is the only well to date that has penetrated the rocks of the stationary block in this area, the structure of the stationary block at this locality is not known. The most logical supposition based on evidence from the fenster region to the east is that the sandstone and dolomite of the Cayuga dip gently to the northwest at the well. Southeast of the well the Cayuga must abut beneath the fault plane and it probably does so not more than a few tenths of a mile from the well. Northwest of the well the dips must steepen. Because the Upper Devonian shales (Brallier shale) which normally overlie the Cayuga dolomite furnished such an excellent gliding plane for the overthrust movement, the fault probably developed at or near the top of the Cayuga over broad areas. Locally the fault may have cut across the Cayuga dolomite into the underlying Clinton shale as has happened for example in Possum Hollow, and the Cayuga may have been entirely removed. Most of the Cayuga dolomite, however, should be preserved beneath the fault over much of the area northeast, north and northwest of the Brooks well.

The trap, which permitted the accumulation of gas in the porous and pervious basal sand of the Cayuga dolomite at the Brooks well, seems to have been formed where the Cayuga abuts beneath the impervious Clinton shale along the lower fault plane of the Pine Mountain overthrust. Clay and gouge along the fault may assist in sealing off the gas-bearing beds. The possibility exists that oil would be found in the Cayuga down dip from the Brooks well, that is, north of the well. The farther north of the Brooks well drilling sites are chosen, however, the deeper it would be to the Pine Mountain overthrust and hence, the deeper to the sandstone of the Cayuga beneath the fault.

Because the Pine Mountain fault plane seems normally to lie parallel with the beds of the overthrust block in the Powell Valley anticline an approximation of the depth of the overthrust fault can be gained by calculations based on the dip of rocks at the surface and the known or inferred stratigraphic position of the fault. If, however, the fault unexpectedly crosscuts from one formation to another in the overthrust block, as it does from the base of the Rome formation to the base of the Maynardville limestone near the B. C. Fugate No. 2 well, the calculation will of course lead to an erroneous result. Along or near the crest of the Powell Valley anticline, however, this example of crosscutting is the only instance of major crosscutting that is known.

The inferred structural situation just described in the Frog Level area seems more favorable for the accumulation of sizable pools of gas or oil than does the structure in the vicinity of the Fourmile fenster. The sandstone in the Cayuga dolomite should also be a more favorable reservoir rock than the Trenton limestone. Whether the accumulation of gas in the Brooks well is an isolated and local occurrence can only be demonstrated by additional drilling. The flow of 225,000 cubic feet gauged at the well is large enough to be encouraging though perhaps not promising.

Search for oil in the Trenton limestone in the Frog Level region is beset by two difficulties: (1) lack of information on the rock structure beneath the overthrust as described above, and (2) lack of knowledge whether the deformation of the stationary block in this area has fractured the impervious Trenton limestone sufficiently to render it a reservoir rock. The Trenton limestone in the Brooks well is presumably nearly horizontal and lies nearly 1500 feet below the major overthrust. Thus it is probably relatively undeformed and unfractured, and hence, impervious. Southeast from the Brooks well the Trenton limestone abuts beneath the overthrust fault plane (Pl. 1, Section AA′), near which it should be more fractured and hence a more favorable reservoir rock for oil accumulation. This junction of the Trenton with the fault is almost surely at least a quarter of a mile southeast of the Brooks well, and probably closer to a mile. The exact location can only be determined by exploratory drilling.

POSSIBILITIES FOR PRODUCTION ELSEWHERE IN THE FENSTER REGION

The porous and pervious rocks of the area, such as the basal sandstone of the Cayuga dolomite and the Clinton sandstone, can be expected to be oil- or gas-bearing only where they have adequate cover to prevent escape of the oil to the surface. Where these formations are exposed in the fensters, any oil and gas they may have contained would have escaped. The search for significant accumulations of Clinch, Clinton, or Cayuga oil or gas in or near the Fourmile or Dean fensters therefore seems to be foredoomed to failure. In or near the Hamblin Branch, Martin Creek and Possum Hollow fensters, any chance for major production from the Cayuga or Clinton is also slim. The Clinch sandstone in these fensters, however, is capped by a considerable thickness of Clinton shale, and so could be oil bearing. The only known promising structure in any of these three fensters is the gentle dome described in the section on the Possom Hollow fenster. The crest of this dome, however, seems to lie near the location of the Holcombe well (Pl. 2) which was a dry hole. Also other dry holes have been drilled through the Clinch sandstone on the south and southwest flanks of the dome. Further exploration of the possibilities for Clinch production in the Possum Hollow region thus does not seem warranted, at least until other more promising areas have been tested.

The search for Trenton oil in the fenster region exclusive of the Fourmile fenster is somewhat different from the search for Clinch, Clinton or Cayuga oil, because the Trenton limestone is not so widely exposed in the fensters, nor is it normally sufficiently pervious for oil to escape readily through it to the surface. The Trenton is not exposed near the Rose Hill oil field. It abuts beneath the Fugate fault where the Fugate slice is uneroded between the Fourmile and Sugarcamp fensters (Pl. 2, Section AA′). However, the fact that the Trenton limestone is covered by overthrust rocks updip from the Rose Hill oil field does not appear to have had any bearing on the local occurrence of the oil, because the Lemons No. 1 well penetrated the Trenton and Moccasin limestones updip from the producing wells and nearer the overthrust, yet neither oil nor gas was found. Hence any part of the fenster region underlain by Trenton limestone might be oil-bearing even though the Trenton beds cropped out in a fenster up dip from the area.

The Trenton is exposed in the Low Hollow part of the Dean fenster and the beds are steeply dipping, hence this immediate area would seem unfavorable. In Low Hollow, however, both an anticline and a small thrust fault are exposed (Pl. 2, Section BB′ and Pl. 40C). Where these structures disappear beneath the overthrust rocks east of Low Hollow would seem to be a favorable place for exploratory drilling in search for Trenton oil. This opinion is based not so much on the commonly accepted anticlinal theory of oil accumulation as on the fact that the proximity of a major overthrust, an anticline, and a minor overthrust may be expected to produce considerable fracturing of the Trenton limestone and make it a possible reservoir rock in which oil disseminated through petroliferous limestone of the Trenton could accumulate.

POSSIBILITIES FOR OIL AND GAS OUTSIDE THE FENSTER REGION

The best chances for oil or gas especially in the pervious sands of the Cayuga, Clinton or the Clinch formation would seem to lie outside the fenster area rather than in or near it. A possible trap is formed wherever one of these formations abuts beneath the Pine Mountain overthrust fault and a long gathering slope is supplied by the long dip slope which carries these formations downward beneath the Middlesboro syncline (Pl. 5B). Along the Powell Valley anticline east or west of the fenster area, chances are good that oil or gas that may have entered the pervious sands would not have escaped to the surface. Unfortunately, however, the fenster area is the only region where the geology of the stationary block is well known; hence the farther from the fensters drilling sites are chosen the more hazardous it becomes to predict where any given formation will abut beneath the overthrust fault plane. Under these circumstances an extensive drilling program is advisable in exploring any new area along the Powell Valley anticline. One or two isolated wells are but shots in the dark, which can, however, be expected to supply valuable information for locating subsequent wells. Geophysical prospecting would probably be of little value in exploring the geology of the concealed stationary block because of the difficulty of correctly interpreting the results where so many unknown factors are involved.

OIL SEEPS

Oil seeps are said to have been known in Possum Hollow for many years and oil is also said to have accumulated in deep water wells in sufficient quantities to be pumped from the wells.[223] In fact, the presence of presumed oil seeps was responsible for the drilling of the first well in Possum Hollow. However, the seeps were not seen by Butts in 1923 or by us in 1944-45. They seem no longer to exist, perhaps because of the intensive drilling that has been done in Possum Hollow. We have examined several reported oil seeps in

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

other parts of the Rose Hill district; all of them proved to be spurious. They consisted either of iridescent films of iron oxide or of organic scum on stagnant bodies of water. No authentic oil seeps are known in the Rose Hill district that might furnish clues to favorable sites for prospecting.

POSSIBLE RESERVOIR ROCKS

SANDSTONES

Sandstones are so commonly thought of as the reservoir rocks in which oil accumulates, that an oil-bearing horizon is apt to be called an oil sand though the rock may not have a grain of sand in it. Almost all the oil so far produced from the Rose Hill district and the large majority of the oil and gas shows have been in limestone. Sandstones are present in the region, however, and some of them are potential reservoir rocks.

Rome formation.—The oldest known sandstones in the region are in the Rome formation and were penetrated in the Brooks well. They probably underlie much of the Frog Level area and may also underlie areas farther west along the Powell Valley anticline, although they are nowhere exposed at the surface. In the Brooks well, two shows of gas and one of oil were reported in the Rome. It is more likely that these shows represent a little gas and oil that has escaped upward along fractures from the Cayuga gas horizon below the Pine Mountain overthrust than that the gas is widely distributed through porous beds in the Rome. The small size of the shows would favor this interpretation. Some of the sandstones in the Rome are moderately coarse and might be porous enough to be reservoir rocks, but there is as yet no evidence that any of them have been utilized by significant accumulations of oil or gas. So much impervious shale is interbedded with the sandstones in the Rome formation that in most places the sandstones are probably effectively sealed above and below and thus unavailable for occupation by migrating oil or gas.

Chepultepec dolomite.—Sandy beds and lenses are fairly common in the Chepultepec dolomite. Most of them are not beds of pure sandstone but are better described as sandy dolomites. Beds of medium-grained sandstone several feet thick, however, are everywhere present at the base of the Chepultepec and thinner sandstones are scattered through the lowest 270 feet. A few beds and lenses of sandy dolomite and sandstone are found in the upper part of the formation, with a little fine-grained sandstone always present at the top. Plate 11C is a photomicrograph of a sandstone from the lower part of the Chepultepec along Chances Branch. The angularity of the sand grains in this specimen is very striking but the grains are better rounded in some beds. The sand grains are in a dolomite matrix, which is dissolved near the surface so that the sandstone appears very porous and friable. A typical specimen of the basal sandstone of the Chepultepec was tested and had an effective porosity of 12.4 percent and a permeability of 3.20 millidarcies parallel to the bedding and of 5.65 millidarcies across the bedding. Although the specimen appeared fresh, it was collected in a very shallow quarry and probably was not entirely unaffected by weathering. Specimens of the Chepultepec sands obtained from diamond drillcores or from recent deep excavations would give more reliable samples for testing, but neither could be obtained in or near the Rose Hill district. The evidence from the quarry specimen is the best now available and indicates that the basal sandstone of the Chepultepec is probably porous and pervious enough to constitute a reservoir rock. Other sands in the Chepultepec might be equally favorable, but most of them are not as thick as the basal sand whose thickness ranges from 2 to 11 feet.

The basal sandstone of the Chepultepec is best seen in the Link Marcum quarry on the east side of Low Hollow. Numerous higher beds of sandy dolomite and sandstone and lenses of sandstone in dolomite can also be seen in the lower part of the Chepultepec along Martin Creek on the south flank of the Powell Valley anticline and along Chances Branch on the north flank. One of the sandy dolomites representative of these beds was tested and had an effective porosity of 2.9 percent. Permeability was negligible both parallel to the beds and across the beds. The Chepultepec dolomite has been drilled recently in the Phipps well where the basal part of the formation lay at the very top of the well so that there was no chance for accumulations of oil or gas. It may also have been penetrated in the McClure well, and the upper part of it may have been drilled in the Parkey well.

Kingsport and Mascot dolomites.—The Kingsport and Mascot dolomites contain scattered sandy beds and sandy lenses, but these beds and lenses are less numerous than those in the Chepultepec dolomite and all are less than a foot thick. Most of the sandy beds consist of sand grains scattered through dolomite, but in the Mascot a few beds are sufficiently sandy to be called sandstones. All the sandy beds are lenticular. Some sections of these formations have several good sandstone beds, but others have none. There is no persistent sandstone at the top of the dolomites of the Knox group comparable to the St. Peter sandstone of the Mississippi River region and the so-called St. Peter of Kentucky and Tennessee.[224] The sandy beds and lenses of the Mascot dolomite are less favorable as reservoir rocks from the standpoint of persistence and thickness than the sands of the Chepultepec and they are probably also less porous than the coarsest sands of the Chepultepec. The Mascot is known to have been drilled only in the Lemons No. 1 well, where the uppermost 82 feet were penetrated without finding more than a few scattered sand grains or any shows of oil or gas. The Kingsport dolomite has not recently been drilled anywhere in the region. Both formations were probably penetrated in the McClure and Parkey wells where no records of the drilling were kept.

Sandy beds and lenses near the top of the Mascot dolomite are well exposed in the road cut on U. S. Route 58, a mile and a half west of Rose Hill and a quarter of a mile east of Mount Carmel Church. A six-inch bed of sandstone is also exposed at the north edge of the southernmost rock-cut in the switchback of the Louisville and Nashville Railroad at Hagan. Dolomites containing scattered sand grains and lenses are exposed in the lower part of the Kingsport dolomite in the Lambs Chapel section (Pl. 13 and Geologic Section 5). It is very doubtful whether any of the sandy beds in the Kingsport and Mascot are thick enough, persistent enough, or porous enough in the Rose Hill district to be reservoir rocks for commercial accumulations of oil or gas.

Murfreesboro limestone.—Sand grains and sandy lenses are present in a few places in the basal conglomerate of the Murfreesboro limestone but the lenses are normally only a few inches thick. The thickest sandstone bed seen at this horizon is at Hagan, and consists of 8 inches of medium-grained sand in a dolomite matrix, which also encloses scattered larger conglomeratic pebbles of dolomite. A specimen of this rock was tested and showed a porosity of 2.9 percent. Permeability was negligible both parallel to the bedding and across the bedding. Because of their lack of continuity and permeability, and their thinness, lenses of sandstone at the base of the Mur-

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[224] Freeman, L. B., Present status of St. Peter problem in Kentucky: Am. Assoc. Petroleum Geologists Bull., vol. 23, no. 12, pp. 1836-1843, 1939.

Born, K. E., Lower Ordovician sandy zones ("St. Peter") in middle Tennessee: Am. Assoc. Petroleum Geologists Bull., vol. 24, no. 9, pp. 1641-1662, 1940.

freesboro limestone have little potentiality as reservoir rocks for oil or gas.

Reedsville shale.—There are no sandstones anywhere between the basal sand of the Murfreesboro limestone and the top of the Trenton limestone, but fine-grained sandy or siliceous limestones are common in the Reedsville shale. Where the lime has been leached at the surface these beds resemble fine grained sandstone, but the fresh rock is dense and hard and is composed largely of carbonate. The sandiest and coarsest beds seen at the surface lie about 150 feet below the top of the formation. This is the exact horizon at which a small gas show was found in the Lemons No. 1 well. Two shows of gas and a light show of oil were also found in the much-faulted and overthickened Reedsville shale in the B. C. Fugate No. 2 well. In outcrop the sandstones of the Reedsville seem too dense and too fine-grained to favor the accumulation of significant amounts of oil or gas.

Clinch sandstone.—The Clinch sandstone contains numerous beds of fine- and medium-grained sandstone and locally contains one or more beds of coarse pebbly sandstone. The medium-grained sandstones appear only in the upper or Poor Valley Ridge member of the Clinch. They form massive beds or zones from 1 to 15 feet thick in Poor Valley Ridge on the north side of the area, but they are as much as 50 feet thick in Wallen Ridge on the south side. The Clinch sandstone of the stationary block which is exposed in the fensters, more closely resembles the Clinch sandstone of Poor Valley Ridge lying northwest of the fensters than of Wallen Ridge because the overthrust block containing both the Wallen Ridge and Poor Valley Ridge exposures of the Clinch sandstone is almost 6 miles northwest (Pl. 5B) of its position before overthrusting.

The medium-grained sandstones of the Clinch consist of subrounded quartz grains in a carbonate and sericite matrix. Plate 24F is a photomicrograph of one of these sandstones. The sandstone appears very porous and friable at the surface but this is partly due to weathering. Fine-grained limy sandstone in platy beds are abundant throughout both members of the Clinch sandstone but most of the limy sandstones are interbedded with equal or greater thicknesses of shale. These fine-grained sandstones seem to be too dense and the beds appear too thin and isolated to be possible reservoir rocks. Coarse pebbly sandstone is uncommon in the Clinch sandstone, though the basal few inches of the formation may contain pebbly lenses. However, in Unit 14 (Geologic Section 10) at Hagan one bed

2 inches thick consists of poorly cemented pebbles up to half an inch in size.

Typical specimens of the Clinch sandstone were collected in the Hagan railroad cut and were tested for effective porosity and for permeability. The results are given below. No. 1 is a specimen of fine-grained limy sandstone or siliceous limestone from near the base of the Hagan member of the Clinch (Geologic Section 10, Unit 3). No. 2 is a fine-grained sandstone that forms a massive and resistant unit in the lower part of the Poor Valley Ridge member of the Clinch (Geologic Section 10, Unit 8). No. 3 is of a massive-bedded, medium-grained *Helopora*-bearing sandstone (Geologic Section 10, Unit 10).

Porosity and permeability of specimens of Clinch sandstone

Specimen No.	*Percent Porosity*	*Permeability in Millidarcies*	
		Parallel to Bedding	*Across Bedding*
1	1.3	(n)	(n)
2	4.1	(n)	(n)
3	8.6	0.90	(n)

The medium-grained sandstone (No. 3) is typical of many of the massive-bedded sandstones in the lower part of the Poor Valley Ridge member of the Clinch. It is porous enough and pervious enough parallel to the bedding to be a potential reservoir rock. Water has been reported from the Clinch sandstone in several Possum Hollow wells, but the shows of oil in the upper parts of several Possum Hollow wells do not appear from the inadequate records to have been in the massive sandstones near the base of the Poor Valley Ridge member, but rather in thinner-bedded sandstone near the top of the member and in the lower part of the overlying Clinton shale. There were no shows of oil or gas in the Clinch sandstone in the Brooks well. The sandstones of the Clinch are best seen in the switchback of the Louisville and Nashville Railroad at Hagan, where the whole formation is perfectly exposed (Geologic Section 10). The ridge-making beds are also exposed in all of the watergaps through Poor Valley and Wallen Ridges and they may also be seen along the Clinch ridges in the fensters.

Clinton shale.—The Clinton shale contains much fine-grained sandstone in platy beds averaging about an inch thick and separated

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(n)—Negligible.

by greater thicknesses of shale. All the sandstones that have been seen at the surface were fine grained and dense. Some are quartzitic and some have carbonate cement. None appears porous enough to be a good reservoir rock. The middle part of the Clinton is very poorly exposed, however, and it might contain coarser and more porous sandstones than any in the better known parts of the formation. The Gilbert Lee No. 1 and W. B. Fulton wells in Possum Hollow both had oil shows in the Clinton. The shows were at widely separated horizons, however, despite the fact that the two wells are only 50 feet apart. The sands do not therefore seem to be pervious to any appreciable extent, and the formation as a whole is believed unfavorable for either oil or gas.

Cayuga dolomite.—The coarsest persistent sandstones in the region are in beds and lenses at the base of the Cayuga dolomite. In different localities, the sandy zones vary from a single thin bed to several beds, each of which may be from a few inches to several feet thick. The sand grains are medium to coarse and the coarsest may be as large as peas. The matrix is carbonate, which is largely dissolved near the surface leaving a very porous friable rock. Though variable in number and thickness, the sandstone beds are very persistent and have been seen at every locality where the base of the Cayuga dolomite is exposed. No porosity or permeability tests were made on this sand because unweathered specimens of it could not be found. It appears to be the most porous and pervious rock in the area.

The Cayuga sand has been drilled only in the Brooks well, where it contained a gas pay that flowed 225,000 cubic feet a day. The rock thus seems to have adequate porosity and permeability to permit the accumulation of gas or oil.

The basal sands of the Cayuga are excellently exposed along the road near the south end of the Martin Creek fenster, and can be seen also in the railroad cut adjoining the mouth of the tunnel at Hagan (Pl. 13).

CARBONATE ROCKS

None of the carbonate rocks of the area have sufficient effective porosity or original permeability to be reservoir rocks. Tests were made on several specimens from carbonate formations in which oil or gas pays or shows have been reported. The lower Copper Ridge dolomite, which typically has a strong petroliferous odor, was also tested. The results of these tests are given on the next page.

Results of tests of carbonate rocks

Rock	*Percent Porosity*	*Permeability in Millidarcies* *Parallel to Bedding*	*Across Bedding*
Copper Ridge dolomite ("stinkstone")	0.7	(n)	(n)
Platy member of Lowville limestone (cryptocrystalline limestone)	0.1	(n)	(not measured)
Trenton limestone (medium-crystalline, light-brown limestone from middle of formation)	1.2	(n)	(n)
Trenton limestone (fine-crystalline, dark-brown limestone from near top of formation)	0.6	(n)	(n)

The very low porosities and the lack of permeability of these limestones and dolomites show that oil or gas in any significant quantities could not be disseminated in original pores through the rock. No types of limestone or dolomite were seen in these or other formations that appeared any more porous or pervious. Openings in the carbonate formations in which oil or gas might accumulate would have to be of some other nature. Solution openings are possible. However, this does not seem to account for the oil in the Trenton limestone and in the upper part of the Moccasin limestone in the Rose Hill field because these formations are not water-bearing. Furthermore, the production of oil from most of the wells has been small but steady suggesting numerous smaller openings rather than open solution channels along beds or joints. Hence, the Trenton and Moccasin oil in the Rose Hill field is believed to be disseminated through small fractures in the limestone which do not seem to be confined to individual beds or stratigraphic zones. Other limestone formations such as the Lowville and Murfreesboro are equally susceptible to fracturing but no oil in paying quantities has been found in them.

The most brittle and most readily fractured of the carbonate rocks are the dolomites of the Knox group and of the upper part of

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(n)—Negligible.

the Maynardville limestone. In many places near the major faults these dolomites have been shattered intensely or have been ground up to a fine breccia. If not recemented, these shattered areas should make excellent reservoirs. Unfortunately the subsurface search for areas of shattered dolomite in which oil might have accumulated would be extremely difficult and probably extremely expensive. None of the wells so far drilled in Lee County, except possibly the Parkey well, has penetrated any of the dolomite formations at or near a major fault, so the possibilities cannot be said to have been tested. This type of potential reservoir appears less promising for oil production, however, than many of the others (1) because brecciated dolomites near the major faults have probably been recemented in most places by water seeping along the fault plane, and (2) because it is highly uncertain whether the petroleum disseminated through the dark-colored dolomites ("stinkstone") of the Knox group is susceptible to being driven out of its source rock into areas of shattered dolomite.

POSSIBLE TRAPS FOR OIL

In order for oil (or gas) to accumulate in paying quantities, not only must reservoir rocks be available that have adequate open spaces to contain the oil, but suitable traps must also be present to prevent the oil from escaping from the reservoir rocks once it has migrated into them. The possible traps discussed below are those that do exist or may exist in the Rose Hill district.

FRACTURED AREAS IN CARBONATE ROCKS

The occurrence of oil in the Trenton and Moccasin limestones has been discussed in the section on the Rose Hill oil field, and reasons were advanced for believing that the oil occurs in fractures in the limestone. The possibility that other limestone and dolomite formations may be fractured sufficiently to contain important amounts of oil or gas has also been considered in the section on reservoir rocks. If areas of fractured carbonate rocks are sealed off in some manner so that oil or gas can enter the fractured area but cannot escape from it, the requisite conditions for an oil or gas reservoir are met. In the Rose Hill field the oil in the fractured Trenton limestone is believed to be trapped because it is surrounded by less fractured or unfractured limestone and the oil in the top of the Moccasin is believed to be trapped because the oil-bearing rocks are overlain by impervious mudstones of the Eggleston limestone.

Another type of trap that might be equally effective and might retain larger quantities of oil in the trap would be formed where impervious rocks above one of the major overthrusts or where gouge along one of the overthrust fault planes overlie areas of fractured limestone or dolomite beneath the fault. The most impervious formations, that might act as seals above the overthrusts, are the thick shales of the Conasauga shale or Rome formation. No well in the area has tested the Trenton limestone or any other brittle formation where it lies close below one of the major overthrust faults. Since the Trenton limestone is known to be oil-bearing in places it would be the most plausible formation to test for oil in this type of structural trap. The area chosen would have to be near enough to one of the fensters so that the position of abutment of the Trenton beds beneath the fault could be predicted with reasonable accuracy, and yet not so near that any oil or gas formerly present could have escaped laterally along beds or fractures to the outcrop of the Trenton limestone in the fensters.

POROUS FORMATIONS SEALED BY AN OVERTHRUST FAULT

The greatest opportunity for sizable production from the Rose Hill district appears to lie in the possible accumulation of oil or gas in one of the porous and pervious formations such as the basal sandstone of the Cayuga dolomite, the Clinch sandstone or possibly sandstones in the lower part of the Chepultepec dolomite. The best available trap in which to retain oil or gas once it may have entered one of these porous and pervious zones, would be formed where the pervious beds lie below impervious rocks along or above one of the major overthrust faults. The gas in the basal sandstone of the Cayuga dolomite in the Brooks well is believed to have been trapped in this manner.

The Conasauga shale or the Rome formation, both of which contain much impervious shale, would probably be effective cap rocks wherever they overlie pervious beds. The Rome seems to have acted in this capacity in the case of the gas pay (?) in the Brooks well mentioned above. Wildcat wells designed to test the possibilities for oil and gas in pervious sands of the Cayuga, Clinch or Chepultepec formations beneath the Pine Mountain overthrust would have to be spotted very carefully to be assured of passing into the desired formation after the overthrust fault was reached. In areas some distance from the fensters this would be extremely difficult and would probably require considerable exploratory drilling. The Brooks well, which hit the gas-bearing Cayuga sands close below the overthrust, was entirely a lucky accident. No amount of surface geologic investigation could have predicted that such would be the result. If subsurface information continues to accumulate as the result of wildcat drilling outside the fenster area it will become easier and easier to plan new drilling sites with reasonable hopes of penetrating the desired formations at the desired positions beneath the overthrust.

Any well aimed at testing Chepultepec possibilities beneath the Pine Mountain overthrust would have to be located far down the south flank of the anticline for the reasons shown in the structure sections (Pl. 2). It would also have to be a deeper test than one located near the crest of the Powell Valley anticline, because the Pine Mountain fault plane as well as the surface rocks dip southeastward from the axis of the anticline. With the present limited knowledge of the geology of the stationary block beneath the flanks of the anticline, considerable exploratory drilling would probably be necessary to find the Chepultepec dolomite at its junction with the fault. Furthermore the chances that sands in the Chepultepec would be oil- or gas-bearing when found must be considered only fair, partly because they may not have sufficient porosity and partly because they may be too far removed from any source beds for oil.

Sands in the Clinch sandstone and Cayuga dolomite are promising (1) because they are somewhat porous and pervious, (2) because they abut beneath the fault at relatively shallow depths in regions where the geology of the stationary block is better known, and (3) because they have already been shown to contain oil and gas at least in small quantities.

ANTICLINAL AND MONOCLINAL TRAPS

Anticlinal traps in the rocks of the stationary block are possibilities, but no major structures of either type involving potentially petroliferous formations exist in the fenster region. They might exist in concealed areas beneath the overthrust rocks, but if so they would have to be found and proved up by drilling.

A minor dome in the Possum Hollow and Wilson fenster region was drilled without success (p. 286). The only other known anticline in the stationary block is a sharp fold in the Trenton limestone in the south part of the Dean fenster. This anticline is believed to be the same as a partly exposed anticline in the Sugarcamp fensters (Pls. 2 and 40C). The anticline plunges eastward beneath the overthrust block at the southeast corner of the Dean fenster. If this eastward plunge persists far enough, Clinch or basal sandstone of the Cayuga may be present across the crest of the anticline beneath the overthrust fault. An anticlinal trap for oil may thus be formed in these beds. This structural situation is hypothetical, and if it exists it would have to be traced out by drilling.

The Rose Hill flexure shown on Plate 1 is a very sharp monocline in the overthrust block. No favorable reservoir rocks are involved in the flexure above the overthrust. Direct evidence is lacking to indicate whether the rocks of the stationary block beneath the overthrust also are folded by the Rose Hill flexure, but theoretical considerations suggest that they are not. If this is correct the line of the Rose Hill flexure would be no more favorable a location for wells to test the rocks of the stationary block than any other location on the north flank of the Powell Valley anticline.

LOGGING OF WELLS IN THE ROSE HILL DISTRICT

All wells so far drilled in Lee County have been with cable tool rigs (Pl. 45B). The recognition of formations and of key horizons within the formations in the cuttings of the wells is comparatively easy in most parts of the section, but is extremely difficult from the base of the Eggleston limestone to the base of the Murfreesboro limestone. Table 14 shows formations, members, zones, and key horizons that may be consistently and readily recognized in cuttings, and the criteria useful in their recognition. It is arranged in the order in which the formations would be encountered in drilling if no faults were met. Thicknesses given are average for the district, and are subject to local variations. In many of the wells the thicknesses actually drilled were considerably greater because of dipping beds, faulting, or overthickening due to squeezing.

TABLE 14.—*Character of formations of the Rose Hill district in well cuttings*

DEPTH IN FEET	FORMATION		CHARACTER IN WELL CUTTINGS	UNITS CLEARLY RECOGNIZABLE IN WELL CUTTINGS
150	Cayuga dolomite		Dolomite, gray, fine crystalline; forms all except lowest 20 to 25 feet of formation. Limestone, gray, fine crystalline. Sandstone, coarse, in basal 5 to 15 feet.	Sandstone, coarse in basal 5 to 15 feet.
475	Clinton shale		Sandstone, white and light gray with a little sandy shale in upper 30 feet. Shale, reddish brown and gray, sandy with 5 to 15 percent of fine-grained white sandstone throughout. Makes main part of formation. Shale, red, making 50 percent or more of samples with rest gray shale and white sandstone. Forms lowest 40 to 70 feet. There may be a few feet of greenish-gray shale at base.	Iron ore of Clinton-type shows as bright-red hematite chips. There may be several iron-ore beds in lower part of formation. Usually one very near base.
658	Clinch sandstone	Poor Valley Ridge member	Shale, gray, sandy with 10 to 20 percent of white fine-grained sandstone. Forms upper 60 to 70 feet of member. Sandstone, white, fine to medium grained, making 20 to 80 percent of sample, with rest greenish-gray sandy shale.	Beds of Clinton-type iron ore may be present at different horizons.
730		Hagan member	Shale, greenish gray; a little white sandstone; a very little limestone. Basal sample should show slight increase in percentage and coarseness of sandstone.	Beds of Clinton-type iron ore may be present at different horizons.

TABLE 14.—*Character of formations of the Rose Hill district in well cuttings—Continued*

DEPTH IN FEET	FORMATION	CHARACTER IN WELL CUTTINGS	UNITS CLEARLY RECOGNIZABLE IN WELL CUTTINGS
	Sequatchie formation	Mudstone, calcareous mottled and interbedded, red and green. Top 50 to 60 feet. Mudstone, calcareous, light gray, with a little pink. 70 feet. Mudstone, calcareous, red and green mottled; some fine crystalline and more limy, verging on limestone. 75 feet. Limestone, gray, and mudstone, calcareous, gray. 40 feet. Limestone, gray, argillaceous and 20 to 40 percent of mottled red and green calcareous mudstone. 35 feet.	Red and green mudstones are distinctive, and formation is an easily recognized unit.
1005	Reedsville shale	Shale, light and dark gray, and limestone light gray and fine and medium crystalline. Fragments of brachiopods and bryozoa abundant. Apt to be faulted and much over-thickened.	Limestone zone near base resembles Trenton limestone, but is gray and finer crystalline than upper part of Trenton.
1350	Trenton limestone	Limestone, brown, medium to coarse crystalline, 5 to 20 percent gray shale. Brown limestone contrasts with gray limestone of Reedsville shale. Abundant fossils. 200 feet. Limestone, gray, medium to coarse crystalline, with some brown limestone and a little gray shale. Abundant fossils. 260 feet.	Bentonite (R13) 15 ft. from top. Apt to be accompanied by a small gas show, and by caving or a mudflow in the hole. Bentonite so thin it may not show in cuttings unless caving occurs. Bentonite (R12) 500 ft. from top. May be accompanied by a little chert or silicified shale. Bentonite (R11) 38 ft. below R12; not apt to show in cuttings.
1905	Eggleston limestone	Limestone, tan, argillaceous or shaly with some tan crystalline and some dense cryptocrystalline limestone. 50 feet. Limestone, dense, tan, cryptocrystalline. 65 feet. Limestone, tan, argillaceous, with white calcite patches. 35 feet.	Big bentonite (R10) 9 feet from top. Apt to cave badly. There may be a gas pocket directly beneath bentonite. Big bentonite (R7) 42 ft. below R10. Apt to cave badly. There may be a gas pocket directly beneath bentonite.
2055			

TABLE 14.—*Character of formations of the Rose Hill district in well cuttings—Continued*

DEPTH IN FEET	FORMATION	CHARACTER IN WELL CUTTINGS	UNITS CLEARLY RECOGNIZABLE IN WELL CUTTINGS
	Moccasin limestone	Limestone, tan, dense, cryptocrystalline. Scattered fossils. Distinction between Hardy Creek member and lower member extremely vague in cuttings.	
2925	Lowville limestone	Moccasin-Lowville contact very vague. Limestone, tan, dense cryptocrystalline with scattered fossils. May contain a very few chips of chert. Members of Lowville not distinguishable in cuttings.	Redbed or argillaceous zones may be recognizable in lower 335 ft. Most conspicuous redbed zone lies 320 ft. from top of formation. Bentonite (R2) 460 ft. from top may be recognizable.
3055	Lenoir limestone	Limestone, tan, dense, cryptocrystalline with chert chips. Limestone, dark brown, fine crystalline with chert chips. Scattered fossils. May have brown coarse-crystalline limestone with abundant fossils at base.	
3125	Mosheim limestone	Limestone, tan, dense, cryptocrystalline; very uniform and pure throughout. Top contact may be vague and lower contact very vague. 30 to 135 feet.	
3345	Murfreesboro limestone	Limestone, tan, cryptocrystalline, and brown and gray fine crystalline. 0 to 30 feet. Limestone, tan, cryptocrystalline and tan and gray fine crystalline with chert chips. 40 to 100 feet. Limestone, tan and gray, fine crystalline, with some cryptocrystalline and a little gray shale. 50 to 100 feet. Dolomite, tan, fine crystalline; limestone, tan, cryptocrystalline; and shale gray. 50 to 100 feet.	Bentonite 5 feet above base of formation.

TABLE 14.—*Character of formations of the Rose Hill district in well cuttings—Continued*

DEPTH IN FEET	FORMATION		CHARACTER IN WELL CUTTINGS	UNITS CLEARLY RECOGNIZABLE IN WELL CUTTINGS
3645	Knox group	Mascot dolomite	Dolomite, white and brown, fine and medium crystalline, with a little gray shale. Top 80 feet only. Lower part has not been drilled in Rose Hill district.	
3845		Kingsport dolomite	Has not been drilled in Rose Hill district.	
4100		Longview dolomite	Has not been drilled in Rose Hill district.	
4800		Chepultepec dolomite	Top 600 feet has not been drilled. Lowest 120 feet as follows: Dolomite, brown, medium crystalline and gray, fine crystalline. Chert fragments, basal 30 feet. Dolomite, light gray, fine crystalline. A little chert. Scattered sand grains. 75 feet. Sandstone, dolomite and chert. 15 feet.	Sandstone zone forming basal 5 to 15 feet of formation.
5240		Copper Ridge dolomite	Dolomite, white, medium crystalline, with a little brown dolomite, shale and chert. 390 feet. Dolomite, brown, medium crystalline with some white dolomite and a little chert. 450 feet.	
5515	Maynardville limestone		Has not been drilled in Rose Hill district.	
6175	Conasauga shale		Top part has not been drilled. Lower part sandstone, greenish white, medium grained, with bronze mica flakes and bright- and dark-green glauconite. A little dark shale, and 10 percent coarse-crystalline limestone.	Abundant glauconite distinguishes Conasauga shale from all formations except the Rome.

TABLE 14.—*Character of formations of the Rose Hill district in well cuttings—Continued*

DEPTH IN FEET	FORMATION	CHARACTER IN WELL CUTTINGS	UNITS CLEARLY RECOGNIZABLE IN WELL CUTTINGS
7825	Rome formation	Contact with Conasauga very obscure. Main difference between formations is absence of coarse-crystalline limestone in upper Rome. Sandstone, light and dark gray with zones of very micaceous and glauconitic sandstone throughout. Some gray and red sandy shale and a little limestone. 840 feet. Sandstone, white, fine to medium grained forming 30 to 100 percent of cuttings; rest gray sandstone and red and gray sandy shale. Much is glauconitic and micaceous. 590 feet. Dolomite, brown, mottled, coarse crystalline. 65 feet. Sandstone, white and gray with 30 to 60 percent of gray micaceous shale. A little red shale and a little limestone. All sandstone micaceous and some glauconitic. 165 feet. Basal Rome not known.	Abundant glauconite distinguishes Rome from all formations except the Conasauga shale. Dolomite, brown mottled, coarse crystalline, making 90 to 100 percent of samples. 65 feet thick.

TESTING SAMPLES FOR OIL CONTENT

Samples of cuttings from wells drilled previous to 1945 were tested to determine the relation of the apparent oil content in the cuttings to the pays and shows reported by the drillers. Acetone was used as the extracting agent for the oil. The method of treatment of the samples was that outlined by Jones.[225]

In all, 61 samples were tested, representing all pays and shows of oil and (or) gas in wells for which cuttings were then available, and including in addition numerous samples close to reported pays or shows. The treated samples were arranged in order of the depth of color of the acetone, and were then classified into six

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[225] Jones, L. W., Acetone for determining oil content of well cuttings: Am. Assoc. Petroleum Geologists Bull., vol. 28, no. 1, p. 124, 1944.

groups. Those samples for which the acetone was entirely clear and colorless were classified in the group designated "no showing"; those having a very faint amber color in the acetone were classified as "very light showing", and increasing intensities of amber color were classified as "light showing", "showing", "good showing", and "very good showing".

Of the 38 samples representing horizons from which pays or shows of oil and (or) gas had been reported, 34 gave positive tests when immersed in acetone. Two of the four samples that gave negative tests were samples of Reedsville shale from horizons in the B. C. Fugate No. 2 well at which shows of oil accompanied by a little gas had been reported. The third was a sample of Moccasin limestone from a horizon in the Lemons No. 1 well at which a show of oil was reported. In this case, however, the next sample below the reported occurrence gave a positive test for oil. The fourth sample that tested negatively was from a horizon in the Lowville limestone in the Lemons No. 1 well at which a small showing of gas had been reported. These results indicate that reported shows of oil in the carbonate formations of the Rose Hill district were corroborated in all cases by testing the sample of the cuttings with acetone. The acetone tests failed to corroborate the two reported shows in a shale, and they also failed to corroborate one small show of gas in a carbonate formation, though they did give positive tests on 7 other samples representing shows in which gas alone was reported.

The correlation between the size of the showing as indicated by the acetone tests and the known or reported size of the showing based on other information was much less satisfactory. Many samples representing shows reported by the drillers as light gave stronger coloration of the acetone than samples representing shows reported as good. At the time the tests were run only three producing horizons had been encountered in the Rose Hill field. The sample from the best of these, the producing horizon in the B. C. Fugate No. 1 well, gave only a "light showing" or light coloration of the acetone, but samples from the two producing horizons in the B. C. Fugate No. 3 well both gave "good showings". The only sample of the 61 that was classified as "very good showing" on the basis of the acetone tests, came from a horizon in the Trenton limestone in the Brooks well where the driller reported only a light showing of oil. Consistently we found that samples directly below reported shows gave stronger tests with acetone than the samples representing the horizon from which the shows were reported.

Thus the testing with acetone of samples of cuttings from the carbonate formations of the Rose Hill district may be expected to reveal showings of oil in all cases and of gas in most cases. The degree of coloration of the acetone, however, does not seem to be an indicator of the promise of the showing. These acetone tests furnish valuable corroboration of the driller's log, and may indicate the presence of oil or gas shows overlooked by the driller. Operators may wish to consider shooting or acidizing horizons where the acetone tests indicate good or very good shows, such for example as the very good showing in the Trenton limestone of the Brooks well, which appeared to the driller to be of little consequence. Acetone tests of samples from cable-tool wells are so simply, quickly, and inexpensively made that their consistent use during the drilling of the carbonate formations of the district is recommended.

POSSIBILITIES FOR OIL ELSEWHERE IN POWELL VALLEY

The Rose Hill district has been intensively studied because it is the only known area along the Powell Valley anticline where the potentially petroliferous rocks of the stationary block can be observed. To date only six wells have been drilled in Powell Valley that started in the rocks of the overthrust block rather than in rocks of the stationary block inside a fenster. These are the McClure, Parker, Brooks, Phipps, and George Yeary wells in the Rose Hill district and the Shown well near Jacksboro, Tennessee. All but the Phipps well are known or believed to have penetrated the Pine Mountain overthrust, but adequate records are available on only three of these, the Brooks, Yeary, and Shown wells. Therefore, little can be done at present toward discussing in specific terms the oil possibilities of the stationary block elsewhere in Powell Valley. Certain generalizations, however, are possible.

From the Jacksboro fault in Campbell County, Tennessee, through the Rose Hill district to central Lee County, Virginia (Pl. 13), the Powell Valley anticline in the Cumberland overthrust block is a simple undeformed structure. There is no reason to doubt that the major structural relations in this whole area are similar to those that have been described in the Rose Hill district.

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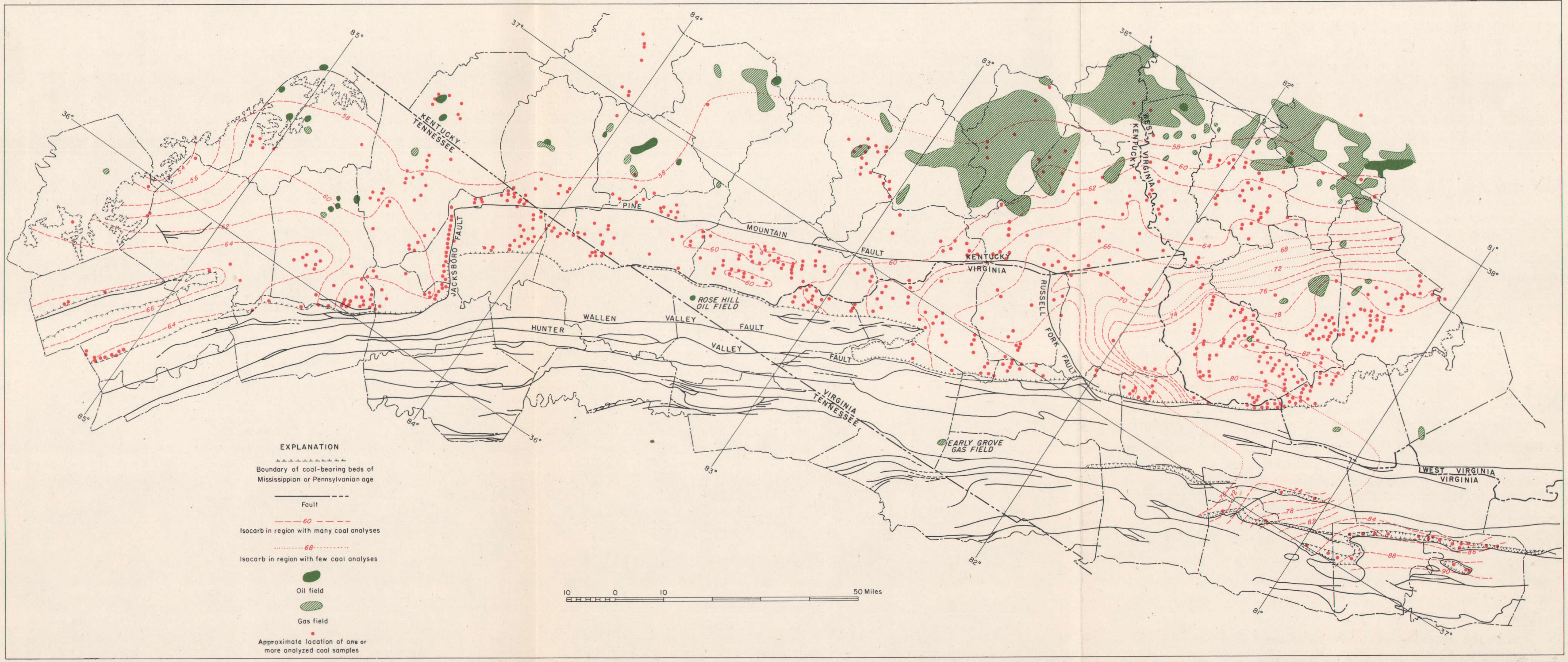

CARBON RATIO MAP OF THE COAL-BEARING PART OF SOUTHWEST VIRGINIA AND ADJACENT AREAS IN WEST VIRGINIA, KENTUCKY, AND TENNESSEE

Possibilities for oil and gas in rocks of the stationary block may be equally as good in the rest of this area as in the Rose Hill district. They may be even better because the roof rocks above the stationary block have not been eroded. Luck would be needed, however, to get oil or gas with the drilling of only one or two wells in a new region along the Powell Valley anticline. Much drilling would be necessary to work out carefully the structures of the concealed stationary block in the search for oil and gas accumulations within its rocks. Along the axis of the Powell Valley anticline southwest of the Rose Hill district the depth to the overthrust is probably everywhere more than 1000 feet and it may reach 3000 feet in places.

In northeastern Lee County and adjoining Wise County the Powell Valley anticline is broken by many faults, which have been shown on maps by Bates,[226] Stose,[227] and Campbell.[228] The relation of these structures to the Pine Mountain overthrust fault is not clear, and the possibilities of this region for oil or gas are therefore difficult to evaluate. The abundance of faulting would appear to make it somewhat less favorable than the region southwest of the Rose Hill district.

EVIDENCE FROM CARBON-RATIOS

In 1915 White[229] proposed the carbon-ratio theory which concerns the relation between the ratio of fixed carbon in the coals of a region and the possibilities for the occurrence of oil. Briefly the theory states that where coal beds have been dynamically metamorphosed so that their fixed carbon content on a moisture-free, ash-free basis exceeds 62 percent, the chances of finding any oil in the region are unfavorable, and above 65 percent they are impossible.

White's original carbon-ratio map included parts of southwest Virginia and adjoining Kentucky but was reproduced on a very

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[226] Bates, R. L., Geology of Powell Valley in northeastern Lee County, Virginia: Virginia Geol. Survey Bull. 51-B, Pl. 6, 1939.

[227] Stose, G. W., Pre-Pennsylvanian rocks, *in* 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, Pl. 2, 1923.

[228] Campbell, M. R., U. S. Geol. Survey Geol. Atlas, Estillville, Virginia, folio (No. 12), 1894.

[229] White, C. D., Some relations in origin between coal and petroleum: Washington Acad. Sci. Jour., vol. 5, pp. 189-212, 1915.

small scale. Eby[230] in 1923 constructed a larger scale map which included most of the Cumberland overthrust block. Since that time many more coal analyses have been published and more oil and gas fields have been found. We have therefore made a new and enlarged carbon-ratio map (Pl. 49), covering the entire Cumberland overthrust block and adjoining regions. All pertinent coal analyses in the State publications of Virginia, Kentucky, and Tennessee and in Technical Papers 626, 656, and 671 of the U. S. Bureau of Mines were plotted. All major faults shown on the state geologic maps of the three states have been reproduced on the carbon-ratio map, including the bounding faults of the Cumberland overthrust block. All oil fields and gas fields also appear. On this map the isolation of the Rose Hill oil field in Lee County and the Early Grove gas field in Scott County, Virginia, is very striking.

In plotting the carbon content of the coals, all available analyses were used regardless of what coal bed they represented. This was necessary, as individual coal beds do not cover a large enough part of the area and there are not enough published analyses to make it feasible to restrict the map to one coal bed or even to a few selected coal beds. We believe that no gross error in the pattern of the map has resulted from this procedure for the following reasons: (1) In some regions where numerous analyses are available, deeper coal beds have a slightly higher carbon content than coal beds above them, as they theoretically should, but in other places the reverse is the case; in general different coal beds in the same area have similar percentages of fixed carbon, and no consistent relation was maintained between stratigraphic position of the coal and its carbon content. (2) The coals of the area covered by the map are almost all of Pottsville age, and the differences between the depths of burial of the coals used is probably minor compared with the total depth of burial beneath eroded younger Pennsylvanian and perhaps even Permian rocks. Thus there is no evidence to indicate that if a carbon-ratio map based on one coal bed could have been drawn for the entire area it would have differed materially from the one that has been drawn on the basis of numerous coal beds.

After all coal analyses were plotted, lines (isocarbs) were

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[230] 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, Pl. 37, 1923.

drawn connecting points of equal fixed carbon content. As both White and Eby have previously noted, the pattern of the isocarbs shows a close adjustment to the regional structure in the vicinity of the Cumberland block. Within the block the fixed carbon content of the coal beds is much lower than it is northeast of the Russell Fork fault or southwest of the Jacksboro fault. On the other hand the fixed carbon content remains practically the same on opposite sides of the Pine Mountain fault, and the presence of the fault seems to have no effect on the manner in which the isocarb lines should be drawn.

Many questions arise as to the reasons for the isocarb pattern. An adequate consideration of these problems would require careful studies of the entire area shown on the map, and is beyond the scope of the present report.

Regardless of the reasons for the regional variations in fixed carbon content of the coals, the evidence of the map bears out very strikingly White's contention that oil fields are unlikely in parts of the Appalachian region whose coals have a fixed carbon content of more than 62 percent. Though gas fields occur where the fixed carbon content of the coals is as high as 80 percent, no oil field has yet been found southeast of the 62 isocarb line. The Rose Hill oil field is very close to where the projected 60 isocarb would lie.

The Powell Valley anticline of the Cumberland block is essentially the area on the isocarb map between the margin of the coal fields and the Wallen Valley fault. In Tennessee and in the southern and central parts of Lee County the coal beds that have been eroded from this region would apparently have had a carbon-ratio very close to 60. On the basis of carbon-ratios all parts of this area would seem to be equally as favorable for the production of oil as is the Rose Hill district. In northeastern Lee County, however, the carbon-ratio rises and it reaches 65 in central Wise County and 67 in central Dickenson County. In this direction, therefore, the chances for oil probably diminish. Gas, which seems much less sensitive to variations in carbon-ratios, might occur anywhere in or beneath the Cumberland block, as far as evidence from carbon-ratios is concerned.

Developments in the Rose Hill Oil Field, January 1947 to March 1950

EXTENT OF THE PRODUCTIVE BELT

The preceding sections on the oil geology of the Rose Hill oil field were originally completed in September, 1945. At that time the field consisted of three producing wells, the B. C. Fugate No. 1, B. C. Fugate No. 3, and Lemons No. 2, all within a few hundred feet of each other in the southern part of the Fourmile fenster. The writers had previously summarized the major outlines of the geology of the fenster area of the Rose Hill district in a preliminary map in the Oil and Gas Investigations Series of the U. S. Geological Survey.[231] In early 1947 the senior author reviewed the new data that had accumulated as the result of the drilling of 20 wells between September 1945 and January 1, 1947. In this interval additional producing wells were drilled in the Fourmile fenster north of the B. C. Fugate wells (the Fugate Estate wells and the Josh Dean No. 1), and four producing wells were also drilled in Iron Mine Hollow of the Fourmile fenster. In the light of the new data, the original interpretations still seemed valid, so that only slight changes were necessary in the manuscript, mostly of a statistical nature. The new wells were also described briefly. At this time the writers also prepared a more detailed map, showing the surface and subsurface geology of the Rose Hill district, and incorporating information on wells drilled up to 1947[232].

Between January, 1947 and April, 1950, 37 more wells were drilled in the Rose Hill district. Successful wells with greater productive capacity than any of the early wells were completed in the Martin Creek fenster and in and north of the Hamblin Branch fenster. A dry hole was completed in the Blackberry Hollow section of the Dean fenster (Logan Snodgrass No. 1) but producers were drilled on the edge of the Dean fenster just across the divide from the Iron Mine Hollow locality of the Fourmile fenster (Glen Yeary No. 1 and Cleve Dean No. 2). During this period also a thorough job of acidization was done

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[231] Miller, R. L., and Fuller, J. O., Geology of the Rose Hill oil field, Lee County, Virginia: U. S. Geol. Survey Oil and Gas Invest. Ser., Prelim. Map 20, 1945.

[232] Miller, R. L., and Fuller, J. O., Geologic and structure contour maps of the Rose Hill oil field, Lee County, Virginia: U. S. Geol. Survey Oil and Gas Invest. Ser., Prelim. Map 76, (2 sheets), 1947.

for the first time on one of the Rose Hill wells, and a dry hole with a small show was turned into a fair producer. Since this initial success with acid on the J. R. Osborn No. 1 well, several other wells have also reacted favorably to acidization, showing a substantial increase in productive rate as the result of the treatment. Some of the early wells, particularly in the Fourmile fenster, had gone dry by 1947, and several of these were deepened and obtained new production from lower horizons in the Trenton. Several of the newer wells came in as gushers, notably the L. E. Bales No. 1, the Dewey Lee No. 1, and the Abney Heirs No. 1, and the initial productive rate on these gushers and on several other flowing wells was several hundred barrels a day, as compared with several score barrels for the early wells in the field.

On the unfavorable side of the picture, drilling up to 1950 had quite clearly outlined the northern and southern margins of the productive belt, and the belt is now known to be slightly less than a mile wide. On the north it is delimited by the following dry holes: George Yeary No. 1 north of the Fourmile fenster, Logan Snodgrass No. 1 north of the Dean fenster, Alfred Shackleford No. 1 north of the Hamblin Branch fenster, and Owens No. 1 and H. B. Nolan No. 1 north of the Martin Creek fenster. On the south side it is delimited by the following dry holes: Clifford Yeary No. 1 south of the Fourmile fenster, Clarence Dean No. 1 west of the Dean fenster, Sensebaugh Heirs No. 1 northeast of the Dean fenster, Beatty Heirs No. 1 in the southernmost part of the Martin Creek fenster, and by eight dry holes in Possum Hollow fenster and one dry hole just southwest of Possum Hollow fenster. At the west end of the belt near the western rim of Fourmile fenster three dry holes have been drilled, B. C. Fugate No. 2 which did not penetrate all of the Trenton, B. C. Fugate 2B, and Patton Ely No. 1. The last of the three obtained a little oil and abundant salt water in the Trenton. Only one test has been drilled along the apparent trend of the productive belt east of the Martin Creek and Possum Hollow fensters. This well, the Grant Smith No. 1, was slightly lower structurally both with respect to the formations of the overthrust block and of the stationary block than the productive wells in Martin Creek fenster. It was a dry hole. Together with the Owens No. 1, it tends to discourage further exploration to the east. It is possible, however, that productive wells can be drilled in the northern part of and north of Possum

Hollow fenster. Furthermore, the Grant Smith No. 1 is not conclusive evidence that the productive belt does not extend east of the fensters, in view of the dry holes drilled in and near the Blackberry Hollow section of the Dean fenster (Logan Snodgrass No. 1 and Joe Chadwell No. 1), which lie between the productive wells of Fourmile fenster and of Hamblin Branch fenster.

STRUCTURAL CONTROL OF THE OIL ACCUMULATION

Enough wells have now been drilled to indicate that the accumulations of oil in the Trenton limestone and locally in the Moccasin limestone seem to be confined to the structurally high area along the Powell Valley anticline. This structurally high area is practically coextensive with the fenster area, exclusive of the region around the Sugarcamp fensters. Furthermore the oil has accumulated in the stationary block in the regions of gentle or nearly flat dip at the top of the long north slope away from the fenster area. Wells drilled only a short distance down this slope, such as the George Yeary No. 1 and the Alfred Shackleford No. 1 are dry, whereas most of the wells in the flat terrace-like belt at the top of the slope are productive. At the south edge of this flat terrace-like belt, where the formations of the stationary block turn upward and one by one are truncated by the Pine Mountain overthrust, either very small producers such as the B. C. Fugate wells or dry holes such as Clifford Yeary No. 1 and Clarence Dean No. 1 are found.

SIGNIFICANT RECENT WELLS

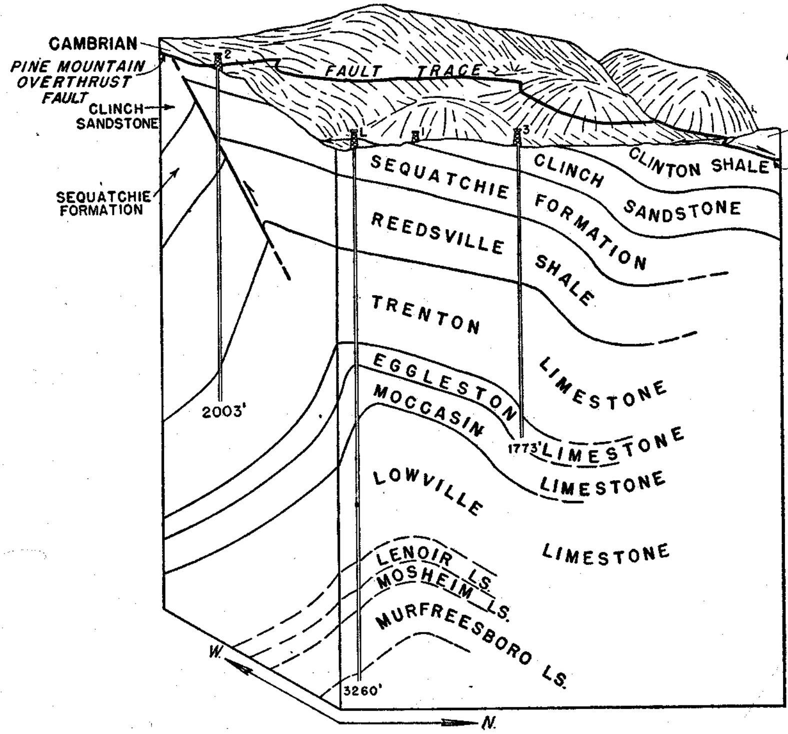
Most of the recent wells in the Rose Hill district have penetrated normal and predictable sections. Most of those that started above the Pine Mountain overthrust have encountered the fault within a few score feet of the depth at which it had been predicted on theoretical considerations. Several wells, however, have shown abnormal or significant features of interest. Most abnormal of all was the Clifford Yeary No. 1 which reached the base of the overthrust block at about 630 feet and entered Moccasin (and/or Lowville) limestone. In view of its proximity to the Sugarcamp fensters in which Moccasin and Lowville are exposed below the overthrust, this much of the record appears normal. However, after penetrating 473 feet of Moccasin-Lowville another fault was crossed and the drill entered Trenton limestone. From here on down the section was normal with the Moccasin, Lowville, Lenoir, and Mosheim limestones penetrated in order. The lowest sample studied, which probably represents the total depth of the well, was at 3130 feet and was in the Mosheim limestone. The presence of an important fault (at 1103 feet) beneath the main Pine Mountain fault plane (at 630 feet) at this locality was not previously known. Neither was the presence of Trenton limestone this far south anticipated. From surface evidence, the Trenton was believed to be truncated by the Fugate fault in the covered interval between the Fourmile and Sugarcamp fensters as shown in Section AA′ of Plate 2 (completed in 1947). Two interpretations are possible: (1) The fault at 1103 feet in the Clifford Yeary No. 1 well is the Sugarcamp fault which is exposed at the surface in both the Sugarcamp and Dean fensters; if so, the belt of Trenton limestone that is concealed beneath the Fugate fault north of North Sugarcamp fenster must swing sharply southward just west of the fenster in order to be present at depth in the Clifford Yeary well; (2) all of the Ordovician formations beneath the Sugarcamp fault that are exposed inside the Sugarcamp fensters are part of a large fault slice, rather than being part of the stationary block as previously believed. The fault at the base of this slice would then be the same fault as the one at 1103 feet in the Clifford Yeary well. The Trenton limestone thus may underlie the northern part of the Sugarcamp fensters area beneath this fault and beneath the Moccasin and Lowville limestone in the fault slice. If the first interpretation is correct, Section AA′ of Plate 2 is essentially correct. If, however, the second interpretation is correct, the section is in error in the Sugarcamp fensters region in that the deeper fault is not shown, and the formations from the Trenton on down are present farther to the southeast than shown in the section. Of the two possibilities the second seems much more probable. Possibly the true situation is even more complex, however.

Another particularly significant recent well is the O. Cavins No. 1 which lies almost 2½ miles south of the Possum Hollow fenster. The well started in the Mascot dolomite of the overthrust block and drilled a normal section to a depth of 1847 feet near the base of the Copper Ridge dolomite, at which depth a fault was encountered. Below this fault is more dolomite, which appears to belong to the Chepultepec dolomite based on the lithology of the cuttings. The well was abandoned at a depth of 2001 feet after

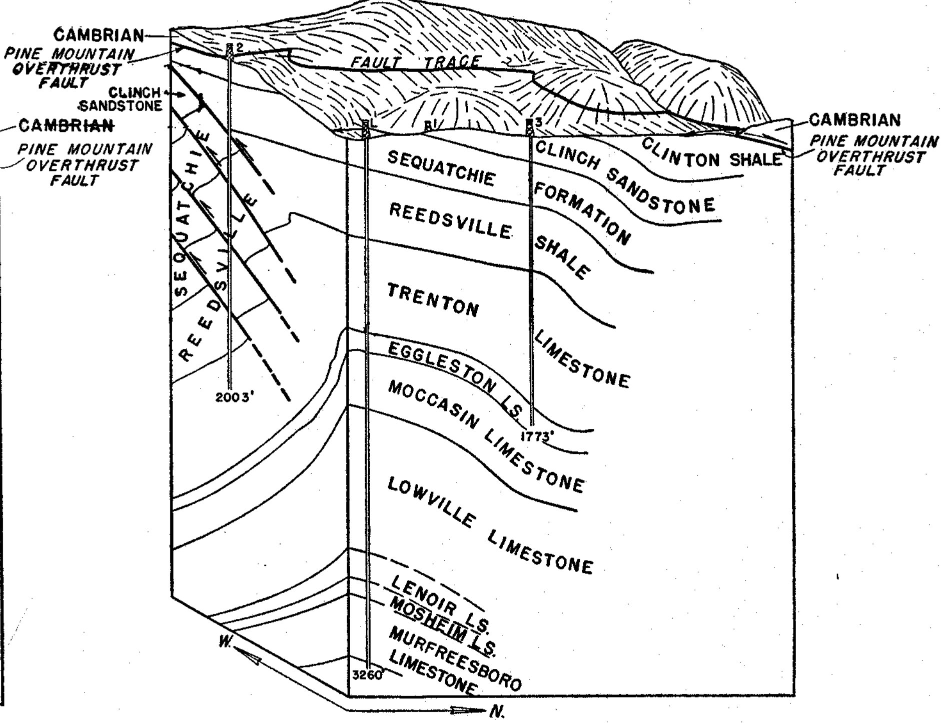
154 feet of the Chepultepec(?) had been penetrated. Although only 154 feet of the sub-fault beds were penetrated, and hence one cannot be sure that other faults are not present at greater depth, the situation encountered in the well is almost exactly what was anticipated in Section BB′ of Plate 1, which was prepared and printed before the Cavins well was drilled. The close accord between the independent evidence from the well and the postulated geology based on indirect evidence that has been shown in the structure section BB′ of Plate 2, strongly supports the conclusions that (1) the fault at 1847 feet in the Cavins well is the Pine Mountain overthrust; (2) the beds beneath the fault are part of the stationary block; (3) the formation at the top of the stationary block here is one of the dolomitic formations of the Knox group and probably the Chepultepec; (4) all formations younger than the Knox group are absent from the stationary block at this locality.

The M. Davis No. 1 well, which lies 1½ miles due ~~west~~ east of Possum Hollow (Pl. 1) was a deeper test and penetrated a more complete section of the stationary block than any previous well in the area. It spudded in practically on the Chepultepec-Copper Ridge contact and drilled to the Pine Mountain fault at a depth of 725 feet continuously in Copper Ridge dolomite. No Maynardville limestone is here present at the base of the overthrust block, but the Copper Ridge above the fault lies directly on Clinton shale below. From here the section was normal to the bottom of the hole at 4406 feet. There was a good show of oil just above the base of the Trenton, but no other shows were reported and the well was a dry hole. The tops and drilled thicknesses of formations are given in the table below. The dips in the vicinity of the well are so gentle that the thicknesses drilled are probably not much in excess of the stratigraphic thickness for those formations penetrated from top to bottom. However, tops of all formations below the Hardy Creek member of the Moccasin are extremely difficult to pick accurately from well cuttings alone.

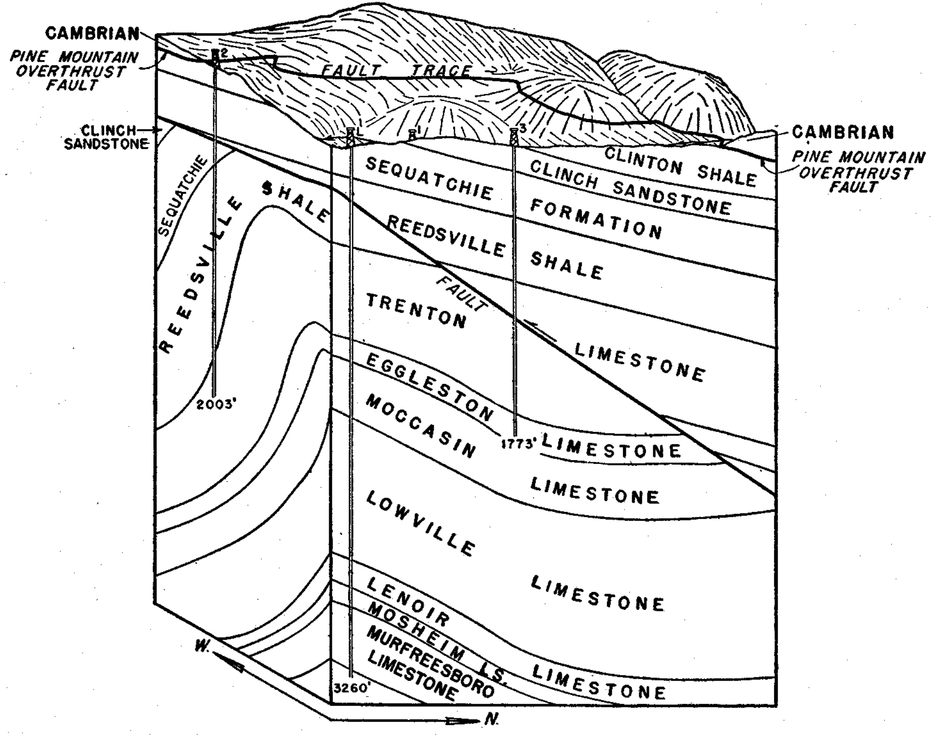
The E. C. H. Rosenbaum No. 1 well, which lies along Martin Creek half a mile east of the town of Rose Hill (Pl. 1), is structurally the northernmost well in the Rose Hill district for which cuttings have been saved, and on which reliable information is available. The Billy Parkey well, drilled in 1928 or 1929, is still farther north structurally, and it may have reached the Pine Mountain fault but no cuttings or driller's logs were saved and



BLOCK 1



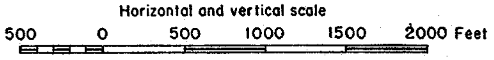
BLOCK 2



BLOCK 3

EXPLANATION OF
WELL NUMBERS

1 – B. C. Fugate No. 1
2 – B. C. Fugate No. 2
3 – B. C. Fugate No. 3
L – Lemons No. 1



BLOCK DIAGRAMS
SHOWING ALTERNATIVE INTERPRETATIONS
OF THE
STRUCTURE IN THE VICINITY OF
B. C. FUGATE AND LEMONS WELLS

TABLE 15.—*Tops and drilled thicknesses of formations in M. Davis No. 1 well*

	Top	Thickness drilled
Copper Ridge dolomite		
Pine Mountain fault—725 feet	....	725
Clinton shale	725	332
Clinch sandstone		
Poor Valley Ridge member	1057	125
Hagan member	1182	56
Sequatchie formation	1238	300
Reedsville shale	1538	469
Trenton limestone	2007	530
Eggleston limestone	2537	159
Moccasin limestone		
Hardy Creek member	2696	149
Lower Moccasin	2845	112
Lowville limestone		
Platy member	2957	243?
Redbed member	3200?	322?
Lenoir limestone	3522?	72?
Mosheim limestone	3594	137
Murfreesboro limestone		
Cherty member	3731	97
Limestone member and dolomite member	3828	192
Mascot dolomite	4020	386
Total depth—4406		

only fifteen-year old recollections of local people were available on this well. The Rosenbaum well started either in the lower part of the Mascot dolomite or the uppermost part of the Kingsport dolomite in a region where these beds dip almost vertically along the Rose Hill flexure. It is difficult at best to pick the contacts between formations of the Knox group from cuttings alone. In this well it is even harder because the drilled thicknesses are greatly in excess of the true thicknesses of the formations. The following tentative tops were picked, however:

Formation name	*Depth to top of formation*
Kingsport dolomite	? (no cuttings 0 to 254 feet)
Longview dolomite	750 ?
Chepultepec dolomite	1190 ?
Pine Mountain fault—1442 feet	
Clinton shale	1442 (not top of Clinton)
Total depth—1456 feet	

Both the Rosenbaum well and the H. B. Nolan No. 1 well lie close to the line of Section BB′ of Plate 1. This plate was printed before the two wells were drilled, so that the data from the wells were not available to control the drawing of the fault plane northward from the Martin Creek fenster. The depth to the fault in the Rosenbaum well and in the Nolan well are both less than section BB′ indicates. Apparently the fault plane has been shown plunging northward at somewhat too steep an angle.

IRON ORES

HISTORY

For many years, iron mining was the only major mineral-producing activity of the Rose Hill district. The iron ores consist of beds of sedimentary red hematite in the Clinton shale. They have been known since the time of the earliest explorations in southwestern Virginia and adjoining parts of Tennessee. Safford[233] called them the "dyestone ores" because of their bright-red color, and they have been called also "fossil ores," "fossil hematites," and "oolitic ores." Ores of this type and of approximately this age are now commonly called Clinton iron ores. They are mined today only in the Birmingham district of Alabama, but they were formerly mined in all of the states in the Appalachian region, from New York to Alabama. In Virginia, Clinton iron ores have been mined in Alleghany, Wise and Lee counties, but the largest production of ore came from Lee County.

According to Holden[234] two forges were operated in the Rose Hill district between 1825 and 1860. One of them was the Milam forge on Martins Creek near Rose Hill, and the other the Bowling Green or Bales forge 5 miles southeast of Rose Hill. Which of the mines supplied ore to these early forges is not known. After the building of the Powell Valley branch of the Louisville and Nashville Railroad, about 1890, many small mines were opened, especially along Poor Valley Ridge. The largest mining operations within the district were those of the Union Iron & Steel Company, the Virginia Iron Coal & Coke Company, and the Boones Path Iron Company. Most of the ore was hauled by wagon or tramline to the railroad and shipped to furnaces at Big Stone Gap, Virginia, and Middlesboro, Kentucky.

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[233] Safford, J. M., Geology of Tennessee, pp. 464-465, Nashville, Tennessee, 1869.

[234] Holden, R. J., Metallic minerals, *in* Watson, T. L., Mineral resources of Virginia, pp. 465-467, Lynchburg, Virginia, Jamestown Exposition Comm., 1907.

Some of the mines were operated only a few years before the easily recoverable ore near the surface was exhausted, but several must have produced for more than 15 years and a little ore was mined and shipped outside the district even after the furnaces mentioned above had closed down. The mines were abandoned not because the ore in the region was exhausted, but because the competition of the rich Lake Superior and foreign iron ores made the operation of small mines and the handling of low grade ore uneconomic. Until the large reserves of the richer and more abundant iron ores approach exhaustion it is unlikely that the Clinton iron ores of the Rose Hill district can again be mined at a profit.

STRATIGRAPHIC POSITION AND THICKNESS OF ORE BEDS

Not all of the hematite beds of the district are in the Clinton shale. A few are interbedded in the Clinch sandstone, both in the lower or Hagan member and in the upper or Poor Valley Ridge member. The beds are persistent along the strike for hundreds or thousands of feet and several were recognizable with certainty for as much as a mile. Several different ore beds have been worked or prospected in the Clinch sandstone.

The hematite beds in the Clinton shale are in most places thicker and of higher grade, and hence were more profitable to mine. The Clinton ore beds lie near the base of the formation, and they seem to represent the same zone of ore. Mines miles apart along Poor Valley Ridge may have been working the same bed of iron ore. Holden[235] who examined many of the mines while they were still operating states: "There are three known seams of this ore in Poor Valley Ridge which seem to correspond with similar seams in the Big Stone Gap region. These vary in thickness from a few inches to several feet. Usually one or two seams are minable and occasionally all three seams are worked at the same mine."

Most of the open-cuts, shafts, and drifts at the mines have slumped and caved in so badly that measurements of the width of the ore beds have been practicable in only a few places. We have not found specific published data on the thickness of the ore beds at individual mines, except a few fantastic figures in very early reports. In almost all places where we have been able to measure the ore beds they have been less than 2 feet thick and in some places beds less than 1

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[235] Holden, R. J., *in* Humbert, R. L., Industrial survey, Lee County, Virginia: Virginia Polyechnic Inst., Eng. Ext. Div., p. 37, 1929.

foot thick seem to have been mined. In the railroad cut at Hagan, for example, an ore bed at the base of the Clinton shale (Geologic Section 10, Unit 19) ranges from 5 to 9 inches in thickness, yet this bed had been mined on the steep hill slope above and a few dozen feet west of the railroad cut. According to local residents two beds were mined in the Fourmile Fenster, the thicker of which is variously reported as having been from 32 inches to 4 feet thick. However, only a small part of this bed is said to have been good ore. The thickest bed measured by us is in the Poor Valley Ridge member of the Clinch sandstone. In the high gap through Poor Valley Ridge a mile and a quarter due west of Rose Hill this bed is, in one place, 43 inches thick. The lower 20 inches of this 43-inch bed is a good grade of ore, but the upper half is more flaggy and contains more impurities.

LITHOLOGIC CHARACTER AND GRADE OF ORES

All the ore beds are of the familiar Clinton-type, whether they are in the Clinton shale or in the Clinch sandstone. The prevailing color is a bright red. Only locally does the ore contain enough limonite to speckle or streak the rock with yellow and brown colors. Almost all of the ore beds are composed of small flattened pellets, which have shallow central depressions. This type has been called "flax-seed" ore, and also "oolitic" ore. Fossils are fairly common but only locally are they abundant in the ore. Crinoid stems are most numerous, but small *Coelospiras* and occasional larger brachiopods have been found. The interstitial material between the pellets and disks of hematite is carbonate and silica. The carbonate is not deleterious as it assists in the fluxing of the ore in furnaces, but the silica is undesirable for it not only lowers the grade of the ore but it makes the ore harder and consequently more expensive to mine. Near the surface much of the interstitial carbonate may be dissolved, leaving an enriched earthy ore. In most of the mines the zone of weathered ore seems to have been confined to levels from a few feet to a few dozen feet beneath the surface. Most of the iron ore is massive, and one bed normally makes up the full thickness of the ore zone. Where low-grade layers are included in thicker ore zones, they are normally separated from the good ore by fairly well developed bedding planes.

Only a few analyses of Clinton ores from mines within the Rose Hill district have been found. These are given in Table 16. The first two analyses have previously been published by R. J. Holden. Analyses 3 and 4 were supplied by Jennie Cole of Ewing, Virginia.

TABLE 16.—*Analyses of Clinton iron ores from the Rose Hill district*

	1	2	3	4
Metallic Iron	40.91	34.09	41.15	31.36
Iron Oxide	....	....	57.36	....
Silica	16.70	6.58	7.95	....
Phosphorus pentoxide	....	....	1.08	....
Phosphorus	0.45	0.58	0.47	....
Lime	5.18	7.72	11.90	....
Magnesia	0.93	3.95	2.79	....
Alumina	....	....	3.46	....
Titanium oxide	....	....	trace	....
Manganese oxide	....	....	0.06	....
Manganese	....	....	0.04	....
Loss on Ignition	....	....	14.99	....

1. Average composition of ore shipped from Boone's Path mines, 2 miles northeast of Rose Hill.
2. Composition of 26 carloads of ore from the Ewing mine in the Fourmile fenster.
3. Hand specimen of ore from the Ewing mine.
4. Weathered hand specimen of ore from the Ewing mine.

The ore in all of the Poor Valley Ridge mines in Lee County, for which analyses are available, appears to have been high in silica. Of the six Poor Valley Ridge mines in Lee County, for which Holden gives analyses, the Boone's Path mines (Analysis No. 1 above) have the lowest silica content. The much lower silica content of the ore from mines in the Fourmile fenster (Analyses 2, 3, and 4) caused this ore to be more desirable, even though the iron content was nearly 7 percent lower. The phosphorus content is a little high but not seriously so. Iron ore of the grade shown by the analyses can be mined profitably today only if it is present in huge tonnages. This is not the case anywhere in the Rose Hill district.

DESCRIPTIONS OF MINES

Iron-ore beds are present wherever the Clinch sandstone and lower part of the Clinton shale crop out, that is, on Poor Valley Ridge and Wallen Ridge and in the Fourmile and Dean fensters. The ore beds on Wallen Ridge are high on the ridge and they are far from main routes of travel, hence only a few prospect pits have been dug in any of the Wallen Ridge ore beds and no important mines have been developed. All three of the other areas of iron-ore-bearing Silurian rocks are the sites of mines that formerly produced significant tonnages of ore.

All known mines and prospect pits of the district are shown on Plate 1. In addition localities where unmined hematite beds are well exposed, have been indicated on the map (Pl. 1).

Poor Valley Ridge mines.—The principal mines along Poor Valley Ridge lie on the northwest slope of the ridge. Almost all of them worked ore beds at or near the base of the Clinton shale. A few prospect pits or very small mines, however, are located in ore beds in the Clinch sandstone at or near the crest of the ridge. The beds in Poor Valley Ridge dip to the northwest, at angles ranging from about 20° in the westernmost mines to 70° in the mines north of Rose Hill.

The northwest slope of Poor Valley Ridge is everywhere steep, rocky and wooded. The mines northeast of Rose Hill, along or near the route of the Louisville and Nashville Railroad through Poor Valley, had trails or chutes from the mines directly down the hillsides to the nearest convenient location for a railroad siding. West of Rose Hill, however, the railroad is in the Indian Creek lowland. Wagon roads run from the mines for considerable distances along the northwest side of the ridge to the nearest gap in the ridge that gives easy access to the Indian Creek lowland and the railroad. Ore from the mines located directly west of Rose Hill was hauled on a small dummy railroad with wooden rails through a small gap in the ridge to Rose Hill. Mules probably supplied the motive power.

There are several groups of old mines along Poor Valley Ridge. Those north of Ewing worked an ore bed from 10 to 20 feet above the base of the Clinton. The bed appears to range from 12 to 15 inches in thickness, and dips 20° to the northwest.

North and northwest of Rose Hill a series of narrow cuts from 50 to 100 feet long occur along the hillside. The ore beds in this vicinity dip about 60° to the northwest. Some of the cuts seem to have followed ore beds downdip not less than 30 feet and in at least two places there were shafts sunk considerably deeper. At least two ore beds were worked, but their thicknesses could not be measured.

One isolated mine occurs just east of Bales Gap, northeast of Rose Hill and only about 30 feet above the railroad. The cut is about 200 feet long and was apparently deep, going well below the water level of the adjacent creek. A large amount of ore, which was never shipped, is now stacked in neat piles near the railroad. Much of it contains well-rounded quartz grains, which were not seen elsewhere in the Clinton ores.

A little farther east a small mine and a prospect pit were dug in an ore bed almost at the crest of the ridge. This ore bed is in the Poor Valley Ridge member of the Clinch sandstone. It appears to be between 1 and 2 feet thick.

The easternmost group of mines, named the Boone's Path mines, lies northeast of Rose Hill and very near the Louisville and Nashville Railroad. The old diggings are strung out along the strike of the beds for nearly a mile, but are interrupted where ravines cut the north slope of the ridge. Most of the excavations were small, but several of the easternmost ones were apparently as large as any on Poor Valley Ridge. The ore beds are not now exposed and their thickness is not known. The average grade of the ores from the Boone's Path mines is given in Table 14. Holden describes the Boone's Path mines as being the largest operations in the region and as having had 7 tipples.

Fourmile fenster mines.—The old mines in the Fourmile fenster were called the Ewing mines by Holden. They were operated by the Union Iron & Steel Company and according to local residents were active from about 1898 to 1907. A narrow-gauge railroad was built from the mines to a siding on the Louisville and Nashville Railroad near Ewing.

Four small pits lie in the main valley of Fourmile Creek, three being west of the main road and one east of the road. The major workings are in the valley of the east fork of the creek, which drains the eastern part of the Fourmile fenster (designated "Iron Mine Hollow" in Figure 14). The numerous mine symbols shown on the map (Pl. 2) represent only a small part of the old workings in this valley, which is pitted with abundant small openings and studded with tailings piles. The ore beds are described as having been closely folded and much fractured but the overall structure must have been that of beds dipping gently northwest on the southeast side of the hollow and nearly flat-lying in the central part of the hollow.

One of the mined areas on the southeast wall of the hollow is on a dip slope from which the ore bed was stripped. On the floor and on the gentle north slopes of the hollow numerous open pits are alined at nearly the same level and follow around the ends of spurs and up ravines. Residents of the region say drifts were driven into the hillside for considerable distances along these flat-lying ore beds. In the 40 years since the mines were abandoned all of the drifts have caved in and the walls of the open pits have slumped. The ore beds that were worked are nowhere exposed today, though many pieces of ore may be picked up on the dumps. Several ore beds that are too thin to be minable can be seen in outcrop. According to local residents two ore beds were worked: An upper "little vein" of good-grade ore was mined on the bottom and north side of the hollow, and a lower "big vein" was mined on the south slope of the hollow and may also have been mined in the floor of the hollow. The "little vein" is variously reported as having been 18 inches, 24 inches and 30 inches in thickness in the workings. The big vein was 32 inches thick but with only 6 inches of good ore, according to one source, and 4 feet thick but containing lots of limestone, according to another source.

It is difficult to estimate how much ore was mined out beneath the hills on the north side of the hollow. Judging from the size of the dumps most of the easily accessible ore must have been removed, and some of the drifts apparently followed the ore beds under the hills possibly for as much as 100 to 200 feet. Unquestionably beds of unmined "ore" are left beneath the hills on the north side of the hollow, and the "ore" beds are believed to continue northward and downward beneath the uneroded rocks of the overthrust block. Very little ore remains on the south side of Iron Mine Hollow.

The ore that was shipped averaged 34.09 percent iron, 6.58 percent silica, and 0.58 percent phosphorus. Although this appears low grade, it contained nearly 8 percent of lime, which made it self-fluxing.

Dean fenster mines.—Several small iron mines lie in the Blackberry Hollow section of the Dean fenster. These mines worked ore beds that are unquestionably in the same belt of Clinton shale that is exposed in the Fourmile fenster, the Clinton beds being connected beneath the tongue of overthrust rocks that separates the two fensters. The more productive iron-pits were in three groups on the steep wooded south slopes of Blackberry Hollow. The ore-bearing beds here are gently dipping and the open cuts were driven back into the hill sides until the thickness of the overburden became too great for profitable mining. The ore beds are not now exposed and we have not been able to establish whether the main bed mined was the "little vein" or the "big vein" of the Fourmile fenster mines, or both.

A small pit, now almost obliterated, lies on the cultivated lower gentle slopes north of the old main workings, and several prospect holes were found on the north side of Blackberry Hollow. A 2-inch and a 3-inch bed of hematite crop out just below the divide at the east edge of the hollow. A little float ore also shows below the Pine Mountain overthrust on the north side of Dry Hollow.

The Dean fenster mines were much smaller operations than were the mines in the Fourmile fenster. The ore from the workings in Blackberry Hollow was hauled in wagons over the divide between the two fensters to the mines in Iron Mine Hollow of the Fourmile fenster. From there it was hauled over the narrow-gauge railroad to the Louisville and Nashville Railroad at Ewing, together with the ore from the mines in Fourmile fenster.

Wallen Ridge prospects.—There has been no mining of Clinton-type iron ore on Wallen Ridge. Much or all of the Clinton shale is faulted out by the Wallen Valley fault in the southwestern part of the district, and almost everywhere else it is deeply buried by talus from the ridge. If ore beds of significant thickness exist in the Clinton shale along Wallen Ridge, they have not been found. Ore beds do exist, however, in the Hagan member of the Clinch sandstone at several places near the crest of the ridge. Three prospect pits have been dug in an ore bed about a foot in thickness, half a mile east of the watergap of Mulberry Creek. These ores may be as good as some of those mined on Poor Valley Ridge, but their inaccessible position near the crest of the ridge apparently discouraged their exploitation.

CRUSHED STONE

The Rose Hill district contains large quantities of limestone suitable for road metal, railroad ballast, and similar uses. Very little quarrying has been done, however, because the large quarries at Wheeler several miles west of the district supply the local demand. The Wheeler quarries are in the upper Lowville and lower Moccasin limestones. In the Rose Hill district, these formations would be equally suitable for crushed stone, as would outcrops of other limestone and dolomite formations.

There are several quarries in the district, that produce small quantities of crushed stone from time to time. The Bales quarry (Pl. 43A) just north of the Martin Creek fenster is in faulted and highly brecciated lower Copper Ridge dolomite and upper Maynardville (Chances Branch) dolomite. Another quarry in massive Copper Ridge dolomite is situated two miles farther south on Martin Creek and a third is on Speaks Branch. A quarry in brecciated dolomite of the undifferentiated Longview, Kingsport and Mascot dolomites occurs north of Dean School. The Mascot dolomite has also been quarried along U. S. Route 58 one mile east of Ewing and along Powell River at the mouth of Fourmile Creek. Limestone of the Low Hollow member of the Maynardville limestone has been quarried along the road at both ends of the Fourmile fenster and also in Low Hollow south of the Dean fenster. Limestone in the lower part of the Trenton limestone was formerly quarried on the south side of Powell River at Parkey Bridge. Limestone and dolomite of a quality suitable for crushed stone are available in the Rose Hill district in quantities greatly in excess of any current local demand.

SAND AND GRAVEL

Gravel has been obtained only from two small pits near the crest of a small hill in the town of Ewing. The gravel is a remnant of a floodplain deposit formed by Indian Creek when its valley floor lay about 100 feet above its present level. A small quarry just east of Low Hollow in weathered basal sandstone of the Chepultepec dolomite, has also been worked for sand.

No extensive deposits of sand or gravel are known in the district, though some of the low terraces of Powell River may have mantles of gravel thick enough to be workable.

CLAY

A large abandoned clay pit is located along the Louisville and Nashville Railroad half a mile northeast of Rose Hill. The clay has been formed by deep weathering of the Reedsville shale. In the walls of the pit the clay still shows the original bedding of the shale. The clay was removed by steam shovel and hauled a short distance to a plant on the edge of town, where it was used for making bricks. The plant has since been dismantled and bricks are no longer made anywhere in the district.

There are, elsewhere in the district, large reserves of clay, derived from weathering of the limestone and dolomite formations. The physical properties of the clays have not been tested.

CHEMICAL LIME

Many small quarries are located in the Ordovician limestones in Indian Creek lowland. The farmers quarried the rock themselves and burned it in small kilns to obtain lime for use on their fields. None of the quarries or lime kilns is now operated.

The Rose Hill district may contain limestone of sufficient purity to be suitable for chemical lime for industrial use. The Mosheim limestone, which almost everywhere consists of massive limestone with no chert and no shaly partings or shale interbeds, seems the most favorable formation. The Mosheim ranges in thickness within the district from 29 feet at Yellow Branch to 136 feet at Rob Camp Church. Other measurements of the thickness of the Mosheim are listed on page 77. Samples of the Mosheim limestone have been collected from two localities not far from the Rose Hill district by B. N. Cooper and R. S. Edmundson of the Virginia Geological Survey. One of these samples from Hagan contained only 82.58 percent calcium carbonate and 4.71 percent magnesium carbonate, but the second sample taken along Station Creek near the Virginia-Tennessee line, two miles east of Cumberland Gap, contained 92.06 percent calcium carbonate and 1.96 percent magnesium carbonate.

Other zones of massive-bedded limestone without shale partings are found in both the Lowville and Murfreesboro limestones. These limestones are equally as pure as the Mosheim limestone, but most of the limestone zones are considerably thinner. Samples of several other limestone formations also have been collected from localities near the Rose Hill district in the western and central parts of Lee County and have been analyzed to determine their suitability for chemical lime. The samples were collected by B. N. Cooper and R. S. Edmundson and were analyzed by Froehling and Robertson, Inc., of Richmond. The analyses are given in Table 17 together with the stratigraphic position from which the sample was taken. Limestones from the same stratigraphic positions within the Rose Hill district may have about the same composition as the samples that have been analyzed.

TABLE 17.—*Analyses of limestone from localities near the Rose Hill district*

	1	2	3	4	5	6	7	8
$CaCO_3$....	82.58	92.06	93.38	94.09	88.39	88.31	91.80	88.72
$MgCO_3$...	4.71	1.96	2.20	2.60	4.29	2.47	2.65	2.04
Fe_2O_3.....	0.16	0.16	0.24	0.28	0.44	0.60	0.28	0.56
SiO_2......	8.84	4.02	2.28	1.00	4.62	5.62	4.98	7.84
Al_2O_3.....	2.32	0.88	1.12	2.46	1.08	2.04	1.06	1.60

1. Mosheim limestone at Hagan, 72 feet thick.
2. Mosheim limestone at Station Creek near the Virginia-Tennessee State line, 2 miles east of Cumberland Gap.
3. Massive birdseye limestone No. 5, in redbed member of Lowville limestone at Hagan, Virginia; 36 feet of beds sampled.
4. Redbed member (?) of Lowville limestone along Louisville and Nashville Railroad at Ben Hur. 140 feet of beds sampled.
5. Lower part of Moccasin limestone along Louisville and Nashville Railroad west of Ben Hur.
6. Composite of Moccasin limestone and lower part of Eggleston limestone along Louisville and Nashville Railroad west of Ben Hur.
7. Middle part of Trenton limestone along Louisville and Nashville Railroad west of Ben Hur. 262 feet of beds sampled starting 144 feet below the top of the Trenton and going down.
8. Upper part of Trenton limestone along Louisville and Nashville Railroad west of Ben Hur. 144 feet of beds sampled.

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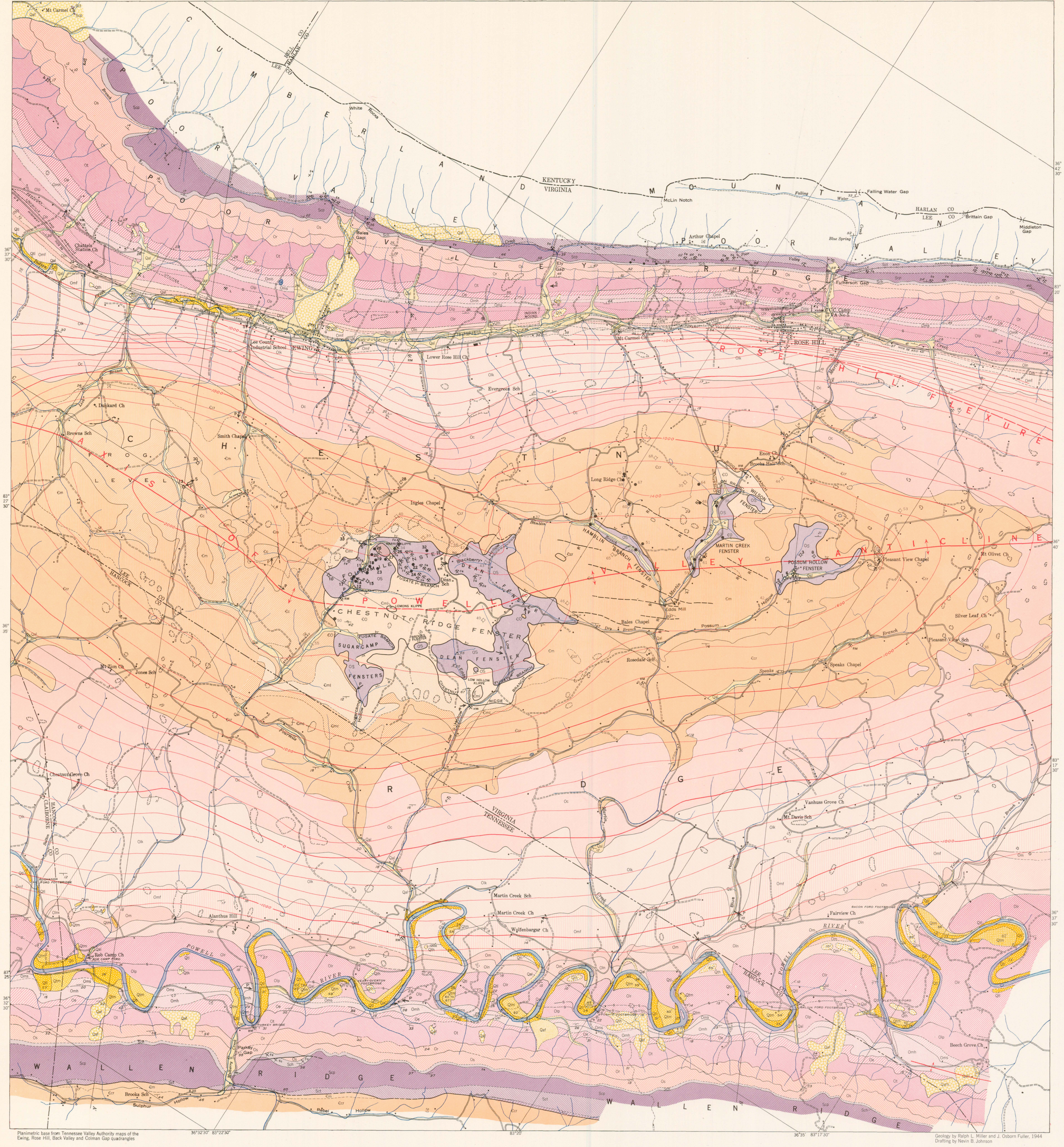
INDEX

VIRGINIA DEPARTMENT OF CONSERVATION
AND DEVELOPMENT
WILLIAM M. McGILL, STATE GEOLOGIST

PREPARED IN COOPERATION WITH
GEOLOGICAL SURVEY
U. S. DEPARTMENT OF INTERIOR

BULLETIN 71 PLATE 1



Planimetric base from Tennessee Valley Authority maps of the Ewing, Rose Hill, Back Valley and Colman Gap quadrangles

Geology by Ralph L. Miller and J. Osborn Fuller, 1944
Drafting by Nevin B. Johnson

EXPLANATION

QUATERNARY

Qal
Alluvium

Qaf
Alluvial fan
(In places Qafh and Qafl indicate high level and low level fans)

Qtl 26′
Low terrace
(Number indicates altitude above Powell River)

Qtm 48′
Middle terrace
(Number indicates altitude above Powell River)

Qth 85′
High terrace
(Number indicates altitude above Powell River. Includes isolated gravel deposits along Indian Creek Valley)

DEVONIAN

Db
Brallier shale
(In structure section A-A′ only)

SILURIAN

Scy
Cayuga dolomite

Sct
Clinton shale

Scp
Sch
Clinch sandstone
(Poor Valley Ridge member, Scp; and Hagan member, Sch)

ORDOVICIAN

Upper Ordovician

Os
Sequatchie formation
(Includes beds of Maysville age)

Or
Reedsville shale

Middle Ordovician

Ot
Trenton limestone

Oe
Eggleston limestone

Omh
Oms
Moccasin limestone
(Including Hardy Creek member, Omh)

Olp
Olr
s
Lowville limestone
(Platy member, Olp; redbed member, Olr Stromatocerium zone, s. Locally two Stromatocerium zones are present)

Lower Ordovician

Oln
Lenoir limestone
(After Charles Butts)

Om
Mosheim limestone
(After Charles Butts)

Omf
Murfreesboro limestone
(After Charles Butts)

Knox group

Olk
Mascot, Kingsport, and Longview dolomites
(Undifferentiated)

Oc
Chepultepec dolomite

CAMBRIAN

Upper Cambrian

€cr
Copper Ridge dolomite

€m €mc €ml
Maynardville limestone
(Including Chances Branch dolomite member, €mc, and Low Hollow limestone member, €ml)

Middle Cambrian

€c
Conasauga shale

Lower Cambrian

€r
Rome formation
(In structure sections only)

OS
Ordovician and Silurian formations undivided in inner fensters
(Detailed geology of inner fensters shown on plate 2)

€O
Cambrian and Ordovician formations undivided between branches of the Pine Mountain overthrust
(Detailed geology between branches of the Pine Mountain overthrust shown on plate 2)

Geologic contact
(Dashed where uncertain)

35
Fault
(Dashed where uncertain. Arrow and number indicate direction and amount of dip and fault plane)

Reverse fault
(R, on upthrown side)

Overthrust fault
(T, on overthrust side)

Axis of anticline
(Axis of Powell Valley anticline dashed where overthrust block has been eroded)

Axis of flexure

1600
Structure contour
(Contour interval 200 feet, datum is top of Maynardville limestone in Cumberland overthrust block)

20
Strike and dip of beds

70
Strike and dip of overturned beds

● 9
Producing oil well
(Number refers to chronological list of wells)

☼ 13
Gas well, capped

2
Dry hole

27
Drilling well

⚒ RM
Quarry for road metal

⚒ L
Quarry for lime

⚒ C
Quarry for clay

⚒ G
Quarry for gravel

⚒ S
Quarry for sand

⚒ Fe
Iron mine

× Fe
Iron prospect

• Fe
Good exposure of iron ore bed

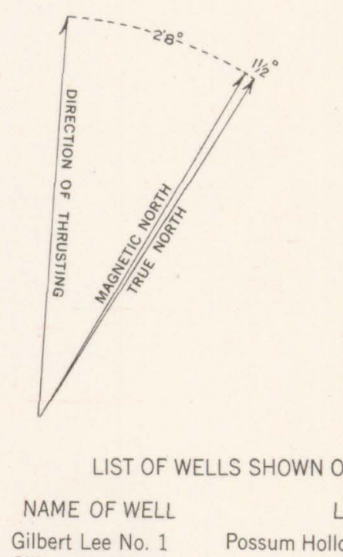
→ P
Locality at which photograph was taken showing direction of view

→ S
Locality at which sketch was made showing direction of view

Sink hole

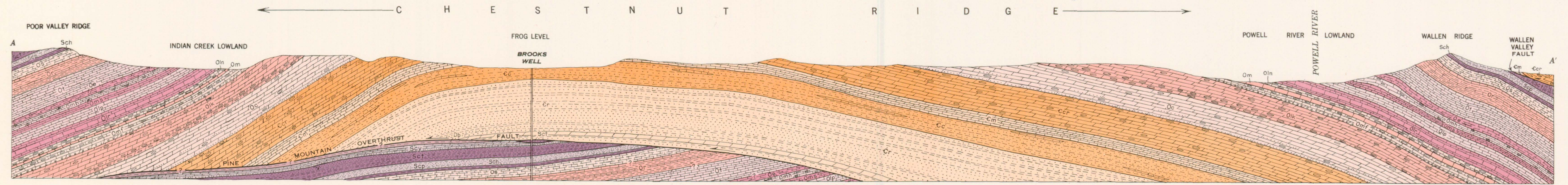
Abandoned course of stream

Note: Detailed geology of the fenster area shown on plate 2

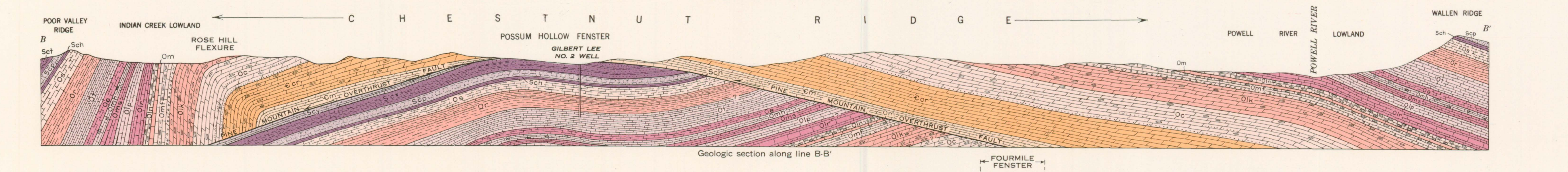


LIST OF WELLS SHOWN ON PLATE 1

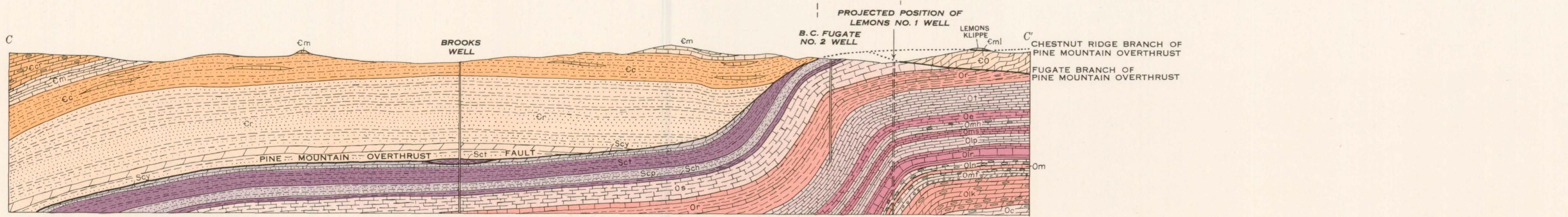
NAME OF WELL	LOCATION
1. Gilbert Lee No. 1	Possum Hollow fenster
2. Gilbert Lee No. 2	"
3. Lon Montgomery	"
4. Billy Parkey	Northwest corner of map
5. Jack Asher	Possum Hollow fenster
6. W. B. Fulton	"
7. Pritchard	"
8. Ingram or Holcombe	"
9. B. C. Fugate No. 1	Fourmile fenster
10. B. C. Fugate No. 2	"
11. B. C. Fugate No. 3	"
12. Lemons No. 1	"
13. Brooks	Frog Level, west central part of map
14. Lemons No. 2	Fourmile fenster
15. Lemons No. 3	"
16. Fugate Estate No. 1	"
17. B. C. Fugate 2B	"
18. Fugate Estate No. 2	"
19. Fugate Estate No. 3	"
20. Fugate Estate No. 4	"
21. Gilbert Lee No. 3	Possum Hollow fenster
22. L. E. Bales	Fourmile fenster
23. Fugate Estate B2	"
24. Stacey Nelson	"
25. G. C. Dean	"
26. Josh Dean	"
27. Fugate Estate B3	"
28. George S. Yeary	North of Fourmile fenster
29. Charles Hobbs	Martin Creek fenster
30. Henly Sutton	Frog Level, west central part of map
31. Nolan	North of Martin Creek fenster
32. Joe Dean	Fourmile fenster
33. Patton Ely	Northwest of Fourmile fenster
34. Andy Ely	Fourmile fenster
35. W. S. Riley No. 1	West of Martin Creek fenster
36. R. L. Bales	Martin Creek fenster
37. Joe Chadwell	North of Blackberry Hollow
38. M. Davis	East of Possum Hollow fenster
39. Cleve Dean No. 1	North of Fourmile fenster
40. W. T. Jenkins	North of Fourmile fenster
41. O. Cavins	Southeast of Possum Hollow fenster
42. Gilbert Lee No. 1	Southwest of Possum Hollow fenster
43. Logan Snodgrass	Blackberry Hollow section of Dean fenster
44. Owens	Northeast of Martin Creek fenster
45. E. C. H. Rosenbaum	Martin Creek east of Rose Hill
46. Sensebaugh Heirs	East of Dean fenster
47. Glen Yeary	Blackberry Hollow section of Dean fenster
48. W. S. Riley No. 2	West of Martin Creek fenster
49. Clarence Dean	Low Hollow near Dean fenster
50. B. C. Fugate No. 1	South of Fourmile fenster
51. Dewey Lee No. 1	North of Hamblin Branch fenster
52. Cleve Dean No. 2	Blackberry Hollow section of Dean fenster
53. Grant Smith	East of Possum Hollow fenster
54. Jim Ray No. 1	Martin Creek fenster
55. Clifford Yeary	South of Fourmile fenster
56. J. R. Osborn	Hamblin Branch fenster
57. J. W. Campbell	North of Hamblin Branch fenster
58. Charles Marcum	Hamblin Branch fenster
59. Beatty Heirs	Martin Creek fenster
60. Abney Heirs	North of Hamblin Branch fenster
61. C. B. Hobbs	Martin Creek fenster
62. Jim Ray No. 2	Martin Creek fenster
63. Charles E. Hobbs No. 2	Martin Creek fenster
64. M. E. McCurry	West of Martin Creek fenster
65. Lee Marcum	South of Hamblin Branch fenster
66. L. E. Bales No. 2	Northeast of Fourmile fenster
67. C. H. Frye	North of Hamblin Branch fenster
68. Alfred Shackleford	North of Hamblin Branch fenster
69. Myrtle Campbell	North of Hamblin Branch fenster
70. Sibbie Ramsey	North of Hamblin Branch fenster



Geologic section along line A-A′



Geologic section along line B-B′



Geologic section along line C-C′.

GEOLOGIC MAP AND STRUCTURE SECTIONS OF THE ROSE HILL DISTRICT, LEE COUNTY, VIRGINIA, AND HANCOCK AND CLAIBORNE COUNTIES, TENNESSEE.

Scale $\frac{1}{24,000}$

1 0 1 2 Miles

5,000 0 10,000 Feet

Contour interval 20 feet
Datum is mean sea level

1952

VIRGINIA DEPARTMENT OF CONSERVATION
AND DEVELOPMENT
WILLIAM M. McGILL, STATE GEOLOGIST

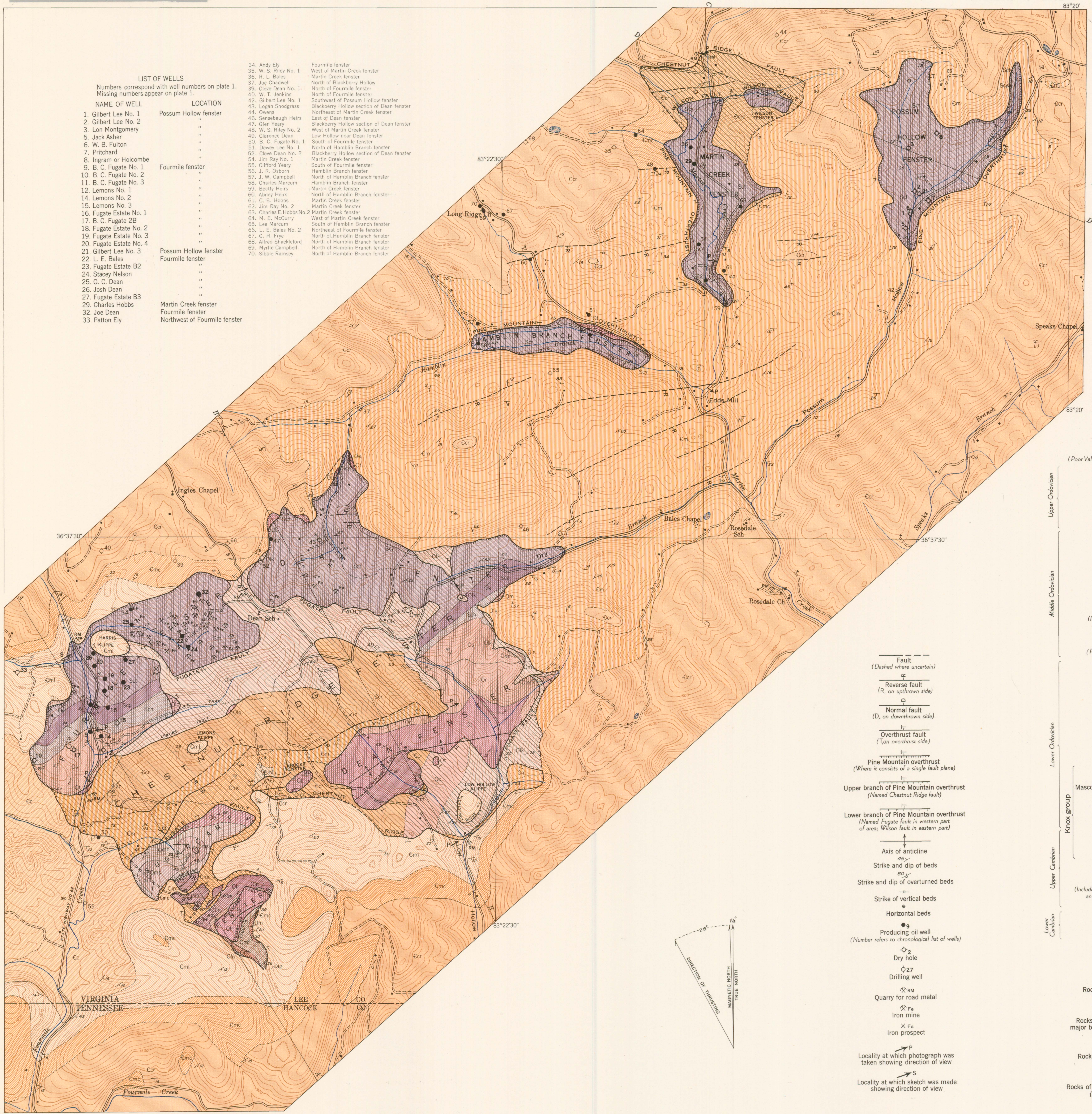
VIRGINIA DIVISION OF MINERAL RESOURCES
James L. Calver, Commissioner
Box 3667, University Station
Charlottesville, Va.

PREPARED IN COOPERATION WITH
GEOLOGICAL SURVEY
U. S. DEPARTMENT OF INTERIOR

LIST OF WELLS

Numbers correspond with well numbers on plate 1.
Missing numbers appear on plate 1.

NAME OF WELL	LOCATION
1. Gilbert Lee No. 1	Possum Hollow fenster
2. Gilbert Lee No. 2	"
3. Lon Montgomery	"
5. Jack Asher	"
6. W. B. Fulton	"
7. Pritchard	"
8. Ingram or Holcombe	"
9. B. C. Fugate No. 1	Fourmile fenster
10. B. C. Fugate No. 2	"
11. B. C. Fugate No. 3	"
12. Lemons No. 1	"
14. Lemons No. 2	"
15. Lemons No. 3	"
16. Fugate Estate No. 1	"
17. B. C. Fugate 2B	"
18. Fugate Estate No. 2	"
19. Fugate Estate No. 3	"
20. Fugate Estate No. 4	"
21. Gilbert Lee No. 3	Possum Hollow fenster
22. L. E. Bales	Fourmile fenster
23. Fugate Estate B2	"
24. Stacey Nelson	"
25. G. C. Dean	"
26. Josh Dean	"
27. Fugate Estate B3	"
29. Charles Hobbs	Martin Creek fenster
32. Joe Dean	Fourmile fenster
33. Patton Ely	Northwest of Fourmile fenster
34. Andy Ely	Fourmile fenster
35. W. S. Riley No. 1	West of Martin Creek fenster
36. R. L. Bales	Martin Creek fenster
37. Joe Chadwell	North of Blackberry Hollow
39. Cleve Dean No. 1	North of Fourmile fenster
40. W. T. Jenkins	North of Fourmile fenster
42. Gilbert Lee No. 1	Southwest of Possum Hollow fenster
43. Logan Snodgrass	Blackberry Hollow section of Dean fenster
44. Owens	Northeast of Martin Creek fenster
46. Sensebaugh Heirs	East of Dean fenster
47. Glen Yeary	Blackberry Hollow section of Dean fenster
48. W. S. Riley No. 2	West of Martin Creek fenster
49. Clarence Dean	Low Hollow near Dean fenster
50. B. C. Fugate No. 1	South of Fourmile fenster
51. Dewey Lee No. 1	North of Hamblin Branch fenster
52. Cleve Dean No. 2	Blackberry Hollow section of Dean fenster
54. Jim Ray No. 1	Martin Creek fenster
55. Clifford Yeary	South of Fourmile fenster
56. J. R. Osborn	Hamblin Branch fenster
57. J. W. Campbell	North of Hamblin Branch fenster
58. Charles Marcum	Hamblin Branch fenster
59. Beatty Heirs	Martin Creek fenster
60. Abney Heirs	North of Hamblin Branch fenster
61. C. B. Hobbs	Martin Creek fenster
62. Jim Ray No. 2	Martin Creek fenster
63. Charles E. Hobbs No. 2	Martin Creek fenster
64. M. E. McCurry	West of Martin Creek fenster
65. Lee Marcum	South of Hamblin Branch fenster
66. L. E. Bales No. 2	Northeast of Fourmile fenster
67. C. H. Frye	North of Hamblin Branch fenster
68. Alfred Shackleford	North of Hamblin Branch fenster
69. Myrtle Campbell	North of Hamblin Branch fenster
70. Sibbie Ramsey	North of Hamblin Branch fenster



Fault
(Dashed where uncertain)

Reverse fault
(R, on upthrown side)

Normal fault
(D, on downthrown side)

Overthrust fault
(T, on overthrust side)

Pine Mountain overthrust
(Where it consists of a single fault plane)

Upper branch of Pine Mountain overthrust
(Named Chestnut Ridge fault)

Lower branch of Pine Mountain overthrust
(Named Fugate fault in western part of area; Wilson fault in eastern part)

Axis of anticline

45
Strike and dip of beds

80
Strike and dip of overturned beds

Strike of vertical beds

⊕
Horizontal beds

● 9
Producing oil well
(Number refers to chronological list of wells)

2
Dry hole

27
Drilling well

RM
Quarry for road metal

Fe
Iron mine

× Fe
Iron prospect

P
Locality at which photograph was taken showing direction of view

S
Locality at which sketch was made showing direction of view

EXPLANATION

SILURIAN

Scy
Cayuga dolomite

Sct
Clinton shale

Scp
Sch
Clinch sandstone
(Poor Valley Ridge member, Scp, and Hagan member, Sch)

ORDOVICIAN

Upper Ordovician

Os
Sequatchie formation
(Includes beds of Maysville age)

Or
Reedsville shale

Middle Ordovician

Ot
Trenton limestone

Oe
Eggleston limestone

Omh
Oms
Moccasin limestone
(Including Hardy Creek member, Omh)

Olp
Olr
Lowville limestone
(Platy member, Olp; redbed member, Olr)

Lower Ordovician

Oln
Lenoir limestone
(After Charles Butts)

Om
Mosheim limestone
(After Charles Butts)

Omf
Murfreesboro limestone
(After Charles Butts)

Knox group

Olk
Mascot, Kingsport, and Longview dolomites
(Undifferentiated)

Oc
Chepultepec dolomite

CAMBRIAN

Upper Cambrian

Ꞓcr
Copper Ridge dolomite

Ꞓm Ꞓmc Ꞓml
Maynardville limestone
(Including Chances Branch dolomite member, Ꞓmc, and Low Hollow limestone member, Ꞓml)

Lower Cambrian

Ꞓc
Conasauga shale
(Upper part only exposed)

Geologic contact
(Dashed where uncertain)

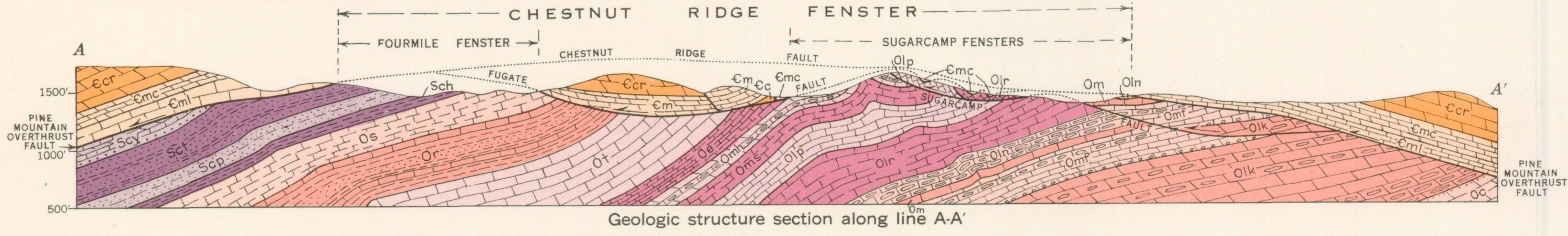
☐
Rocks of Cumberland overthrust block

▨
Rocks in Fugate and Wilson slices between major branches of the Pine Mountain overthrust

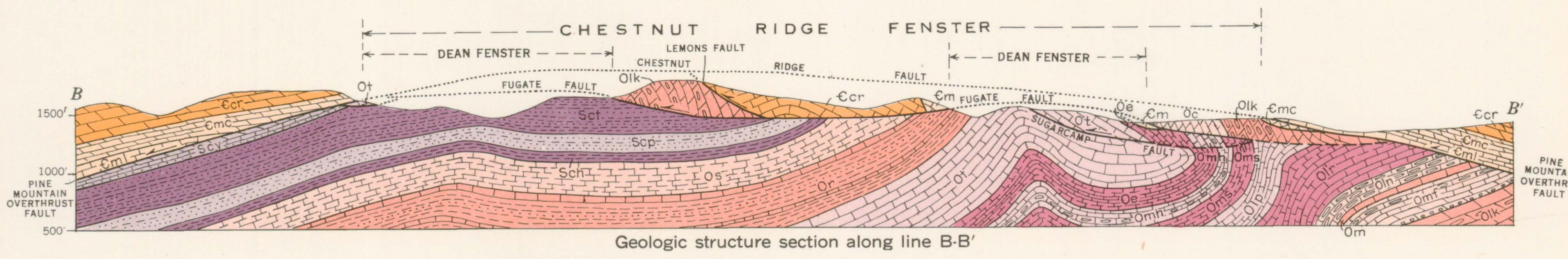
▥
Rocks of stationary block in inner fensters

▨
Rocks of Sugarcamp slice above Sugarcamp fault
(Enclose innermost Sugarcamp fenster)

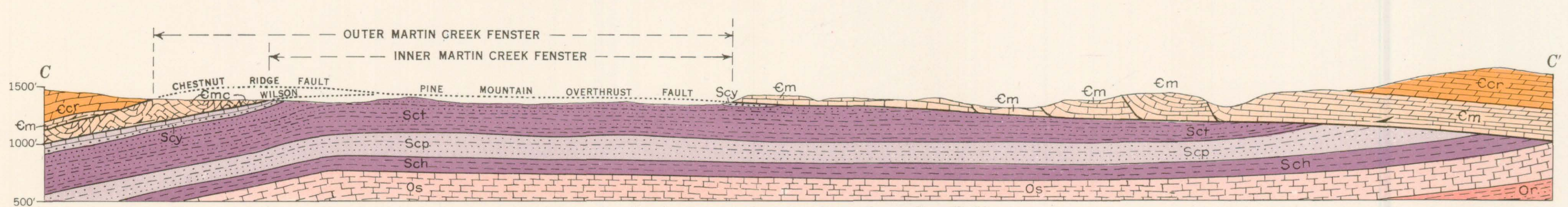
Geology by Ralph L. Miller and J. Osborn Fuller, 1944
Topographic base compiled by the U. S. Geological Survey, and the Tennessee Valley Authority from aerial photographs



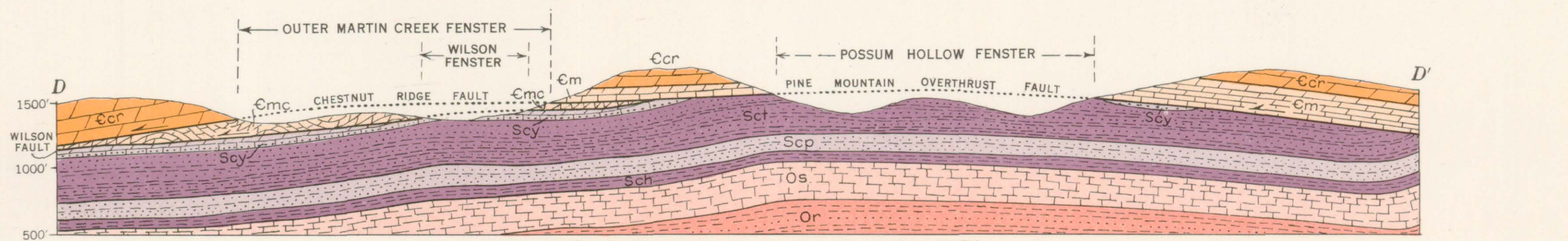
Geologic structure section along line A-A'



Geologic structure section along line B-B'



Geologic structure section along line C-C'.



Geologic structure section along line D-D'

DETAILED GEOLOGIC MAP AND STRUCTURE SECTIONS OF THE FENSTER AREA OF THE ROSE HILL DISTRICT, LEE COUNTY, VIRGINIA

Scale $\frac{1}{12,000}$

1,000 0 5,000 10,000 Feet

0 0.5 1 2 Miles

Contour interval 20 feet
Datum is mean sea level

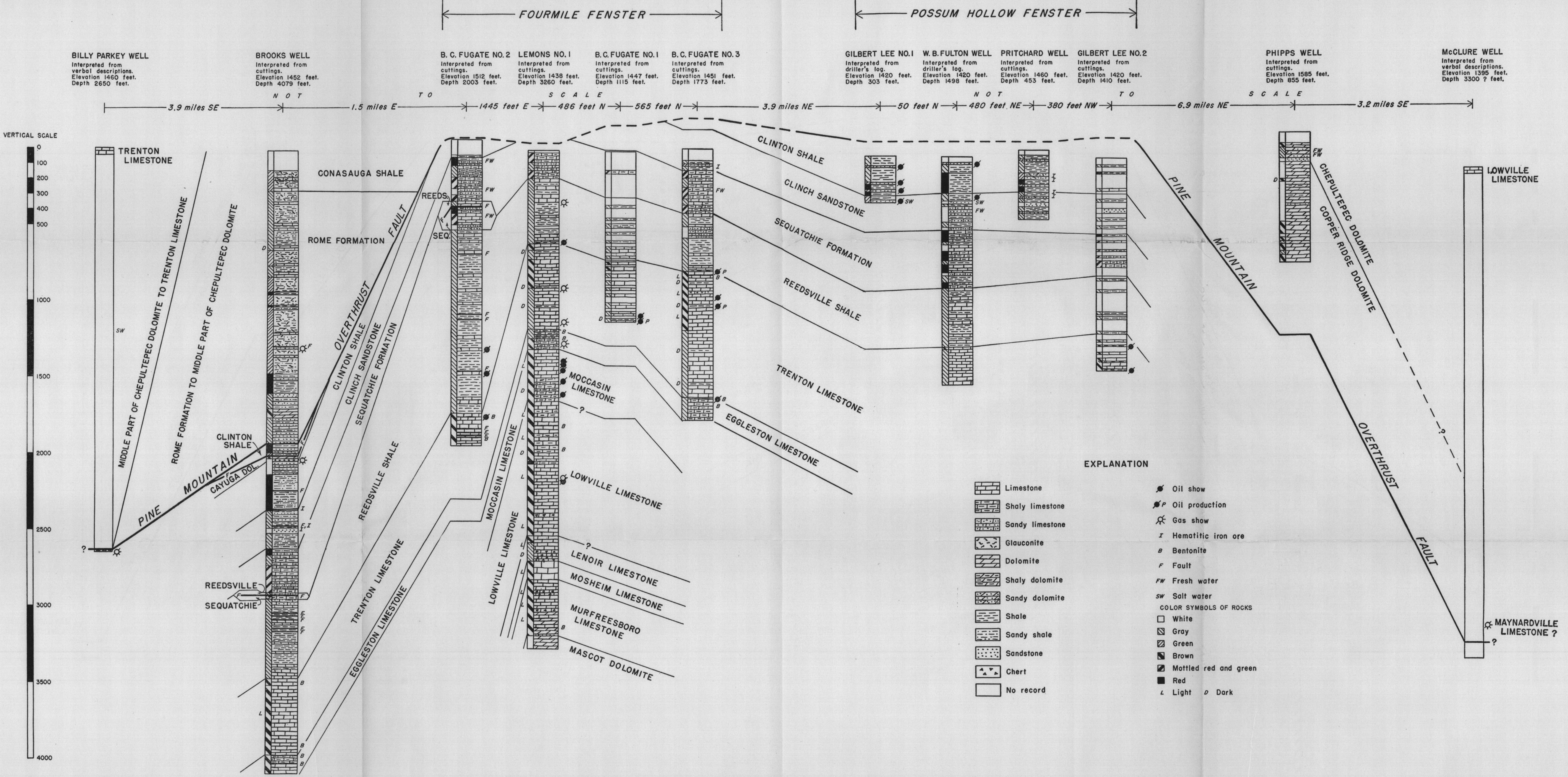
1952

A. GEOLOGY OF THE OVERTHRUST BLOCK

B. GEOLOGY OF THE FUGATE AND WILSON SLICES

C. GEOLOGY OF THE STATIONARY BLOCK

Geologic maps of the principal structural zones of the fenster area.



INTERPRETATION OF RECORDS OF IMPORTANT WELLS IN LEE COUNTY, VIRGINIA