Geology of Northeasternmost Tennessee

GEOLOGICAL SURVEY PROFESSIONAL PAPER 311

Prepared in cooperation with the Tennessee Division of Geology

Geology of Northeasternmost Tennessee

By PHILIP B. KING *and* HERMAN W. FERGUSON

With a section on the

DESCRIPTION OF THE BASEMENT ROCKS

By WARREN HAMILTON

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UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1960

UNITED STATES DEPARTMENT OF THE INTERIOR

FRED A. SEATON, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

The U.S. Geological Survey Library has cataloged this publication as follows:

King, Philip Burke, 1903–

Geology of northeastermost Tennessee, by Philip B. King and Herman W. Ferguson; with a section on the Description of the basement rocks, by Warren Hamilton. Washington, U.S. Govt. Print. Off., 1959.

v, 136 p. illus., maps, diagrs., profiles, tables. 30 cm. (U.S. Geological Survey. Professional paper 311)

Part of illustrative matter fold. in pocket.
Prepared in cooperation with the Tennessee Division of Geology.
Bibliography: p. 4–9, 126–129.

1. Geology—Tennessee. 2. Petrology—Tennessee. I. Ferguson, Herman White, 1916– joint author. (Series)

[QE75.P9 no. 311] G S 59–218

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington 25, D.C.

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GEOLOGY OF NORTHEASTERNMOST TENNESSEE

By Philip B. King and Herman W. Ferguson

ABSTRACT

The geology of an area of 660 square miles mostly in the northeastern corner of Tennessee and small adjacent areas in Virginia and North Carolina is the subject of this report. The region lies principally in the Unaka province, with extensions northwestward into the Appalachian Valley and southwestward into the Blue Ridge province. The report combines results of surveys made between 1941 and 1953 by the U. S. Geological Survey, the Tennessee Division of Geology, and the Tennessee Valley Authority, and is published in cooperation with the Tennessee Division of Geology.

Northeasternmost Tennessee is a region of widespread mineralization, and was formerly important for mineral production. Iron, manganese, and bauxite have been mined, and the region has been prospected for phosphate, tripoli, zinc, pyrite, and barite. However, mineral deposits are dealt with only incidentally in this report. Chief attention is given to the rock formations, their structure, and their land forms, all of which are basic to an interpretation and evaluation of the mineral deposits.

The consolidated rocks of northeasternmost Tennessee are largely of sedimentary origin and of early Paleozoic age, but they lie on a basement of plutonic and metamorphic rocks of Precambrian age. The basement rocks are principally exposed in the Blue Ridge province along the southeastern edge of the region of this report, but they also crop out in smaller areas farther northwest, in diverse structural situations. The basement rocks include some granitic intrusions that were probably injected as sheets at relatively shallow depth late in Precambrian time. But most of the basement rocks are evidently older and have had a much more complex history; their fabrics reflect structures superposed during successive epochs of plutonism, metamorphism, and deformation. During the earlier episodes, in Precambrian time, a terrane whose initial character is unknown was converted by plutonic metamorphism into gneiss, migmatite, and granitic rocks. During a subsequent episode, perhaps in early Paleozoic time, the basement rocks on the southeast were extensively sheared and mylonitized. In later Paleozoic time, when all the rocks of the region were deformed and broken into large-scale thrust blocks, the basement rocks were further sheared along relatively narrow zones of movement.

In the northern part of the region the Mount Rogers volcanic group wedges in between the basement rocks and rocks of definite Paleozoic age. The group is a sequence of silicic flows and tuffs and clastic sedimentary rocks many thousands of feet thick, which were probably laid down during latest Precambrian time.

The early Paleozoic sedimentary rocks include rocks of the Lower, Middle, and Upper Cambrian series, and of the Lower and Middle Ordovician series. Sedimentary rocks below the Middle Ordovician are 12,000 to 18,000 feet thick, of which the lower 6,000 to 10,000 feet belongs to the Lower Cambrian series. The Middle Ordovician series may exceed 5,000 feet in thickness in places. Because the Lower Cambrian series is very thick, and has been duplicated structurally, it occupies by far the widest area of outcrop in the region. In general, the older sedimentary rocks lie to the southeast, nearest the Precambrian basement, and the younger rocks lie to the northwest, in and near the Appalachian Valley, but in detail the sequence has been disordered by great low-angle thrusts, and lesser folds and faults.

The initial Paleozoic deposit, the Chilhowee group, is a mass of clastic rocks—conglomerate, arkose, shale, and quartzite, with some thin beds of basaltic lava in the lowest formation. Diagnostic Lower Cambrian formations are known only near the top, although worm tubes (*Scolithus*) occur through the upper half. The Chilhowee group forms the high ridges of the Unaka Mountains.

The Chilhowee group is overlain by a great carbonate sequence, which has been worn down into valleys and lowlands between the mountains. The lower two units of the sequence, the Shady dolomite and Rome formation, belong to the Lower Cambrian series; succeeding them are the Conasauga group (Middle and Upper Cambrian) and the Knox group (Upper Cambrian and Lower Ordovician), a mass of dolomite and limestone with the thin Nolichucky shale present in places at the top of the Conasauga.

The carbonate sequence is succeeded by a thick body of shale and sandstone of Middle Ordovician age, the youngest Paleozoic rocks still preserved in the region. Conglomerate interbedded in the Middle Ordovician rocks records an important orogenic episode, earlier than the late Paleozoic orogeny which produced most of the visible structures.

The structure of northeasternmost Tennessee is representative of that of the southern Appalachians which were formed during later Paleozoic time and were characterized by great low-angle thrust faults that have been considerably warped.

The traces of three major low-angle faults—the Holston Mountain, Iron Mountain, and Stone Mountain faults—divide the region into four structural units. Northwest of the Holston Mountain fault are the deformed Paleozoic rocks of the Appalachian Valley; between the Holston Mountain and Iron Mountain faults is the Shady Valley thrust sheet, which has been warped down into the Stony Creek syncline; between the Iron Mountain and Stone Mountain faults is the Mountain City window; southeast of the Stone Mountain fault are the plutonic and metamorphic basement rocks of the Blue Ridge province.

The rocks of the Appalachian Valley and the Mountain City window are part of the same structural block, and have been overridden 18 miles or more by the rocks of the Shady Valley thrust sheet; this thrust sheet is, in turn, a lower slice of the great overriding mass of the Blue Ridge province than has

moved along the Stone Mountain fault. The Shady Valley thrust sheet overrode previously deformed rocks; but the rocks of the thrust sheet lie in the relatively open Stony Creek syncline. Latest structures in the region are a series of right-lateral transcurrent faults, perhaps produced by continuation of thrusting movements southwest of the region of this report.

Either during the deformation or shortly after, hydrothermal minerals were introduced locally in the consolidated rocks, producing small deposits of sphalerite, pyrite, specular hematite, and barite.

During the Cenozoic era, degradation lowered parts of the land surface from levels near the present mountain summits to levels near the present streams. Degradation proceeded unequally; the limestone and dolomites especially were worn down to lowlands, with the quartzite and other clastic rocks remaining as high mountain ridges.

Degradation also proceeded intermittently, with times of stillstand when the weaker rocks were extensively leveled and times of accelerated downcutting. There is little evidence of any former high-level erosion surfaces, except perhaps on the summits of Holston and Iron Mountains, but a very extensive former surface was cut lower down at the level of valley floors that stand several hundred feet above the modern streams. The time of cutting of the valley floor surface was one of deep and prolonged weathering, during which the carbonate rocks (especially the Shady dolomite) were thickly blanketed by residuum, and were in turn covered by quartzite wash from the adjoining mountains. It was also a time of mineralization, when widely distributed deposits of iron and manganese oxides were formed in the residuum, and local deposits of bauxite accumulated in depressions on the valley floor surface.

Since the valley-floor surface was formed, the streams have cut down to their present levels, and talus and rock streams have accumulated on the mountain slopes, probably chiefly during the more rigorous climatic conditions of Pleistocene time.

INTRODUCTION

PLAN AND PURPOSE OF REPORT

This report describes the geology of Johnson and parts of Sullivan and Carter Counties, Tenn., and small contiguous parts of the Washington County, Va., and Ashe, Watauga, and Avery Counties, N. C.; it presents the results of a long investigation by many geologists, who were working under the auspices of the U. S. Geological Survey, the Tennessee Division of Geology, and the Tennessee Valley Authority. The geologic map accompanying the report (pl. 1) includes an area of 660 square miles.

The geology of northeasternmost Tennessee is typical of that of the southern Appalachians. Here the great thrusts stand forth in all their majesty, their actual surfaces of movement are as well exposed as in many more arid countries, and the geometry of the structures can be worked out rather fully because the formations are readily recognizable.

The region is of economic interest as one of widespread mineralization, and formerly was important for mineral production. It has produced approximately 350,000 tons of iron concentrate, 27,500 tons of manganese concentrate, and 10,000 tons of bauxite; also, various localities have been prospected for phosphate, tripoli, zinc, pyrite, and barite.

The mineral resources were treated in a report of the Tennessee Division of Geology and U. S. Geological Survey published in 1944 (King, Ferguson, Craig, and Rodgers, 1944). As that report described the individual deposits rather fully, and as mineral development from then until 1954 was comparatively modest, this information is not repeated here, nor has the record been brought up to date.

However, the report of 1944 furnished only a summary of the geological environment of the mineral deposits, here set forth in detail. The mineral deposits themselves are treated only as they bear on the general geologic record. The report, nevertheless, affords basic materials for the economic geologist—descriptions of the mappable formations and their key beds, of the structures and the land forms, and of the processes that contributed to the localization of mineral deposits. The report thus provides the economic geologist with the tools, so to speak, by which an intelligent survey of the mineral possibilities can be undertaken.

PRESENT INVESTIGATION

This report is based on fieldwork as follows (see also index map on pl. 1):

Between 1941 and 1943 a party of the U. S. Geological Survey under the direction of Philip B. King and supervised by Hugh D. Miser investigated the manganese deposits of the present area and contiguous areas to the southwest. The party mapped in detail the Shady Valley district, the Stony Creek district, and part of the Hampton district, and reconnoitered adjacent areas. At various times the party included John Rodgers, Lawrence C. Craig, Laurence E. Smith, Clemens A. Nelson, and Warren J. Souder. Rodgers, especially, made many preliminary examinations of the fundamental geologic problems, and advised other members of the party on these problems as the work progressed.

At the time the Geological Survey party was working in the area, the Tennessee Division of Geology did cooperative work nearby. This work was done by Herman W. Ferguson under the direction of Walter F. Pond, then State geologist. Ferguson mapped in detail parts of the Mountain City and Hampton districts, and aided in preparation of the economic report of 1944.

After the work of the Geological Survey was finished in 1943, Ferguson continued mapping the Butler district, part of which was soon to be flooded by Watauga

Lake; about a year was devoted to this work. Still later, mainly in 1949, Ferguson resumed mapping in areas between those he had previously surveyed and reviewed and reinterpreted the area as a whole.

In 1942 and 1943, and again in 1947 and 1948, geologists of the Tennessee Valley Authority examined the sites of engineering works at the Watauga and South Holston Dams in detail, and studied in reconnaissance the reservoir areas of these dams. This work, which was under the direction of Berlen C. Moneymaker, chief geologist, was done by Cecil B. McGavock, Jr., Leland F. Grant, John M. Kellberg, and their assistants, McGavock being primarily responsible for the South Holston area and Grant and Kellberg for the Watauga area (Tennessee Valley Authority Geologic Branch, 1949, p. 357–385). Although these geologists have taken no part in preparing the present report, they have generously contributed the results of their work.

In 1953 and 1954 Warren Hamilton of the U. S. Geological Survey made a reconnaissance of the metamorphic and plutonic basement rocks of northeasternmost Tennessee, which were not previously studied during the present project.

During 1950 to 1954 King and Ferguson mapped additional small areas to complete the work. In 1950, Ferguson extended the mapping of the Stone Mountain fault northeastward into North Carolina and in 1951 and 1953 he mapped in reconnaissance the northeast end of the Mountain City window in Virginia. In 1953 King mapped the younger carbonate rocks of the Elizabethton and Denton Valley areas in the southwest and northwest parts of the region shown on the geologic map.

Besides the work outlined above, the Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Department of Agriculture (now part of the Soil Conservation Service) has completed soil maps of Johnson, Carter, and Sullivan Counties, in cooperation with the Tennessee Valley Authority. The maps have been published only in part, but manuscript copies were made available for use during compilation of the geologic map. From the soil maps it is possible to deduce the parent materials of the soils, whether derived from alluvium, colluvium, or from various kinds of bedrock. The maps were therefore used in many places for indicating the outlines of the alluvial areas, and as a check on bedrock contacts where geologic mapping was inadequate.

The present report was prepared by King in 1953 and 1954. He has been responsible for organizing and assembling the manuscript, maps, and illustrations, and he has also done the greater part of the writing of the report. Although an attempt has been made to preserve as impartially as possible the diverse observations and conclusions of the many contributing geologists, the styling and overall interpretations are necessarily those of King.

However, the contribution of the Tennessee Division of Geology, mostly the work of Ferguson, equals that of the other organizations. Because of Ferguson's duties, first as assistant State geologist and State geologist, and later in private economic work, he was unable to take part in writing, but he has served as a friendly critic and counselor as the work progressed.

ACKNOWLEDGMENTS

The authors and their colleagues are indebted to many geologists, mining engineers, local residents, and others, without whose assistance and cooperation the present report could not have been completed. The extent of this assistance can be only inadequately acknowledged, and the help of some may unintentionally have been slighted.

Greatest debt is owed to Hugh D. Miser, geologist in charge of Appalachian manganese investigations during World War II. Miser took a deep personal interest in the investigation of northeastern Tennessee, and participated in many field conferences with mature aid and counsel, both on the manganese deposits and the general geology.

The successive State geologists of Tennessee, Walter F. Pond, H. B. Burwell, Herman W. Ferguson, and William D. Hardeman, supported the investigation throughout, and encouraged personnel of both the Tennessee Division of Geology and the U. S. Geological Survey in the mapping and fieldwork. They made accessible for incorporation in the present report the field sheets, notebooks, and manuscripts resulting from the Tennessee Division phase of the investigation.

Thanks are due to the geologists of the Tennessee Valley Authority, Cecil B. McGavock, Jr., Leland F. Grant, and John M. Kellberg, for an opportunity to study the Watauga Dam area with them while construction was in progress and to Berlen C. Moneymaker, chief geologist, for permission to use the results obtained by these geologists, both on the Watauga and the South Holston areas, in the present report.

The staff of the Soil Survey office of the Soil Conservation Service (formerly Bureau of Plant Industry, Soils, and Agricultural Engineering) in Knoxville, and especially Max D. Edwards, senior soil correlator, Southern States, have been unfailingly helpful in furnishing data relating to the soils of northeasternmost Tennessee, and in aiding in the interpretation of the geology of these soils.

During the later phases of the investigation, King and Ferguson have been aided and advised from time to time in the field by their colleagues of the U. S. Geological Survey who have been stationed in Tennessee—John Rodgers, Robert A. Laurence, Robert B. Neuman, Jarvis B. Hadley, George D. Swingle, and Warren Hamilton.

PREVIOUS WORK

Probably the first geologic work done in eastern Tennessee was by Gerard Troost, the first State geologist, between 1831 and 1845. He recognized the probable presence of the Cambrian and Silurian systems that had been established in Great Britain only a few years previously. This work was of a very general nature and little was contributed that applies specifically to northeasternmost Tennessee.

The first significant work within northeasternmost Tennessee was that of James M. Safford, second State geologist, immediately before and after the Civil War. His final report, published in 1869, vividly presents the general aspects of the topography and geology of the State, and includes many observations on local details.

The mountain-forming rocks of the Unaka province along the eastern edge of the State, including the ranges of northeasternmost Tennessee, were assigned by Safford to the Ocoee conglomerate and slate and to the Chilhowee sandstone, which were classed as of Potsdam or "lower Silurian" age. A section of Chilhowee rocks in the Doe River gorge through the Iron Mountains south of Elizabethton was presented by Safford (1869, p. 201), at the same locality where a detailed section was measured during this survey. Conglomerate and slate farther northeast on the Iron Mountains, near Laurel Creek, were assigned to the Ocoee (1869, p. 195–196). Shale and carbonate rocks overlying the Chilhowee sandstone were termed the Knox group, the lowest unit of which was his Knox sandstone (the present Rome formation). The Shady dolomite, which actually intervenes between the Rome and the Chilhowee, was thus unrecognized, at least in its true stratigraphic position. Although faults were indicated, especially the Iron Mountain fault of this report, the sections show them as standing at high angles, and no particular significance seems to have been attributed to them (fig. 1*A*).

Between 1890 and 1905 much of the region was mapped by geologists of the U. S. Geological Survey and the results were published in folios—the Roan Mountain (1907) and Cranberry (1903) by Arthur Keith, and the Bristol (1899) by M. R. Campbell. During the same period Keith began a survey of the Abingdon quadrangle, that would have completed the mapping of the region, but this work was not completed and the results were not published.

Keith classified the stratified rock formations of the region much as in the present report. He divided the Chilhowee group into the Unicoi, Hampton, and Erwin formations, although the first two names were earliest used in print by Campbell in the Bristol folio. Keith was able to work out refinements in terminology and order of succession of the higher strata that had not been recognized by Safford for, as he remarks (1907, p. 4),

> The region around Elizabethton and Johnson City in Tennessee is the only one in the Appalachians south of Virginia where there is an unbroken sequence of the formations from the base of the Cambrian into the Ordovician.

The Shady dolomite was thus located and defined and the Honaker dolomite was separated from the Knox dolomite above by recognition of the thin intervening Nolichucky shale. Keith's name "Watauga shale," an excellent local term, has been superseded by Rome formation, earlier defined by C. W. Hayes (1891, p. 143) in the Rome area, Georgia.

Keith clearly recognized the synclinal nature of the long Shady Valley-Stony Creek belt (his "Iron Mountain syncline"), and described the inward-dipping thrusts of the Iron Mountains and Holston Mountain on either side (Iron Mountain and Holston Mountain faults of present report) (fig. 1*B*). He also recognized a major low-angle thrust fault, downfolded into the syncline on Buffalo Mountain southwest of the area of the present report, but farther northeast lying within the basement rocks. However, he attributed the thrusts in the Iron Mountains and Holston Mountain to a sort of wedge structure, produced by shearing subsequent to the major thrusting. Butts (1932, p. 84–86, pl. 26), many years later, offered the probably correct interpretation that these inward-dipping thrusts are parts of a single low-angle fault (fig. 1*C*), tectonically below the one of Buffalo Mountain.

Other reports dealing with special phases of the geology of northeasternmost Tennessee are included in the annotated bibliography below:

Safford, J. M., 1856, A geological reconnaissance of the state of Tennessee, being the author's first biennial report, presented to the 31st General Assembly of Tennessee, December, 1855: Nashville, Tenn., 164 p., map.

A report preliminary to the longer report of 1869, but containing the first use of many of the stratigraphic names.

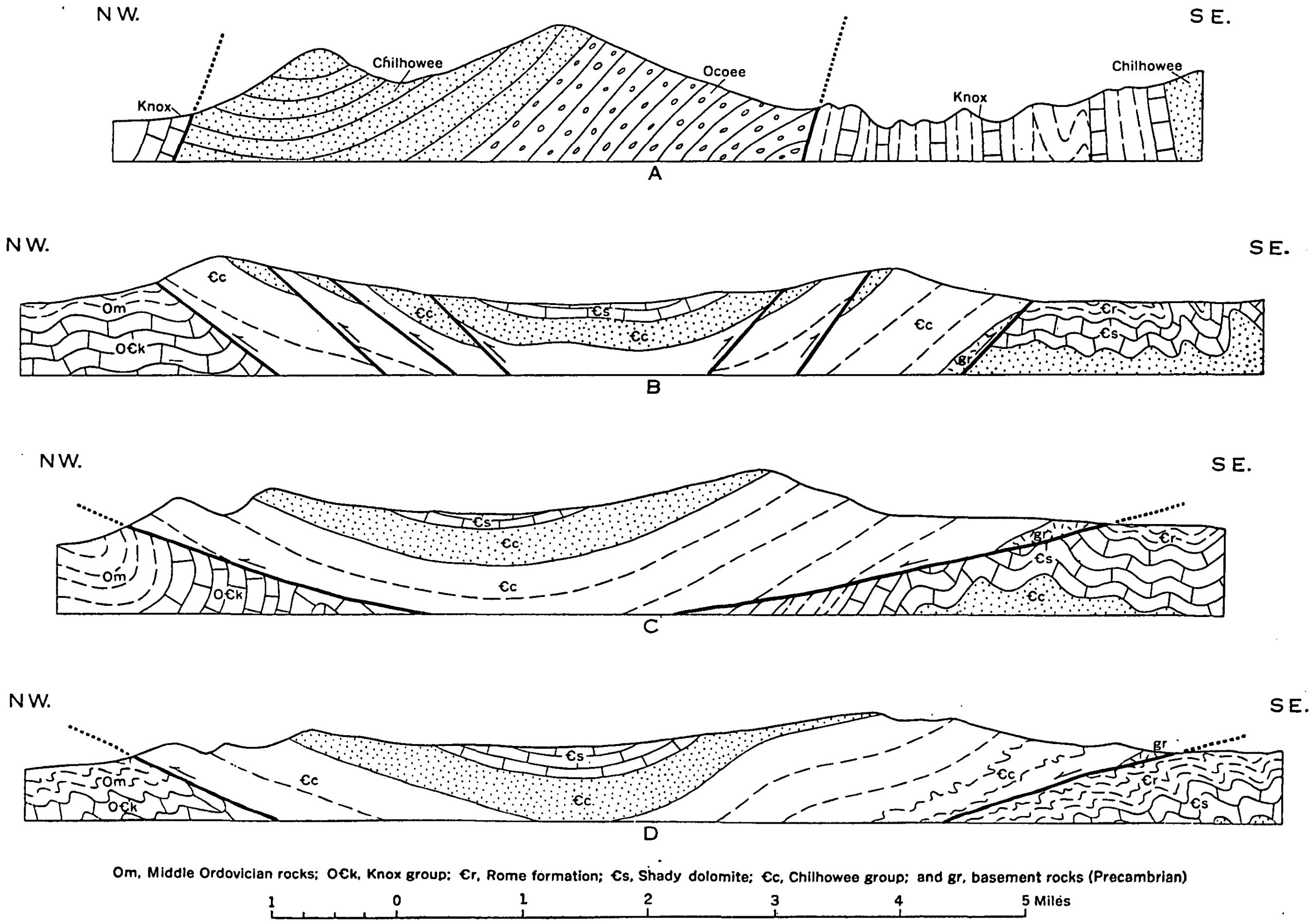

FIGURE 1.—Sections showing successive interpretations of the structure of Holston Mountain, the Iron Mountains, and the intervening Stony Creek syncline *A*, Safford (1869, p. 195); *B*, Keith (1907, section A A'); *C*, Butts (1932, pl. 26); *D*, This report (section 13, pl. 17). Sections *C* and *D* are drawn across Shady Valley along nearly the same line; section *A* is to the northeast, along Laurel Creek and section *B* is to the southwest, at the upper end of Stony Creek valley. Note marked differences between the later interpretations in sections *C* and *D*, and the earlier interpretations in sections *A* and *B*.

Guyot, Arnold, 1861, On the Appalachian system: Am. Jour. Sci., 2d ser., v. 31, p. 157–187.

Very general notes on geography of highlands of North Carolina and Tennessee, including discussion of altitudes and geographic terminology.

Guyot, Arnold, 1863, Notes on the geography of the mountain district of western North Carolina, founded on observations in the summers of 1856, 1859; 1860: Report to Superintendent of the Coast Survey, manuscript report in files of U. S. Coast and Geodetic Survey, 86 p., map.

Principally a geographic description of the Appalachian Highlands in western North Carolina and adjacent parts of eastern Tennessee, including some notes on northeasternmost Tennessee. Makes recommendations as to military significance of the highlands during the Civil War.

Safford, J. M., 1869, Geology of Tennessee: Nashville, Tenn., 550 p., map.

The first comprehensive account of the geology of Tennessee, with many observations on the physical features and the geology within the region of the present report. Still a useful and vivid introduction to Tennessee geology.

Killebrew, J. E., 1881, Iron and coal of Tennessee: Tennessee Bur. of Agriculture, 220 p.

Contains much useful information on iron deposits of northeasternmost Tennessee, and on early iron mining operations.

Willis, Bailey, 1886, Notes on the samples of iron ore collected in east Tennessee, *in* Report on the mineral industries in the United States (exclusive of precious metals) with special investigations into the iron resources of the republic, and into the Cretaceous coals of the northwest: U. S. Tenth Census (1880), v. 15, p. 331–350.

An appraisal of the limonitic iron deposits of eastern Tennessee, including many valuable observations on those in Carter and Johnson Counties of northeasternmost Tennessee.

Penrose, R. A. F., Jr., 1891, Manganese, its uses, ores, and deposits: Arkansas Geol. Survey Ann. Rept. for 1890, pt. 1, 642 p.

Contains description of manganese and iron deposits in Shady Valley (p. 414–416), apparently based on personal examination.

Keith, Arthur, 1892, Geology of Chilhowee Mountain in Tennessee: Philos. Soc. Washington Bull., v. 12, p. 71–88.

Presents the thesis that the dolomite lying on the Chilhowee group (actually Shady) represents a transgressive overlap of the much younger Knox dolomite, and that the succeeding red shale (actually Rome) is a "shore deposit" of the Knox. Discussion centers on Chilhowee Mountain, but evidence is also cited in Stony Creek valley and elsewhere in northeastern Tennessee.

Keith, Arthur, 1895, Some stages of Appalachian erosion: Geol. Soc. America Bull., v. 7, p. 519–525.

Interpretation of erosional history of Appalachian Valley and Unaka Mountains in Tennessee, based mainly on correlation of surfaces at similar altitudes. Area includes northeasternmost Tennessee, although no specific references are made.

Campbell, M. R., 1899, Description of the Bristol, Va.-Tenn. quadrangle: U. S. Geol. Survey Geol. Atlas, Folio 59, 8 p., maps, sections.

Includes northwestern part of area of this report.

Keith, Arthur, 1902, Folded faults in the southern Appalachians (abs.): Science, new ser., v. 15, p. 822–823.

First published statement of presence, in northeasternmost Tennessee and elsewhere, of major low-angle faults whose roots are in the basement rocks, which have been folded subsequent to emplacement.

Keith, Arthur, 1903, Description of the Cranberry, N. C.-Tenn. quadrangle: U. S. Geol. Survey Geol. Atlas, Folio 90, 9 p., maps, sections.

Includes the southeastern part of the area of this report; contains the first use in their type areas of many of the Lower Cambrian formation names.

Garrison, F. L., 1904, The iron ores of Shady Valley, Tennessee: Eng. and Min. Jour., v. 78, p. 590–592.

A note on the iron resources of the Shady Valley district.

Keith, Arthur, 1907, Description of the Roan Mountain quadrangle: U. S. Geol. Survey, Geol. Atlas, Folio 151, 11 p., maps, sections.

Includes southwest part of area of this report, and presents final interpretations of Keith on the geology of northeasternmost Tennessee.

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

Includes brief notes on manganese deposits in northeasternmost Tennessee as known immediately prior to World War I (p. 73–75).

Glenn, L. C., 1911, Denudation and erosion in the southern Appalachian region and the Monogahela basin: U. S. Geol. Survey Prof. Paper 72, 137 p.

Includes description of physiography and erosional conditions of Watauga River basin, with emphasis on effects of great flood of 1901 (p. 34–41).

Anonymous, 1912, The iron ores of east Tennessee: The Tradesman, v. 68, p. 36–37.

Summarizes occurrence and development of iron ores in east Tennessee, with analyses and production statistics.

Ashley, G. H., 1912, "Fools gold": Resources of Tennessee, v. 2, p. 69–71.

Brief note on pyrite mines of Stony Creek Valley.

Jarvis, R. P., 1912, The valley and mountain iron ores of east Tennessee: Resources of Tennessee, v. 2, p. 326–360; also Tennessee Geol. Survey Bull. 2 C.

Gives data on iron mining and iron production in Carter and Johnson Counties (p. 339–343, 347–350).

Reynolds, A. D., 1912, Deposits of ores: Manufacturer's Record, v. 61, p. 60.

Reports occurrence of iron ore near Marbleton, northern Unicoi County, and in Carter County.

Watkins, J. H., 1913, Bauxite near Elizabethton, Tenn.: Eng. Min. Jour., v. 95, p. 604–605.

Describes the deposit of bauxite near Keenburg north of Elizabethton, with photographs and analysis.

Glenn, L. C., 1914, A tripoli deposit near Butler, Tenn.: Resources of Tennessee, v. 4, p. 29–35, also Science, new ser., v. 39, p. 403.

Describes occurrence of tripoli in weathered calcareous rocks of Rome formation in vicinity of new townsite of Butler.

Purdue, A. H., 1914, Bauxite in Tennessee: Resources of Tennessee, v. 4, p. 87–92.

Contains data on bauxite deposit near Keenburg, north of Elizabethton.

Phalen, W. C., 1915, Bauxite and aluminum: U. S. Geol. Survey Min. Res. U. S., 1914, pt. 1, p. 183–209.

Contains a note on bauxite deposit north of Elizabethton (p. 187).

Watkins, J. H., 1915, Phosphate rock in Johnson County, Tenn.: Min. and Eng. World, v. 43, p. 217–218.

Report on occurrence of phosphate in Johnson County, with analysis.

Jenkins, O. P., 1916, Phosphates and dolomites of Johnson County, Tenn.: Resources of Tennessee, v. 6, p. 51–106.

Deals principally with phosphate deposits in Shady dolomite of Johnson County, but contains many useful observations on general geologic features of the county.

Purdue, A. H., 1916, Notes on manganese in east Tennessee: Resources of Tennessee, v. 6, p. 111–123.

Contains notes on manganese deposits and mining development in northeasternmost Tennessee as they existed at beginning of World War I.

Stose, G. W., and Schrader, F. C., 1918, Manganese deposits of east Tennesseee: Resources of Tennessee, v. 8, p. 150–207, 227–324.

A preliminary edition of report of 1923.

Maxwell, H. V., 1919, Manganese ore in east Tennessee: Eng. and Min. Jour., v. 107, p. 149.

An account of mining developments in northeastern Tennessee during World War I.

Bayley, W. S., 1923, The magnetic iron ores of east Tennessee and western North Carolina: Tennessee Div. Geology Bull. 29, 252 p.

Deals mainly with magnetic iron ores of Cranberry district a short distance south of area of this report, but includes description of hematitic magnetite prospects in basement rocks south of Pond and Little Pond Mountains within region of this report (p. 241–251).

Morse, P. F., 1923, The bauxite deposits of Mississippi: Mississippi Geol. Survey Bull. 19, 208 p.

Includes note on bauxite deposit near Keenburg north of Elizabethton (p. 75–77).

Stose, G. W., and Schrader, F. C., 1923, Manganese deposits of east Tennessee: U. S. Geol. Survey Bull. 757, 154 p., map.

Describes geologic setting of manganese deposits of east Tennessee, including those within region of present report; describes development of manganese mines and prospects during World War I, including those in Johnson and Carter Counties (p. 36–78).

Barrell, Joseph, 1925, The nature and environment of the Lower Cambrian sediments of the southern Appalachians: Am. Jour. Sci., 5th ser., v. 9, p. 1–20.

General summary of stratigraphy of Chilhowee group and Ocoee series, based on mapping by Keith, with interpretations of origin of sediments. Incidental references to northeasternmost Tennessee.

King, W. R., 1931, Surface waters of Tennessee: Tennessee Div. Geology Bull. 40, 165 p.

Includes an account of the flash flood of 1925 near Cardens Bluff on the Watauga River.

Wright, F. J., 1931, The older Appalachians of the south: Denison Univ. Bull., v. 31, p. 143–250; also Sci. Lab. Jour., v. 26.

Summary of evidence for the erosional history of the Unaka and Blue Ridge provinces. Contains notes on former erosion surfaces in the basins of the Doe and Watauga Rivers (p. 196–197), but much of the remainder does not bear directly on region of this report.

Butts, Charles, Stose, G. W., and Jonas, A. I., 1932, Southern Appalachian region: Internat. Geol. Cong., 16th Washington, 1932, Guidebook 3, 94 p., maps.

Contains a description, by Butts, of the route from Bristol to Mountain City across Shady Valley (p. 84–86), within the region of present report. Interprets the Shady Valley syncline as an outlier of a thrust sheet from the southeast, with Holston Mountain and Iron Mountain faults joining beneath it.

Butts, Charles, 1933, Geologic map of the Appalachian Valley of Virginia: Virginia Geol. Survey Bull. 42, 56 p., map.

Geologic map (scale 1:250,000) includes Virginia part of region dealt with in present report. Brief text is preliminary to that of longer report of 1940.

Wright, F. J., 1936, The newer Appalachians of the south, Pt. 2, south of the New River: Denison Univ. Bull. v. 36, p. 93–142; also Jour. Sci. Laboratories, v. 31.

Interpretation of erosional history of Appalachian Valley in Tennessee and adjacent states; includes brief mention of river terraces near Elizabethton (p. 119).

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GEOGRAPHY

PHYSICAL GEOGRAPHY

Northeasternmost Tennessee lies centrally in the southern Appalachian Highlands, mostly in the northwestern part of the Blue Ridge province (Fenneman, 1938, p. 173), or Unaka province. Its edges extend southeastward into the main part of the Blue Ridge and northwestward into the lowlands of the Ridge and Valley province, the Appalachian Valley (pl. 2*B*).

UNAKA PROVINCE

The Blue Ridge forms the southeastern rampart of the Appalachian Highlands from Pennsylvania to Georgia between the Ridge and Valley province and the Piedmont province. North of Roanoke, Va., the Blue Ridge is truly ridgelike, but to the south its broadens into a plateau as much as 70 miles broad. Most of this plateau is formed by metamorphic and plutonic rocks, but on the northwest side, in the Tennessee–North Carolina segment, are high forested ridges of clastic sedimentary rocks, the Unaka province (Fenneman, 1938, p. 173–174). According to Safford (1869, p. 22):

> Several prominent portions of the chain, lying in different and distant counties, have the name Unaka locally applied to them. As it is desirable . . . that the entire chain should, like the Blue Ridge, have a general and distinctive name, I have, borrowing the one above, denominated it the Unaka Chain.

In the northeasternmost Tennessee the Unaka ridges are formed by quartzite, arkose, and associated sandy and silty shale of the lowest part of the Paleozoic column, which stand in northeastward-trending strike ridges, and locally have been carved into dip slopes and mesalike outliers.

The northwestern ridge, Holston Mountain, extends in a high escarpment along the edge of the Appalachian Valley for 30 miles southwestward from Damascus, Va., to a point north of Elizabethton, Tenn., where it ends in lower country (pl. 2*A*). Paralleling it on the southeast are the equally lofty but narrower Iron Mountains, which extend across the whole region to the Doe River although they are breached toward the northeast by the water gap of Laurel Creek, and toward the southwest by water gap of the Watauga River. Farther southeast, and in part forming the Tennessee–North Carolina boundary, is a third series of ridges, less regular than the first two but forming a more or less connected chain. These ridges bear many local names but the whole chain is collectively termed the Stone Mountains.

Between the Unaka ridges are valleys and lowlands of varying width carved from carbonate rocks (limestones, dolomites, and limy shales). They are extensively blanketed by residual clay and by bouldery wash spread out from the adjacent ridges, but in places the limestones and dolomites form a karst topography, and the shales form low knobby hills.

Stony Creek valley is a long tongue of lowland between Holston Mountain and the Iron Mountains that opens into the Appalachian Valley on the southwest, near Elizabethton. Shady Valley (fig. 35), a more isolated and elevated oval depression, lies along the same trend to the northeast. Between the Iron Mountains and Stone Mountains, the broader Johnson County cove (Safford, 1869, p. 49) extends diagonally across the southeast part of the county; a narrower southwestward extension, the Doe River cove (Safford, 1869, p. 24) is closely hemmed in at the sides by the Iron Mountains and Stone Mountains. South of Mountain City the Johnson County cove is split in the middle by a dozen or more narrow, parallel, closely spaced ridges, many separately named. It is appropriate here to designate the whole group as the Doe ridges from Doe Mountain, one of the larger and higher of the group, and this name will be used for them throughout the succeeding text.

APPALACHIAN VALLEY

In its northwestern part the Ridge and Valley province (Fenneman, 1938, p. 195), carved from folded and faulted Paleozoic rocks, consists of closely packed northeastward-trending ridges. Its southwestern part, close to the Unaka province, is a broad lowland, the Appalachian or Great Valley, formed in carbonate rocks and shales. It includes the northwest part of the map area and to the southwest extends around the end of Holston Mountain in a broad embayment, near Elizabethton, which reaches up to the foot of the Iron Mountains. The embayment shows clearly in the middle distance of figure 2, between Elizabethton and Buffalo Mountain.

Within the region of this report the valley is diversified mainly by knobs formed by shale of Ordovician age. Toward the northwest, near Bristol, the knobs stand in comparatively narrow belts that lie between lowlands of carbonate rocks, but on the southeast, along the base of Holston Mountain, they expand into a hilly wilderness as much as 5 miles broad, whose inaccessibility has been heightened in recent years by flooding of the lower ground by South Holston Lake.

MAIN PART OF BLUE RIDGE PROVINCE

The part of the Blue Ridge southeast of the Unaka province is formed by metamorphic and plutonic rocks that have been eroded into steep hills and irregularly disposed mountain groups, generally without systematic pattern (fig. 2 foreground). Some distance southeast of the region of this report the highlands end in an abrupt escarpment that overlooks the Piedmont. The Unaka province on the northwest does not form the main drainage divide; this lies instead near the rim of the escarpment, the southeastern slope draining to the Atlantic and the northwestern slope into the Tennessee and New Rivers, which are in turn tributaries of the Ohio. Most of the region of this report is thus drained by the northwestward-flowing Watauga River and its tributaries, and a part by tributaries of the South Fork of the Holston River, which belong to the Tennessee River drainage system. The northwestward-flowing streams of the Blue Ridge province pass through the mountains of the Unaka province

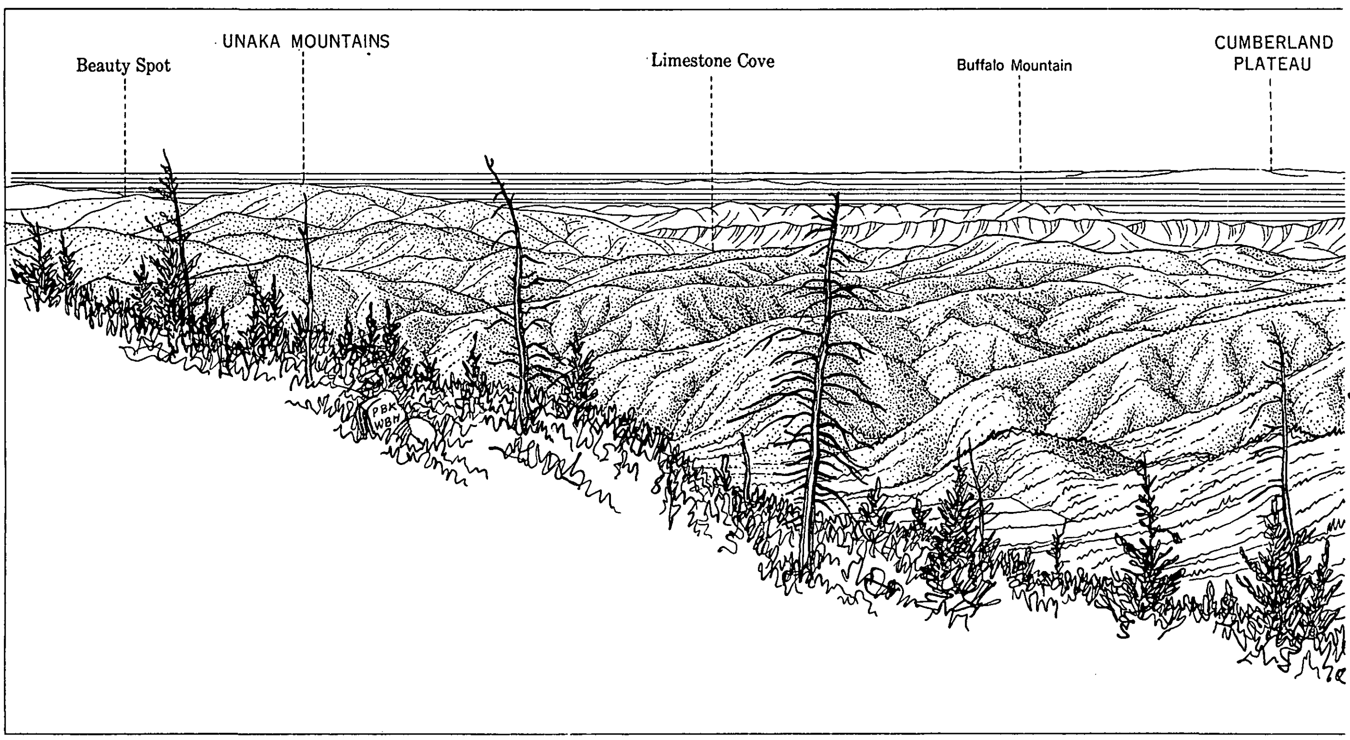


FIGURE 2.—Panorama from summit of Roan Mountain, looking northwestward across Unaka provinces; eastern third of middle ground in picture ground (about 12 miles distant) shows linear ridges of the Unaka province, of rocks of the Chilhowee group; background is the lowland of Hamilton.

in deep and rocky cuts before entering the Appalachian Valley.

The traveler who proceeds southeastward from the Unaka province into the main part of the Blue Ridge province observes at once a change in the style of the landscape. Instead of an abrupt differentiation between high forested ridges and cleared lowlands, many features are mingled. Broad basins and longitudinal valleys are wanting, yet there are many narrow stretches of level ground along the streams. Ridges are gently rounded for the most part, but crags and rocky domes appear in places. Uplands are in part densely forested, but such is the nature of the soil that patches of ground have been cleared for cultivation and pasture far up the flanks.

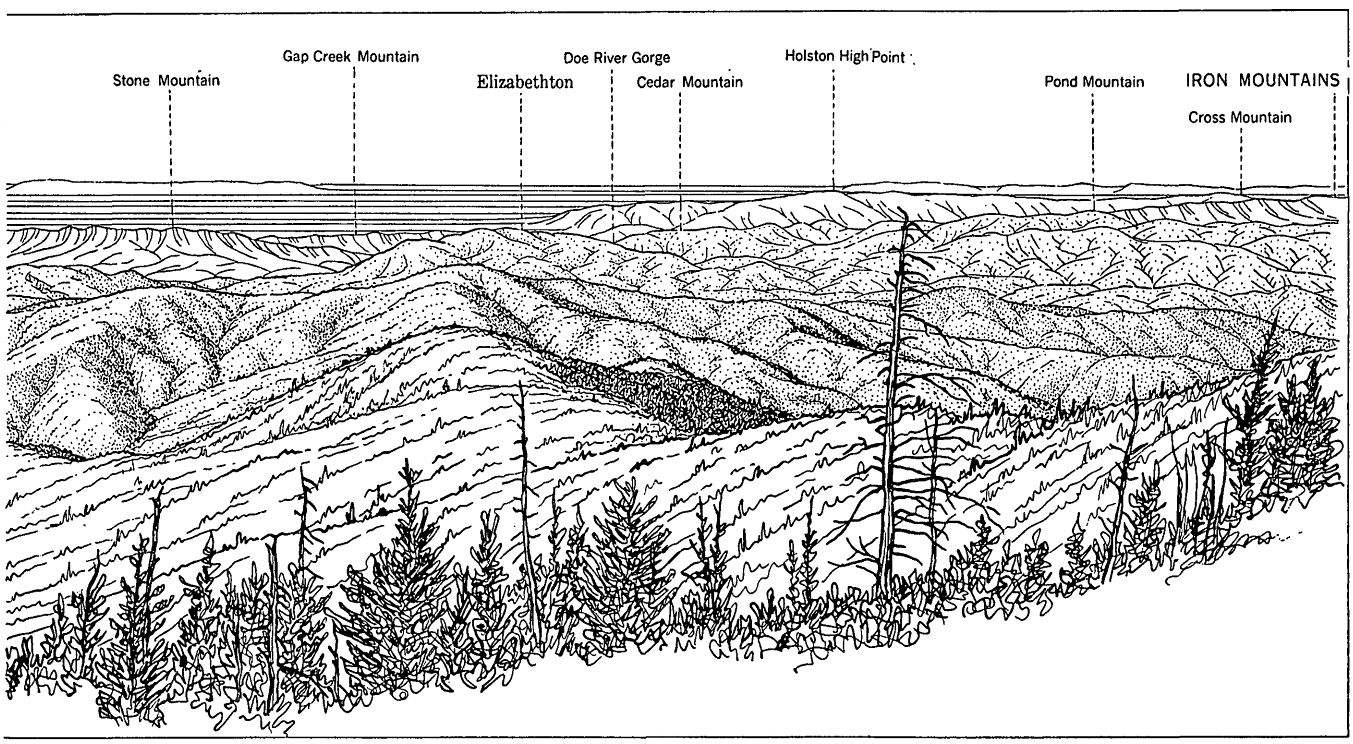
One of the principal exceptions to the general formlessness of the mountains of the Blue Ridge province is the Rich Mountain—Snake Mountain group (pl. 2*A*) along the eastern edge of the region of this report. This group follows a linear or slightly curved course and is eroded from a sheet of relatively resistant hornblende gneiss; the range overlooks lower hill country on the west in a bold escarpment whose base, like the bases of the Unaka ridges, is strewn with bouldery alluvium washed down from above.

RELIEF

The highest point in the region, on Snake Mountain in the Blue Ridge province at the eastern edge of the map area, rises to an altitude of nearly 5,600 feet (pl. 2*A*), but summits project above 4,000 feet entirely across the Unaka province to their northwestern edge. Holston High Point, at the margin of the Appalachian Valley on Holston Mountain, rises to 4,332 feet; the highest point on the Iron Mountains rises to 4,236 feet; and various summits in the Stone Mountains rise to 4,329, 4,657, and 4,982 feet, the last near the common corner of Tennessee, North Carolina, and Virginia. The Watauga River and South Fork of the Holston River leave the map area on the west at altitudes of about 1,500 feet. Maximum relief in the region is therefore about 4,000 feet. The relief is, of course, spread over a considerable distance, but local relief from mountain base to mountain top is commonly 2,000 feet or greater, and many of the slopes near the crests of the escarpments are precipitous.

HUMAN GEOGRAPHY

Northeasternmost Tennessee was the scene of the first settlements "west of the Alleghenies" (or Blue Ridge divide), and the first in the present State of Ten-



lies within region of this report. Foreground shows the anastomosing ridges of the Blue Ridge province, formed of basement rocks; middle the Appalachian Valley; and on the skyline the Cumberland Plateau (about 60 miles distant). Redrawn from photographs by Warren nessee. The earliest cabins were built in 1769 and 1770 near the present Johnson City and near the old townsite of Butler, but the principal nucleus of settlement was "Watauga Old Fields" near the junction of the Watagua and Doe Rivers and the present city of Elizabethton, where earlier clearings by the Cherokee Indians offered a more favorable place for laying out fields and farms than the surrounding virgin forest.

The settlers believed themselves to be under the jurisdiction of Virginia until the Virginia-North Carolina line was surveyed farther north, and they found themselves on land that had been set aside by the Crown for the Cherokee Indians. They then banded together as the "Watauga Association" to establish law among the settlers and some mode of living with the Indians; this has been called "the first independent governmental body organized by native Americans." At Sycamore Shoals on the Watauga River, below the present city of Elizabethton, the conference of March 1775 was held between the Cherokees, the Watauga settlers, and Judge Richard Henderson of the Transylvania Land Co. At this conference vast tracts in Tennessee and Kentucky were transferred by barter with the Indians and opened to European settlement, all without the sanction of the British authorities.

Thus was born the spirit of independence among these settlements that later was manifested by the gathering of the mountain men to repel British troops at the Battle of Kings Mountain, South Carolina (1780), the establishment of the abortive State of Franklin (1784–88), and finally by admission of the State of Tennessee to the Union (1796).

Interest in minerals of the region began even before European settlement, when reports were circulated of deposits of iron, lead, silver, and copper. The first metal produced was iron, needed for the farming implements and weapons of the settlers. Iron works were established in the Watauga valley shortly after settlement by the Carter and Taylor families; the first forge in Carter County was set up by Landon Carter in 1795 at the foot of the mountain near Elizabethton. Iron was also mined and smelted in Shady Valley shortly thereafter, the product being fashioned in long curved strips, capable of being carried out by pack horses across the surrounding mountain barriers (Killebrew, 1881).

Although northeasternmost Tennessee has thus been settled for nearly 200 years, it still presents great contrasts in land use: modern industrial towns and the Tennessee Valley Authority dams and engineering works, compared with isolated farmsteads, little more advanced than those of the first settlers, and broad expanses of forest.

The ridges of the Unaka province have largely remained in forest, as have the "flatwoods" in the shale-knob country between the foot of Holston Mountain and the South Fork of the Holston River. The forests are mostly second or third growth timber, which has sprung up since the lumbering operations of 30 to 50 years ago. Much of the forest land is now in Cherokee National Forest. Outside the main forested areas, the hills and mountains of the Blue Ridge province and the shale knobs in the Appalachian Valley are partly timbered and partly have been cleared for pasture or cultivation. The carbonate lowlands have mainly been cleared and converted to farmland, except for occasional woodlots.

Largest settlement in the region is Elizabethton in the southwestern part (pl. 2*C*), an industrial city of 11,000 people and the seat of the Bemberg and North American rayon plants—so located for the available labor market, as raw materials are brought in from elsewhere. The rayon plants have created a large suburban development in the surrounding area, especially in Stony Creek valley, which is settled by mill hands who travel considerable distances each day to work and who maintain small farms in their off hours. Damascus, Va., a town of 2,000 people at the north edge of the region, is the seat of a chemical plant and a furniture factory, both drawing raw materials from the forests of the immediate vicinity. Other towns are Mountain City, a farming community of 1,500 people, and county seat of Johnson County; Hampton, which is largely tributary to Elizabethton; and Butler, now moved to higher ground from its original site because of flooding of Watauga Lake.

Although there has been considerable development of the mineral resources of northeasternmost Tennessee, mining has played only a small part in the life of the community, as operations have been widely dispersed and activity has fluctuated greatly from year to year.

Northeasternmost Tennessee was once served by railroads that extended up most of the major mountain valleys, but the region is now almost without rail service (pl. 2*C*). Only short spur lines extend into the region—the East Tennessee and Western North Carolina Railroad from Johnson City to Elizabethton in the southwestern part of the region, and a line of the Norfolk and Western Railway from Abingdon, Va., through Damascus, to West Jefferson, N.C., in the northeast part of the region. Offsetting the present dearth of railroad lines has been the continued construction of motor highways, which now provide good access to nearly all parts of the region. (pl. 2*C*).

DESCRIPTION OF THE BASEMENT ROCKS

By Warren Hamilton

GENERAL FEATURES

Within this region, rocks older than the Paleozoic sedimentary rocks are exposed mainly in the Blue Ridge province. Small outlying areas occur along the southeast base of Iron Mountains from the Tennessee-Virginia State line to Watauga Lake. The basement rocks lie in diverse structural situations (pl. 15). A small part of them southeast of the Stone Mountains near the southern edge of the map area lie unconformably beneath the Paleozoic rocks of the Mountain City window, but most are in thrust sheets that have been carried for varying distances relatively northwestward over the rocks of the window. The basement rocks of Iron Mountains lie in the Shady Valley thrust sheet, and those farther southeast are in thrust sheets above the Stone Mountain fault family.

The basement consists of massive migmatitic and gneissic granitic rocks. Those in a small area south of Pond and Little Pond Mountains in the Mountain City window are granitic intrusions probably injected as sheets at a relatively shallow depth late in Precambrian time. The remainder of the basement rocks have had a much more complex history, and their fabrics reflect structures superimposed during successive episodes of plutonism, metamorphism, and deformation in Precambrian and Paleozoic time.

The basement rocks of the region are exposed in bold outcrops along the Watauga River and other deeply incised streams, and in cuts along many roads and highways. The most prominent rocks in the exposures are granitic; effect of weathering is greater in the more schistose and more mafic rocks. In a few places, as along the Iron Mountains, the rocks have decayed extensively to saprolite.

PREVIOUS WORK

Most of the basement rocks in this region were studied and mapped by Keith for the Cranberry and Roan Mountain folios (1903, 1907), and were divided by him into several lithologic units, including the Cranberry and Beech granites, metarhyolite, and Linville metadiabase. Like Keith, the present author found that these rocks were pervasively sheared, but was unable to recognize Keith's rock units, and here uses a different classification. In places, distinctions may be recognized in the granitic rocks that correspond to the boundaries between the Cranberry and Beech granites as mapped by Keith, but these do not appear to have general significance. The metarhyolite and metadiabase were supposed by Keith to be related to rocks so named in the Grandfather Mountain area to the southeast; although they may be valid units there, they are not in this area. No mappable metadiabase was seen in the areas so mapped by Keith, although small dark dikes cut the plutonic rocks throughout most of the map area; the supposed metarhyolite layers are actually layers of mylonite. Nevertheless, Keith's work in the southern Appalachians, done rapidly a half-century ago with far fewer exposures than are now available, established many of the principles of the evolution of the region.

The magnetite deposits of the basement rocks were studied by Bayley (1923), most of his work being done on the ores of the Cranberry district south of the map area, but including examination of prospects near Pond and Little Pond Mountains. His report includes petrographic descriptions of the associated basement rocks, and he recognizes the cataclasis to which the rocks had been subjected; however, Bayley described as "rhyolite" many rocks which are clearly mylonitized granite.

In a general account of the metamorphic rocks of the southern Appalachians, Jonas (1932, p. 240) recognized the regional cataclasis of the basement rocks near the present area, but, unlike the present writer, believed this cataclasis to be closely related to the late Paleozoic thrusting and deformation.

PRESENT INVESTIGATION

The present investigation is based upon road traverses during 4 weeks in 1953–54. The author also profited from a field visit with Richard Goldsmith, D. A. Brobst, and F. D. Eckelmann to various localities between this area and the Great Smoky Mountains. Similarities in many of the rocks of this wide area suggest a similar history, perhaps recording contemporaneous deformation of varying type and intensity.

Prospectors for uranium were active in the area during 1954 and 1955. In April 1955 the author visited the several most promising reported localities with R. A. Laurence and Q. D. Singewald. Radioactive pegmatite on Big Flats Branch near the Doe River was found to contain small amounts of secondary uranium minerals along fractures. North of Row Branch, several large trenches have been cut in pink granite with a high radiometric count, but no mineable concentration of radioactive material was exposed.

Descriptions and interpretations of the basement rocks are based on study by binocular microscope of 320 hand specimens, and by petrographic microscope of 25 thin-sections of specimens selected to give spot control to the binocular examinations. In the descriptions which follow the stated amounts of minerals are crude volumetric percentages, estimated by comparison with black-and-white patterns of various areal densities. The figures for individual specimens are given as estimated and adjusted to total 100 but the figures have been rounded off where they express ranges of composition in several specimens. The accuracy of the estimates varies with the amount, size and character of the minerals, and the figures are approximations.

The present study was insufficient to work out many details of the basement rocks within the region of this report, and the interpretations made herein may require revision when more detailed mapping has been done. It is believed, however, that a sufficient number of facts have been established so that the study will serve as a basis for subsequent investigations of the basement rocks in this part of the Blue Ridge province.

SUBDIVISIONS OF THE BASEMENT ROCKS

In the descriptions which follow, the basement rocks are grouped geographically. Some units contain rock types duplicated in part by adjacent units, but on the basis of the reconnaissance the character and proportions of the types in each unit seemed distinctive of the unit. Where major reverse faults could be traced into the basement they were recognized as contacts between units of contrasting lithologic character. A few units, such as the granite south of Pond and Little Pond Mountains and the chloritized quartz diorite of the Roan Creek area, are unlike the rest, and may be of different origin and age.

BASEMENT ROCKS OF MOUNTAIN CITY WINDOW

Most of the Mountain City window consists of Paleozoic sedimentary rocks, but the underlying basement is exposed on the southeast (pls. 1, 15). This basement differs from that elsewhere in that it lies beneath rather than above the major low-angle faults; before faulting it must have been widely separated from the other nearby basement rocks. Two conspicuously different groups of rocks are present—a plutonic complex exposed at two localities, and an intervening body of granitic rocks.

PLUTONIC COMPLEX OF PARDEE POINT AND BUCK RIDGE

Near the south edge of the map area, at Pardee Point 2 miles south of Hampton, rocks of the plutonic complex are exposed in the upper end of the gorge of the Doe River through the Stone Mountains (pl. 1). The complex is overlain unconformably on the north by the basal sandstone and conglomerate of the Unicoi formation, as seen in cuts on the abandoned line of the East Tennessee and Western North Carolina Railroad (fig. 7). Plutonic rocks at Pardee Point are much more varied than those in most of the region and include massive uniform granite, layered granite, quartz monzonite and granodiorite, altered diorite, and fine-grained gneiss. Some of the diorite is spectacularly porphyritic, with plagioclase euhedra as much as 5 centimeters long in an altered greenish groundmass; no similar rocks have been observed elsewhere in the region. East of Pardee Point, the complex includes migmatite and coarse gneiss.

Plutonic rocks of a comparable complex occur in a small area about 12 miles east, on Buck Ridge, a southeastern spur of Little Stone Mountain. The rocks are bordered on the north by the Unicoi formation which probably overlies them unconformably, although the actual contact was not observed. They are bordered on the south by sheared migmatite, which forms the country rock southeast of this part of the Mountain City window. No outcrops were found on Buck Ridge, but abundant float blocks consist of a mixture of rock types including pink to white quartz monzonite, fine-grained granodiorite, coarse pink pegmatite, and gray granodiorite gneiss. There is also a unique porphyritic quartz monzonite with euhedral phenocrysts of altered gray-green plagioclase as much as a centimeter long in a fine-grained, gray-purple, granitic groundmass.

The plutonic complex of both these localities includes greater varieties of rock types within small areas than is common elsewhere in the region. The rocks are slightly altered, but unlike most of the other basement rocks of the region, the rocks at Pardee Point and Buck Ridge are not pervasively sheared.

GRANITIC ROCKS SOUTH OF POND AND LITTLE POND MOUNTAINS

South of Pond and Little Pond Mountains, between the two areas of plutonic rocks just described, the Unicoi formation lies unconformably on coarse, massive, light-colored granitic rocks. These have been traced along the strike for 6 miles from the Little Pond Mountain fault southwestward to the alluvial field at Dennis Cove (pl. 1); their relations to the plutonic complex at Pardee Point farther west along the same outcrop belt have not been determined. Southeastward, the granitic rocks are succeeded abruptly by flaser gneiss which lies above the Unaka Mountain fault and outside the Mountain City window.

The granitic rocks were studied in most detail near Brushy Ridge, between Dennis Cove and Stony Creek. Here coarse pink granite is predominant, but contains a band of finer-grained red granite, 900 feet wide, on the west and a band of fine-grained porphyritic granite, 1,200 feet wide, on the east. Relations between the bands were mostly not observable, but in one road cut a vertical fault separates coarse granite from porphyritic granite. The granitic rocks are massive, with virtually no directional structures except a faint local streaking. In places, they contain steeply dipping intercalations of phyllite that strike generally eastward. In one road cut, four phyllite layers in a group are 2, 5, 10, and 3 feet thick, and the intervening bands are 0.7, 8, and 60 feet thick; in another cut, phyllite layers as much as 30 feet thick are present. Contacts of granite and phyllite are sharply defined. The phyllite layers might be either altered dikes intrusive into the granite or thin septa of sedimentary and volcanic rocks. The latter interpretation is preferred, but the evidence is not conclusive.

Massive homogeneous granitic rocks occur elsewhere in the outcrop belt. On the southwest side of Dennis Cove, west of Brushy Ridge, the few fresh specimens were of coarse gray or pale-orange biotite-hornblende quartz monzonite; along Stony Creek east of Brushy Ridge the rock is biotite granodiorite; on Row Branch near the east end of the outcrop area it is coarse pink leucogranite. Near Stony Creek and Row Branch, the rocks lack internal directional fabric. One steeply dipping phyllite layer was noted on Stony Creek. The pink leucogranite of Row Branch is similar to the granites of Brushy Ridge, and is assumed to be correlative with them. The rocks of Dennis Cove and Stony Creek are similar also in being massive, uniform, and unsheared, and are tentatively considered to be a part of the same unit, although they may instead belong to the plutonic complex of Pardee Point and Buck Ridge.

The uniformity of each of the masses of the granitic rocks south of Pond and Little Pond Mountains, their lack of directional fabric, and their sharp contacts with rocks of low metamorphic grade indicate that they are intrusive, probably emplaced at shallow depths. If the contacts between the various granitic bodies on Brushy Ridge are parallel to the phyllite intercalations and the rare internal streaking, the granite bodies probably represent a series of sheet intrusions. The history of these granitic rocks obviously has been much less complex than that of any other plutonic rocks of the region, including the plutonic rocks elsewhere in the Mountain City window. The author believes that the granitic rocks are considerably younger than the other basement rocks; possibly they are intrusive equivalents of the silicic volcanic rocks of the Mount Rogers group that underlies the Unicoi formation farther north near the Tennessee-Virginia State line.

Granitic rocks more like those south of Pond and Little Pond Mountains than of other units in the region occur in the Mountain City window southwest of the map area. Specimens collected by King east of Erwin, at Beauty Spot on the crest of Unaka Mountains in the core of the Limestone Cove window (fig. 2), are of grayish-red granite containing potash feldspar in a matrix of finer grained quartz, chlorite, and plagioclase. The granite is darker than those south of Pond and Little Pond Mountains, but resembles them in its uniformity and lack of directional fabric.

Like the autochthonous plutonic complexes of the Pardee Point and Buck Ridge areas and unlike most of the other basement units, the granitic rocks south of Pond and Little Pond Mountains have not been subject to cataclasis.

In 10 specimens of the coarser granite of the Brushy Ridge area, potash feldspar makes up about 60 to 70 percent of the rock; plagioclase, 5 to 25 percent; quartz, 15 to 20 percent; and mafic minerals, 1 to 5 percent. The potash feldspar is light red or pink and forms irregular crystals, mostly 1 to 5 mm in diameter, but some as large as 10 mm. The plagioclase forms anhedra, 1 to 2 mm across, interstitial to the potash feldspar; plagioclase is white to pale greenish. Hornblende, the dominant mafic mineral, forms stubby anhedra 1 to 2 mm in diameter, and is chloritized. Biotite, present in small amounts in some specimens, is also chloritized. Blue-purple fluorite occurs in most specimens, either as vein coatings or disseminated grains. Several specimens contain disseminated euhedra of pyrite.

One thin section of the finer grained red granite from the Brushy Ridge area contains roughly 55 percent orthoclase, 25 percent slightly altered plagioclase (An_{30}), 18 percent quartz, and 2 percent chlorite, with sparsely disseminated pyrite and fluorite. Grain size varies from 0.1 to 3 mm, and is mostly between 0.5 and 2 mm; potash feldspar is in general larger than quartz and plagioclase. The section shows no crushing or incipient granulation.

Three specimens of the nearby porphyritic granite or quartz monzonite contain about 45 to 65 percent potash feldspar, 20 to 40 percent plagioclase, 10 to 15 percent quartz, and 2 to 5 percent mafic minerals. The potash feldspar is pink or pale red, and mostly forms grains 0.5 to 1 mm in diameter. Perthite forms phenocrysts as much as 0.6 by 1 by 2 cm. The quartz and plagioclase grains are of about the same size as the potash feldspar in the groundmass; the plagioclase is pale yellowish gray. Most of the mafic material is chloritized hornblende, which forms small clusters of tiny crystals, but there is a little chloritized biotite, and these dark minerals give the rock a finely speckled appearance.

In specimens of the light-colored biotite-hornblende quartz monzonite from southwest of Dennis Cove, potash feldspar makes up 35 to 45 percent of the rock; plagioclase, 30 to 40 percent; quartz, about 20 percent; and hornblende and biotite, 3 to 5 percent. The potash feldspar is cream to very pale orange, thus much lighter than elsewhere in the granitic complex; it forms crystals 1 to 10 mm in diameter. The plagioclase is finer grained than the potash feldspar and is white to very pale yellowish green. Both biotite and the more abundant hornblende are chloritized. Magnetite is present in small amounts. The rock locally has a very faint banding and alinement of mafic grains, and one outcrop contains biotite-rich clots as much as 2 cm across, with random orientation.

Each of two specimens of the biotite granodiorite from the Stony Creek area contains about 25 percent potash feldspar, 45 percent plagioclase, 20 percent quartz, and 10 percent chlorite and biotite; the rock is medium grained, with crystals 1 to 3 mm in diameter. The potash feldspar is pale orange; the plagioclase is pale green, although its cleavage surfaces remain bright and the albite twinning conspicuous. Chlorite and biotite form large flakes. The rock is cut by veins of pink aplite.

A specimen of the coarse leucogranite from Row Branch contains 75 percent pink potash feldspar, 5 percent greenish-yellow plagioclase, 20 percent quartz, and traces of hornblende and blackish-red hematite. The rock also contains purple fluorite and coarse pink pegmatite.

BASEMENT ROCKS OF THE IRON MOUNTAINS

Crystalline basement rocks crop out at intervals along the southeast base of the Iron Mountains, from the vicinity of Laurel Bloomery to Watauga Lake (pls. 1, 15). The areas of outcrop are lenticular, being bordered on the southeast by the underlying Iron Mountain fault and on the northwest by the unconformably overlying Unicoi formation; each area terminates by convergence of the fault and unconformity. The basement rocks of the Iron Mountains lie at the base of the Shady Valley thrust sheet, the next higher structural block above the Mountain City window; presumably they lay southeast of the basement rocks of the window before the thrusting. During the present investigation, only the northern areas of basement rocks were studied, from Laurel Bloomery southwest to U. S. Highway 421.

The basement rocks are much more deeply weathered here than elsewhere, so that fresh outcrops are rare. The rock in most of the exposures has decayed to a tan saprolite in which only the quartz is still unweathered. According to observations by Ferguson, decay of the basement rocks in the areas near Watauga Lake is even greater than that in the areas studied.

In the least-weathered exposures between Laurel Bloomery and U. S. Highway 421, the dominant rock is orange quartz monzonite. Along Highway 421, the quartz monzonite is gneissic and contains schistose sugary layers. In a road cut half a mile northwest of Eureka, light-gray massive granodiorite lies amidst the quartz monzonite. In many places the quartz monzonite is filled with irregular masses of orange-red pegmatite as much as 10 feet across and constituting from 5 to 30 percent of the outcrops. Near Shingletown both quartz monzonite and pegmatite are cut by vertical porphyry dikes several feet thick, striking east-southeast, with sharply bounded walls. None of the plutonic rocks observed along the foot of the Iron Mountains show effects of pervasive shearing.

Quartz constitutes only 10 to 15 percent of the rock. The amount of potash feldspar is variable, so that part of the rock has the composition of granite, although most is quartz monzonite. In the associated pegmatites, potash feldspar dominates and, in part, forms crystals a foot in length; quartz constitutes about 15 percent and occurs mostly as intergrowths in the feldspar. A specimen of quartz monzonite from west of Laurel Bloomery contains reddish-orange crystals of potash feldspar as much as 5 mm in diameter, set in a matrix of finer grained plagioclase, quartz, and chlorite; the plagioclase is light greenish gray.

The light-gray granodiorite near Eureka is conspicuously finer grained and less altered than the nearby quartz monzonite. It is made up of 70 percent white or light-gray plagioclase in subhedral crystals, 1 to 2 mm in diameter; 15 percent white potash feldspar in irregular poikilitic grains, 2 mm in diameter; 12 percent gray quartz in 1-mm anhedra; and 2 percent greenish-black chlorite in small plates. The rock is traversed by tiny epidote veins, with or without chlorite, which make up about 1 percent of the rock. Potash feldspar adjacent to the epidote veins is a pale orange.

BASEMENT ROCKS SOUTHEAST OF MOUNTAIN CITY WINDOW

GENERAL FEATURES AND TERMINOLOGY

The Mountain City window is bordered on the southeast by a complex of crystalline rocks that extends far southeastward into North Carolina.

Unlike the crystalline rocks in the Mountain City window and the Shady Valley thrust sheet, those to the southeast have only tectonic contacts with the Cambrian sedimentary rocks (pl. 1), and their Precambrian age cannot be established within the area by stratigraphic means. Various lines of evidence, however, suggest that these crystalline rocks, like those to the northwest, are of Precambrian age. The crystalline rocks above the window, like those within it, are plutonic, and some of the Blue Ridge rocks are similar to those of the Iron Mountains. Plutonic rocks including similar types are continuous for tens of miles to the southwest, where they are overlain unconformably by sedimentary rocks of the later Precambrian Ocoee series. The few available radiometric determinations of the rocks, though perhaps questionable, indicate a Precambrian age.

The rocks of this complex are migmatite, gneiss and varied grantitic rocks. Over wide areas they have been metamorphosed retrogressively by pervasive cataclasis and by reconstitution to minerals of the greenschist facies. The rocks lie in thrust sheets above the faults of the Stone Mountain family and override the rocks of both the Mountain City window and the Shady Valley thrust sheet. Before the thrusting of late Paleozoic time they lay many miles, perhaps several tens of miles, from the rocks they now overlie. Different units of the complex adjacent to the Mountain City window can be distinguished on their gross lithologic characters and appear to be separated by major thrusts that are members of the Stone Mountain fault family.

In order to describe the cataclastic rocks produced during this later metamorphism, the following terms have been selected from the writings of Knopf (1931), Buddington (1939), and Turner (Williams, Turner, and Gilbert, 1954):

Mylonite.—Microscopically brecciated rocks showing little recrystallization. Rocks have felsitic appearance and may or may not be banded or contain small porphyroclasts.

Phyllonite.—Phyllitic and schistose rocks derived by the shearing of coarser grained rocks with accompanying reconstitution of micaceous minerals.

Flaser gneiss.—Gneissic rocks whose foliation is at least in part cataclastic. Porphyroclastic lenses and bands occur between the laminae of recrystallized finely sheared material.

Mortar gneiss.—Rocks showing only a little crushing, largely between and on the peripheries of grains.

In the account that follows, the lithologic units into which the basement rocks southeast of the Mountain City window have been divided will be described in arbitrary geographic order, from southwest to northeast, without regard to their inferred positions in the various thrust sheets of the Stone Mountain fault family.

COMPLEX OF LUNSFORD BRANCH AREA

The southwesternmost unit of basement rocks in this belt is a complex of quartz monzonite and granite that has been highly sheared. The complex lies mainly west of the Elk River, where it is well exposed along Lunsford Branch. Southeastward, it crosses the Elk River above Twisting Falls and extends into Dark Ridge (pl. 1). The unit is bordered on the northeast and north by the Unaka Mountain fault, along which it overrides not only the Paleozoic sedimentary rocks and the Precambrian basement rocks of the Mountain City window, but also the migmatite of the Watauga River area.

Prior to cataclasis, the rocks of the complex were mostly coarse quartz monzonite and granite, in part massive and in part with crude gneissic structure, which were cut by pegmatites, quartz veins, and dark dikes. In many outcrops along the lower course of Lunsford Branch these original characters are well preserved, but in much of the area they have been nearly obliterated. The once-coarse rocks have been largely converted into flaser gneiss, phyllonite, and mylonite, all types being intercalated in many of the larger outcrops. Potash feldspar grains are pink, and folia are greenish. Dark dikes were transformed into greenschist, and the quartz veins into finely granulated quartz.

Excellent exposures of the cataclastic rocks occur at the west end of Dark Ridge, which is formed of a gently dipping sequence of intercalated phyllonite and flaser gneiss, apparently derived from coarse granite and quartz monzonite. Even the least-crushed rocks have a strong cataclastic foliation, with long lenses a few millimeters thick of quartz and potash feldspar, separated by folia of sericite and finely ground quartz and feldspar, and with porphyroclasts of coarsely perthitic microcline. Much of the rock is strongly lineated silver-green phyllonite, which enwraps numerous large knots of crushed quartz.

The study of a thin section of phyllonite showed that it contains rounded clasts of quartz and feldspar, 1 or 2 mm in diameter, in a minutely granulated groundmass of quartz and feldspar, most of it with a grain size of 0.01 to 0.02 mm and much of it finer. About 5 percent of this specimen is cericite, which occurs in well-defined folia.

A thin section of flaser gneiss, from near the small hematite deposit indicated on the geologic map (123 on pl. 1) contains augen of quartz and feldspar with a maximum length of 5 mm, around which flow fine-grained quartz, feldspar, and sericite. The large grains of the augen are broken by many granulated fractures, and many quartz grains are cut into thin leaves with granulated margins. A big crystal of plagioclase (An_{30}) shows smoothly arched albite twins. The groundmass is mostly a granular mosaic of 0.02 mm quartz and feldspar, with about 5 percent sericite in thin anastamosing folia.

Throughout the unit, small amounts of the rocks have been converted to platy, dense, fine-grained mylonite, some resembling rhyolite superficially. Bayley (1923, p. 244–251) described some of the rocks of the complex near old hematitic magnetite prospects on Lunsford Branch, and presented several chemical analyses; he recognized the cataclastic structure of the coarser rocks, but termed the strongly mylonitized layers "slate," "eruptive," and "whet rock."

MIGMATITE OF WATAUGA RIVER AREA

The migmatite that composes the next unit of basement rocks to the northeast is typically exposed in the gorge of the Watauga River, from the Stone Mountain fault southeastward to the border of the map area (pl. 1), as well as on North Carolina Route 603, which follows the south side of the river. The unit extends southwestward around the south side of Little Stone Mountain and northeastward nearly to the heads of Little Beaverdam and Cove Creeks. The unit is overridden on the southwest by the complex of the Lunsford Branch area, and is apparently overridden on the northeast by gneiss like that of the Forge Creek area.

The rocks of the unit consist of complexly interlayered patchy migmatite, crudely layered to uniform granitic rocks, and layered gneiss; they are cut by light and dark dikes and by pegmatites. The whole complex has been extensively sheared.

PLUTONIC FEATURES

Along the Watauga River, the migmatite is dominantly quartz monzonite and granodiorite, with a subordinate amount of granite and quartz diorite. It is bluish green to pink and has a patchy structure, with patches of all sizes of coarse to fine granitic rocks, pegmatites, coarse gneiss, and dark fine-grained rocks. The patches are sharply defined where adjacent rocks are of widely different composition and texture, but vaguely bounded where adjacent rocks are coarse and granitic. Locally the patchy structure gives place to layered structure that varies from vague streaks in relatively homogeneous rocks to sharply divided layers of unlike composition.

Plate 3*A* shows gneissic granodiorite, complexly and discordantly veined by light-colored granitic rock. Elsewhere nearby, the granodiorite is migmatitic, and contains abundant layers and patches, obviously of metamorphic rocks.

Layering becomes more prominent southeastward, where massive or crudely layered granitic rocks are intercalated with conspicuously layered and strongly foliated gneiss that has a higher proportion of mafic minerals. Most boundaries between massive light colored rocks and dark gneiss layers are indistinct, with proportions of layered and massive rocks changing through thicknesses of tens or hundreds of feet. Some of the layered gneiss contains sharply bounded alternating layers a few millimeters to several feet thick, the thicker being rich in quartz and feldspar and the thinner rich in dark minerals, mostly biotite and chlorite; potash feldspar is distributed irregularly. Other layered gneiss, generally coarse and light colored, is more massive, with broad and poorly defined layering in which there is only slight variation in proportions of feldspars to each other and to dark minerals.

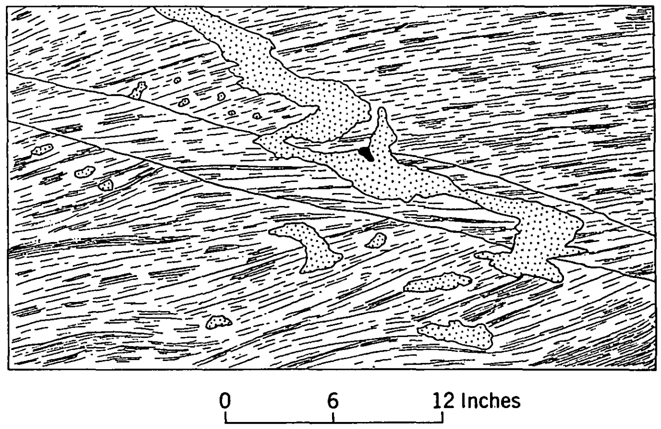


FIGURE 3.—Ptygmatic pegmatites and cataclastic foliation. The straight dike (outlined by heavy lines) is 3 inches thick; both it and its wall rocks are crossed by small ptygmatic pegmatite bodies (stippled). The foliation is cataclastic. Road cut on North Carolina State Route 603, 1 mile east of Beech Creek. Drawn from a photograph.

Associated with the layered gneiss, although much less common, is veined migmatite, of which a sample is illustrated on plate 3*B*. Geometric relations of rock types in the outcrop pictured indicate that the granitic rocks have in part intruded and in part replaced the metamorphic rocks.

Coarse pegmatites are common in many of the rocks along the Watauga River and form sharply bounded dikes and veins and irregular masses with gradational boundaries against the host rocks.

The formation of ptygmatic pegmatites without deformation is recorded in a cut on North Carolina State Route 603, a mile east of Beech Creek (fig. 3). A straight dike of granodiorite is cut by ptygmatic pegmatites, hence the ptygmatic masses must have formed with their present shapes.

CATACLASTIC FEATURES

Plutonic structures in the migmatite of the Watauga River area have been partly masked and obliterated by cataclasis and retrogressive reconstitution. The effects of the late shearing increase southeastward, as indicated by the following rough estimates of cataclastically metamorphosed rock types:

	Approximate percentage of rock types in Northwest part	Southeast part
Uncrushed rock and mortar gneiss	40	10
Flaser gneiss	55	70
Phyllonite	5	20

Shearing was accompanied by recrystallization and reconstitution, and the grade of retrogressive metamorphism increases southeastward. To the northwest, the new minerals are very fine grained and belong to the muscovite-chlorite subfacies of the greenschist facies. To the southeast, as along Cove Creek, the recrystallized rocks are coarser and phaneritic and belong to the biotite-chlorite subfacies, and crystallization continued after cessation of shearing. Throughout the unit, sheared and unsheared rocks are intercalated in various thicknesses and proportions; many outcrops expose flaser gneiss and phyllonite intercalated with mortar gneiss or uncrushed rock. Pegmatites in the plutonic rocks were generally more resistant to shearing than the host rocks.

Cataclastic foliation commonly roughly parallels the earlier plutonic foliation but in places diverges from it at low, or less commonly, at high angles. In some places the later foliation crosses and partly shears out isoclinal folds that were produced during the plutonic metamorphism. These relations are conspicuous in cliffs along Cove Creek near Phillips Branch, as illustrated by plate 4*A*. The gneiss in the cliffs forms large lenses that represent sheared-out parts of isoclinal folds. The axial, or *b* lineation of the folds trends northwest and is nearly parallel to the younger *a* lineation (slickenside type, perpendicular to boudin axes) of the cataclastic foliation. Other localities near the Watauga River have similar structural orientations and indicate that the directions of tectonic transport during the two periods of metamorphism were nearly at right angles to each other.

Some of the cataclastic foliation developed with little shear offset. At the outcrop illustrated by figure 3, a strong cataclastic foliation crosses a straight dike at an angle of about 25°. The precise contact between dike and wallrock has been obscured by the crushing, and there are quarter-inch offsets of the contact zone along many folia, but the overall contact remains straight. In thin section, both dike and wallrock are seen to be flaser gneiss, with little-crushed augen and laminae separated by folia of finely crushed material. Fine-grained quartz, feldspar, epidote, and biotite were reconstituted; large biotite grains were deformed. Here, as elsewhere, the pegmatite was much more resistant to crushing than were the other rocks, and shows no megascopically apparent cataclastic structure.

LITHOLOGIC CHARACTER

The average composition of sixteen specimens of uncrushed granitic rocks collected along the Watauga River is 34 percent potash feldspar, 40 percent plagioclase, 22 percent quartz, and 4 percent biotite and chlorite. One specimen is granite with 70 percent potash feldspar; the remainder are quartz monzonite and granodiorite with 20 to 45 percent potash feldspar, 20 to 65 percent plagioclase, 15 to 30 percent quartz, and a trace to 10 percent of mafic minerals. Grains vary from 2 to 6 mm in diameter, those of potash feldspar being larger than those of other minerals.

Typical examples of the sheared rocks along the Watauga River are those in road cuts on North Carolina State Route 603, 0.4 mile northwest of Laurel Creek Falls, which (except for the pink gneiss) were derived from coarse light-colored crudely gneissic granodiorite. Rocks showing varying effects of shearing are intercalated, and thin sections were studied of the following types, noted in order of increasing cataclasis:

1. Pink mortar gneiss and flaser gneiss, derived from pegmatite. Pegmatites at this locality are bounded by shear zones and have pod shapes. The pegmatites are less sheared than the host granodiorite gneiss.

2. Flaser gneiss, derived from coarse granodiorite gneiss, containing lenses of fresh pink microcline as much as 0.5 cm thick, 2 cm wide, and 4 cm long with a little quartz, separated by layers of crushed quartz, plagioclase, and microcline and by thin folia rich in fine (0.02–0.05 mm) chlorite and muscovite with a little epidote. The plagioclase (An_{25-40}) is much altered, and many grains are bent. Quartz and microcline are broken by many narrow seams of crushed grains. Grains of relict biotite are bent and broken, and basal sections show distinctly developed pressure figures with minute needles of rutile(?). Sphene shows closely spaced cleavage cracks. Traces of magnetic and allanite are present.

3. Flaser gneiss, finer grained and better foliated, with thinner lenses of microcline and with straighter and more continuous folia. Lenses are 1 to 4 mm thick and are strongly lineated. Contains more finely crushed quartz and feldspar and more muscovite than example 2, but otherwise similar.

4. Flaser gneiss, with more muscovite, more finely crushed quartz and feldspar, and more prominent folia than example 3. Lenses of microcline are mostly less than 2 mm thick, and few uncrushed remnants of crystals are larger than 1 mm. About 15 percent of the rock is muscovite, and folia of muscovite with finely granulated quartz and feldspar and a little chlorite flow smoothly around the larger lenses. The

folia are minutely crinkled in places. The minor relict biotite is in shredded lenses.

5. Phyllonite, gray-green, with small stubby lenses of microcline isolated by folia of muscovite and fine quartz and feldspar. About 20 percent of the specimen is sericite with some chlorite, 20 percent is of 0.2 to 1 mm grains mostly of microcline but including quartz and plagioclase, and 60 percent is of quartz and feldspar smaller than 0.2 mm and mostly between 0.02 and 0.05 mm.

Plate 4*B* illustrates an outcrop a few hundred yards east of the rocks just described. Flaser gneiss of this outcrop was produced by cataclasis of crudely layered dark gneiss. The microcline is white here and to the east, rather than pink as in the rocks described above and in most of those farther west and northwest.

In the southeast part of the area, the metamorphic grade of the retrogressive reconstitution was higher than elsewhere, and new biotite was formed. The cataclastic rocks vary from mortar gneiss to phyllonite; uncrushed material is dominantly coarse quartz monzonite gneiss. Micaceous folia are composed largely of muscovite and biotite. Light-colored dikes, intruded into the granitic rocks prior to shearing, are crushed, foliated, and in part broken by boudinage. Dark dikes are now represented by fine- to medium-grained chloritic schist.

A single thin section of flaser gneiss from southeast of George Gap was studied and showed, as expected from hand specimen study of the southeastern samples, much more recrystallization and reconstitution than did samples from the rest of the area. Cataclastic textures dominate the larger grains and the gross fabric, but the groundmass texture is dominated by recrystallization. Large quartz grains show strain. The large feldspar grains are mostly altered and relict, but some microcline porphyroblasts are intergrown with marginal grains and cut the foliation. Crushed seams in the large grains are recrystallized. Large biotite grains are bent relics, partly chloritized, with pressure figures; small undeformed crystals of biotite are abundant in recrystallized folia, where they are in granoblastic intergrowth with 0.05–0.1 mm grains of muscovite, albite, epidote and quartz. Recrystallization apparently continued after the ending of cataclasis, and it is likely that the thermal peak of retrogressive metamorphism occurred later than the dynamic peak.

A thin section from a specimen of altered coarse hornblende-biotite-quartz monzonite was examined in which cataclasis was not apparent in hand specimen. The section showed abundant tiny crushed zones, 0.02–0.05 mm thick, of very fine quartz, feldspar and muscovite, at grain boundaries and cutting through crystals. Quartz is intricately strained, and has featherlike undulating extinction. Possibly most of the rocks of the area which show no megascopic evidence of shearing are similarly incipiently crushed.

CHLORITIZED QUARTZ DIORITE OF ROAN CREEK AREA

For 4 miles along the upper course of Roan Creek and extending southwestward along the lower course of Bulldog Creek, the basement rocks are feldspathized and altered quartz diorite (pl. 1), well exposed in cuts along U. S. Highway 421. This unit lies against the Chilhowee group on the west, from which it is separated by one of the lower faults of the Stone Mountain family. It forms a narrow band of outcrop, half a mile or less wide, and is succeeded on the east by gneissic rocks like those along Forge Creek; this contact is also a fault, as narrow slivers of sandstone of the Chilhowee group occur in places along it.

CHARACTER OF THE QUARTZ DIORITE

Where least altered, the rock is massive or crudely banded, fine grained (0.5 to 1 mm), equigranular, and greenish gray. In a dozen specimens of nonfeldspathized quartz diorite collected along Roan Creek, saussurite constitutes 60 to 85 percent of the samples; quartz, 5 to 20 percent; potash feldspar, a trace to 5 percent; chlorite and hornblende, 5 to 20 percent; and magnetite several percent. In the one thin section studied, plagioclase is thoroughly altered to sericite and clinozoisite. A small body of amphibolite, composed of hornblende, chlorite, and saussuritized plagioclase, was noted at one locality on Roan Creek.

PEGMATITE AND GRANITIC PATCHES

The quartz diorite was penetrated by abundant red or reddish orange pegmatites in random veins and dikes, crudely concordant lenses, knots, and complex irregular masses, many 10 or 20 feet across. Fractures in the pegmatites are coated by reddish black or specular hematite, with some associated pyrite; epidote veins are common.

In the quartz diorite, especially near the pegmatites, are patches and bands of small porphyroblasts and augen of orange or red microperthitic microcline, 1 to 5 millimeters long. These evidently resulted from feldspathization of the quartz diorite before shearing and alteration.

Where quartz diorite was most feldspathized, there are also patches of coarse granitic rocks, most with exposed maximum dimensions of a few feet or yards but some as much as a hundred feet across. These course granitic rocks are well exposed near the switchbacks on U. S. Highway 421 three-quarters of a mile north of Key Station. Although common in the quartz diorite, they make up only a minute fraction of the whole rock unit, and are less abundant than the pegmatites. The granitic rocks are quartz monzonite or granodiorite, made up of red microcline, saussuritized plagioclase, quartz, and mafic minerals.

Contacts between the granitic patches and the surrounding rock are irregularly gradational; there is no brecciation or rotation of the host rock; there are no offshooting dikes. With few exceptions, the granitic rocks do not appear to be injected bodies. From various outcrops, a complete gradational sequence can be worked out between altered quartz diorite and granitic rocks, although not all intermediate types are present near all granitic contacts. The sequence follows: Fine-grained quartz diorite; fine-grained quartz diorite with potash feldspar porphyroblasts; quartz monzonite and granodiorite, highly varied in texture and composition even in small patches, with coarser texture than the preceding but finer than the succeeding; and massive medium- to coarse-grained dark-colored quartz monzonite and granodiorite. The transition from quartz diorite to coarse quartz monsonite or granodiorite takes place within a few feet or yards. The coarse granitic rocks, thus, seem to have been formed by feldspathization and recrystallization of the quartz diorite during the emplacement of the pegmatites and before the rock alteration.

EFFECTS OF SHEARING

As in the other basement rocks southeast of the Mountain City window, effects of shearing are common, although the nature of the rock renders them less evident. Locally, fine-grained chloritic schist is seen, but in most outcrops the fine grain, uniform dark color, and weather staining of the chloritized quartz diorite make it difficult to distinguish between massive and sheared parts except on freshly broken surfaces, and it has not been possible to determine the relative proportions of sheared and unsheared rock. The shearing took place after the pegmatites were emplaced and the granitic patches had formed, as they also are crushed locally into gneiss and schist that enclose large porphyroclasts of potash feldspar.

Only a small part of the patches of coarse granitic rocks has been sheared, and it is inferred that the surrounding quartz diorite is also less sheared than the adjacent basement rock units.

GNEISS OF FORGE CREEK AREA

The northeasternmost unit of basement rocks southeast of the Mountain City window is a complex of gneisses typically exposed along Forge Creek and its tributaries (pl. 1). Similar rocks extend 6 miles southward from Forge Creek, east of the quartz diorite unit just described, to the upper course of Bulldog Creek; these override the chloritized quartz diorite and possibly also the migmatite of the Watauga River area farther southwest.

PLUTONIC FEATURES

The rocks of the unit are mostly crudely banded coarse gneiss with an average composition of quartz monzonite; however, they include granite, granodiorite, and quartz diorite, with many intercalations of dark schist and altered amphibolite. The different types alternate in layers a few inches to many tens of feet thick. Contacts of granitic layers are gradational, but those of granitic rocks and markedly contrasting types such as amphibolite are sharp. Within the larger layers are fainter layers expressing minor compositional variations.

The gneiss contains irregular crosscutting masses of coarse orange-pink granite pegmatite, which in places along Forge Creek constitutes 20 to 35 percent of the outcrops. Some of the pegmatites have sharp contacts, but many are narrowly gradational along their borders with the enclosing rocks. Some of the pegmatites are zoned, with margins rich in potash feldspar and cores rich in quartz. In many places, fractures and cleavage cracks in the pegmatites are coated by flakes of specular hematite.

The gneiss is also intruded by abundant basic dikes, a few feet to 20 feet or more thick. Many of these dikes have been transformed to fine greenschist.

CATACLASTIC FEATURES

Subsequent to the initial plutonism and the introduction of the pegmatites and basic dikes, the rocks of the unit were extensively sheared. The original coarse plutonic rocks were converted into flaser gneiss, phyllonite, and mylonite, which now make up about a third of the volume of the complex; the transformation is more complete in the southern part of the unit.

Near Forge Creek the coarser crushed rocks are gneiss with lenses and augen of relict potash feldspar and quartz in a schistose matrix of epidote, chlorite, sericite, and minutely crushed quartz and feldspar; the quartz and feldspar lenses are a few millimeters thick and two or three centimeters long. With increasing effect of crushing and decrease of grain size, the proportion of quartz lenses decreases; with the same change, the thickness of the micaceous laminae increases, probably by conversion of feldspar to mica.

The finely crushed rocks are abundant. Phyllonite made up of thin lenses of finely crushed quartz and feldspar embedded in a greasy-lustered micaceous matrix is common. Still finer grained varieties include greenish phyllonite and white or gray laminated mylonite. A thin section of schistose mylonite of felsitic appearance contains minutely ground quartz, microcline and plagioclase, in 0.01 to 0.1 mm grains, with some augen less than 0.5 mm wide and with very thin laminae of chlorite and muscovite.

On McEwen Branch southeast of Forge Creek, fine-grained foliated quartzite occurs as thin intercalations in flaser gneiss; although this quartzite might be of metasedimentary origin, it seems more probable that it was derived by the crushing of vein quartz.

Near Roan and Bulldog Creeks, the rocks are more extensively sheared than to the north along Forge Creek, and the proportion of phyllonite increases. Near State Line Gap at the head of Bulldog Creek, fine-grained, gray, platy mylonite is abundantly intercalated in crushed granite and quartz monzonite. The mylonite was mapped as metarhyolite by Keith (1903).

LITHOLOGIC CHARACTER

From Forge Creek and vicinity, 18 specimens of uncrushed or little crushed granitic gneiss were collected. They have the following composition:

	Range of composition (percent)	*Average composition (percent)*
Quartz	10–35	19
Plagioclase (commonly altered)	5–65	38
Potash feldspar	Tr.–80	34
Mafic minerals (chloritized hornblende and biotite)	3–20	9
Magnetite, epidote, hematite, fluorite	(1)	(1)

[1] Minor amounts.

In the uncrushed gneiss, the feldspar grains are commonly 1 to 5 mm in diameter, the potash feldspar grains being larger than the plagioclase and the grains of quartz and other minerals finer. Some of the gneiss contains crystals of potash feldspar as much as 1.5 cm long.

A thin section of flaser gneiss is composed of fractured fragments of quartz and microcline, mostly smaller than 0.5 mm even in the large lenses, in a stringy matrix of more finely crushed quartz and feldspar with laminae of muscovite with a little chlorite.

AMPHIBOLITE OF SNAKE AND RICH MOUNTAINS

A short distance east of the map area, crystalline rocks like those of the various units just described are bordered by a great body of dark amphibolite whose western edge forms the high crests of Snake and Rich Mountains. The amphibolite was mapped as Roan gneiss by Keith (1903). The layering of the amphibolite dips gently southeastward away from the basement rocks along the edge of the Mountain City window, and presumably it overlies them, although the actual contact is concealed by extensive alluvial deposits on the west slope of Snake and Rich Mountains.

The amphibolite is composed mostly of hornblende and plagioclase with minor amounts of quartz; there are also associated biotitic rocks. Parts of the amphibolite are uniform, whereas other parts are layered, with alternating layers rich in hornblende and rich in quartz and feldspar.

INTERPRETATION OF STRUCTURES OF THE BASEMENT ROCKS

GENERAL FEATURES

The structural features of the basement rocks were produced during successive episodes of deformation and metamorphism. No original structural features have survived, except perhaps for some of the compositional layering of the rocks. The rocks possess fabrics of varying degrees of complexity that record successively superposed structures, the younger masking and partly obliterating those preceding. The most complex rocks are those in the thrust sheets of the Stone Mountain family southeast of the Mountain City window, where more generations of superposed structures can be recognized than farther northwest in the Shady Valley thrust sheet and Mountain City window.

In the rocks southeast of the Mountain City window, the oldest visible structures, if compositional layering of uncertain origin be excepted, are plutonic. The plutonic rocks were in turn subjected to low-grade metamorphism, dominantly cataclastic, during which they were sheared and to some degree recrystallized and reconstituted, to form mylonite, phyllonite, and flaser gneiss. Still later, thrust faults, folds, local shear zones, fracture cleavage, and associated structures developed. Three broadly distinguishable metamorphic and structural epochs are thus suggested, although in view of the highly complex rock fabrics and the reconnaissance nature of the field work, such a classification probably represents an oversimplification. Dating of these epochs is based in part on stratigraphic relations with sedimentary rocks of known age, in part on radiometric age determinations, and in part on evidence more indirect. The plutonic metamorphism took place almost certainly in Precambrian time, and the thrusting and some of the other late deformation in late Paleozoic time. Dating of the regional retrogressive metamorphism is less certain, but the best evidence suggests an early or middle Paleozoic age.

The structures in the basement rocks of the Iron Mountains in the Shady Valley thrust sheet and at Pardee Point in the Mountain City window are likewise products of plutonic metamorphism but show no effects of regional cataclasis and only moderate effects of the latest deformation. The massive granitic rocks south of Pond and Little Pond Mountains in the Mountain City window have relatively simple original structures, and the metamorphic rocks associated with them are of far lower metamorphic grade than those elsewhere in the basement rocks; their features are so different from those of the remainder of the basement rocks that they probably formed after the plutonic metamorphism of the rest of the basement rocks, although still during Precambrian time.

Structural symbols on the geologic map (pl. 1) indicate the various types of planar and linear structures. With several exceptions, each type appears to have been restricted to one of the three broad episodes of deformation. Isoclinal folds and coarse plutonic foliation probably were developed exclusively in Precambrian time. Cataclastic foliation and lineation were mostly formed during the period of regional shearing, probably in early or middle Paleozoic time, although some was associated with thrust faulting during late Paleozoic time. Fracture cleavage and related structures in the basement rocks may be of the same age as the cleavage that formed in later Paleozoic time in the Paleozoic sedimentary rocks of the Unaka province and Appalachian Valley.

STRUCTURES OF PRECAMBRIAN AGE

The oldest visible structures of the basement rocks are products of plutonism; the original nature of the rocks and their condition prior to plutonism are speculative.

These rocks show compositional layering of varying degrees of coarseness and perfection. The thicker layers, several feet to hundreds of feet thick, perhaps reflect both intruded materials and initial stratigraphic differences, but many of the thinner layers, a few inches to a small fraction of an inch thick, may have formed by metamorphic segregation of previously more homogeneous rocks. The compositions of most such thin layers suggest metamorphic segregation rather than initial stratigraphic differences, as adjacent layers often appear to have compositions unlikely to occur as alternating layers in sedimentary or volcanic rocks. Such a situation is most obvious in the layered amphibolite: alternating layers are largely of either hornblende or plagioclase. Alternating layers of sedimentary or volcanic rocks of such compositions are unlikely, but the average compositions of both types of layers may be those of basic or intermediate igneous rocks. Stratigraphic layering may have controlled metamorphic differentiation, as layering thought to be sedimentary is parallel to that considered to have grown by segregation.

Coarse migmatitic granitic rocks are intercalated concordantly throughout the more obviously metamorphic rocks in layers of all thicknesses, and rocks of intermediate texture and composition are abundant. Contact metamorphism has not altered the neighboring rocks, indicating that there was probably no steep temperature gradient between them and the granitic rocks at the time of formation of the latter. The granitic rocks are crudely layered, with variations in feldspar ratios and in abundance of mafic components between layers. If the granitic rocks formed from magmatic intrusions, then their concordance, layering, and foliation suggest that intrusion preceded or accompanied plutonic metamorphism of the surrounding rocks. These features of the granitic rocks can also be interpreted to suggest that they, like the obviously metamorphic rocks with which they are associated, may be products of plutonic metamorphism, representing rocks of original compositions that were most readily susceptible to chemical and physical mobilization.

In the gneissic rocks, foliation is commonly parallel to the compositional layering. Both foliation and layering, although dipping in various directions in detail, are generally inclined gently southeastward; these are not necessarily the attitudes in which the structures were formed, but have undoubtedly been influenced by the several later deformations to which the rocks have been subjected.

Isoclinal folds are common in the conspicuously layered gneiss near the Watauga River and have heights from trough to crest of a few inches to many tens of feet. Fold axes trend westward or northwestward where measured. As this is probably a *b* lineation (Cloos, 1946, p. 6) formed at right angles to the direction of tectonic transport during metamorphism, the observed trends indicate a considerably different orientation of the deforming forces than during later periods, when the direction of tectonic transport was relatively northwestward. No isoclinal structures were observed in the crudely layered gneiss or in the more massive granitic rocks, perhaps because these rocks were too mobile during metamorphism to retain such features if they were ever formed.

In the basement rocks beyond the region of this report, to the south and southeast in the Blue Ridge province, gneiss and schist with marked contrast in the composition of the different layers increase in volume and granitic and magmatitic rocks decrease. Thus the folio mapping by Keith shows wide expanses of Carolina and Roan gneiss, and correspondingly smaller areas of Cranberry and other granites. Contrasting layers more than a few inches thick in these rocks probably represent in large part, original stratification of sedimentary and volcanic rocks, greatly modified by deformation; isoclinal folds are abundant. These features indicate that in this region structural coherence was not lost during metamorphism. Intensity of plutonic metamorphism evidently increased northwestward toward the region of this report, where the rocks apparently attained much greater mobility.

That the injection and plutonic metamorphism took place in Precambrian time can be proved stratigraphically in the northwestern blocks by unconformable relations of the basement rocks and structures to the Unicoi formation of Early Cambrian age. Also the injection and plutonic metamorphism was probably earlier than the formation of the Mount Rogers volcanic group, which underlies the Unicoi formation. The Mount Rogers group has only a slaty cleavage, parallel to that in the Paleozoic sedimentary rocks to the northwest and probably related to the late Paleozoic deformation. Moreover, conglomerate in the Mount Rogers group contains fragments of earlier granitic rocks, mostly light-colored granite and quartz monzonite similar to the rocks of the Forge Creek area. The Mount Rogers group is believed to be unconformable beneath the Unicoi formation, and to be of late Precambrian age.

The age of the injection and plutonic metamorphism cannot be proved stratigraphically in the blocks southeast of the Mountain City window because no Cambrian sedimentary rocks occur there, but correlation is likely because of the general similarity of the plutonic rocks and structures to those farther northwest. This inference is supported by some of the radiometric age determinations made of specimens from adjacent localities in the Blue Ridge province. Rodgers (1952, p. 421–422) lists four determinations (lead-uranium) of 600 to 680 million years for monazite from Mars Hill. The divergence of two determinations (helium) of 830 and 1,260 million years for magnetite from Cranberry shows those two to be unreliable. A determination of 580 million years on monazite from one of the Spruce Pine pegmatites, for which many determinations of much younger age have been made, must be in error. The age determinations of specimens from Mars Hill if correct, indicate the age of the episode of injection and plutonic metamorphism, rather than the age of the country rocks themselves.

The complexity of some of the rocks suggests that the episode of plutonic metamorphism recorded by the Mars Hill age determinations may have been only the youngest of several Precambrian episodes of high-grade metamorphism. For example, the feldspathization of the fine-grained quartz diorite unit and the structures illustrated by plate 3*A* record what might have been two distinct episodes.

STRUCTURES PROBABLY OF EARLY OR MIDDLE PALEOZOIC AGE

In the basement rocks southeast of the Mountain City window, the rock fabric is dominated by regional shearing superimposed on the earlier plutonic structures and partly masking and obliterating them. Along the Watauga River, where field observations were made for 8 miles across the strike, the effect of shearing increases toward the southeast, so that relatively fresh granitic rocks and moderately crushed gneiss in the northwestern exposures gives place southeastward to increasingly abundant flaser gneiss and phyllonite. Reconstitution that accompanied and followed the shearing similarly increases to the southeast, changing from muscovite-chlorite subfacies of the greenschist facies to the biotite-chlorite subfacies. Pervasive shearing is absent in the basement rocks of the Shady Valley thrust sheet and Mountain City window; as these are the only areas where the basement rocks are overlain by a cover of rocks of Paleozoic age, the age of the shearing cannot be dated by stratigraphic means. The cataclasis is older than the late Paleozoic thrusting, as along the Watauga River its greatest effects are farthest to the southeast, away from the faults of the Stone Mountain family along the edge of the Mountain City window. The late Paleozoic faults crosscut the cataclastic foliation (pl. 5*B* and fig. 19) and are marked by narrow zones of sheared rocks of quite different character (pl. 5*C*).

Shearing, recrystallization, and limited reconstitution modified the plutonic rocks in varying degrees, many varieties of sheared rocks occurring even within small areas or single outcrops. Cataclastic rock types range from those with only incipient granulation through flaser gneiss to phyllonite and mylonite. Potash feldspar and quartz were most resistant to shear, and rocks such as pegmatite and leucogranite that contain high proportions of these minerals were, in general, least crushed. Plagioclase and mafic minerals were less resistant to shear and alteration, and rocks containing them in large quantities were converted to strongly foliated cataclastic rocks. Shearing was commonly accompanied and followed by some recrystallization and retrogressive reconstitution.

Foliation produced by the cataclasis dips at gentle to moderate angles, mainly to the southeast, and the dips in other directions in some areas perhaps resulted from later flexing and rotation. The foliation generally parallels the earlier plutonic foliation, probably not because the two planar structures were related in time or were produced by similarly oriented forces, but because the later shearing tended to follow planes already existing and because the earlier foliation tended to become rotated into parallelism with the younger shear planes.

The shear planes are marked by a distinct lineation, made up of slickensides, alined mica, and augen of quartz and feldspar. The lineation trends generally northwestward where the foliation strikes northeastward, and is an *a* lineation, formed in the same geometric sense as slickensides. The *b* lineation of boudinage, locally present in ruptured pegmatite and aplite dikes, is alined at right angles to this *a* lineation (pl. 5*A*). At least near the Watauga River, the northwestward-trending *a* lineation of the sheared rocks is broadly parallel to the axial *b* lineation of the isoclinal folds formed during the period of plutonic metamorphism, indicating that the forces causing the two epochs of deformation were oriented nearly at right angles to each other. Under rare circumstances the lineation of boudinage can be in the *a* direction, and uncommonly the lineation of cataclastic rocks is in the *b* direction; that both would be found over such a large region as this is virtually impossible.

The structures formed by regional cataclasis are younger than the Precambrian plutonic metamorphism and older than the late Paleozoic thrusting. The cataclasis might have occured either during a distinct tectonic episode of intermediate age, or during a late stage of the Precambrian plutonic cycle, or during an early stage of the late Paleozoic thrusting. As the cataclastic structures occur only in the southeastern part of the area, where a cover of Paleozoic rocks is lacking, they cannot be dated within the area by stratigraphic means; however, dating is suggested by evidence from outside the map area.

In the Great Smoky Mountains, southwest of the report area, J. B. Hadley and Richard Goldsmith have found plutonic rocks, similar to those of northeast Tennessee, that have been metamorphosed along with the overlying Ocoee sedimentary rocks, of later Precambrian age. This post-Ocoee regional metamorphism varies from greenschist to amphibolite facies, hence the metamorphism of the basement rocks is in large part retrogressive. The post-Ocoee metamorphism has been found by King, Hamilton, and R. B. Neuman to have preceded the emplacement of the Great Smoky thrust fault in late Paleozoic time. If this metamorphism was synchronous with the retrogression in northeast Tennessee, then a Paleozoic (post-Ocoee) age of the retrogression is indicated.

In the Spruce Pine district, North Carolina, 20 miles south of the region of this report, schist and gneiss, in part continuous with the basement rocks of northeasternmost Tennessee, were similarly metamorphosed retrogressively; apparently after this many large pegmatite bodies were injected. Possibly the retrogression and the injection of pegmatites were parts of a single cycle of metamorphism and deformation. Age determinations by the lead-uranium method on specimens of uraninite from pegmatites of the Spruce Pine district have yielded ages of 310, 340, 350, and 370 million years (Rogers, 1952, p. 418–419); Ecklemann and Kulp (1954) state that new values indicate an age of about 320 million years, and Brobst (1955) gives a value of about 350 million years.[1] There are few good determinations of the absolute age of Paleozoic rocks whose stratigraphic ages are closely known, and still fewer checks on the accuracy of radiometric age determinations. Comparison of the Spruce Pine pegmatite age determinations with the list of all available ages tabulated by Faul (1954, table 9) shows that the Spruce Pine determinations are similar to or slightly older than those of the New Hampshire and Oliverian plutonic series in New Hampshire, both of which have been assigned Devonian ages on field evidence. The Spruce Pine determinations are only slightly younger than those of New York pegmatites which Rodgers (1952) considers to be Late Ordovician. Allowing for slight errors in procedures and assumptions in all of the determinations involved, the Spruce Pine pegmatites might be of Ordovician, Silurian, or Devonian age. As most pegmatites are related to episodes of metamorphism and deformation, the injection of the Spruce Pine pegmatites may have occurred only a short time after the retrogressive metamorphism of the Precambrian rocks.

According to Overstreet and Griffitts (1955, p. 566), radiometric determinations on rocks from the Shelby quadrangle of the North Carolina Piedmont indicate an age of about 400 million years for high-grade metamorphism and granitic injection there. One determination on a younger granite gave an age of about 285 million years. This plutonism might be correlative with the retrogression of northeast Tennessee, which could thus be of early Paleozoic age.

As indicated by the stratigraphic descriptions (p. 57–61), rocks of the Middle Ordovician series in the northwest part of the region of this report, and elsewhere in the southeast part of the Appalachian Valley, form a thick clastic sequence that contains local lenses

[1] Since the manuscript for the report on northeasternmost Tennessee was last revised by its authors many additional radiometric determinations of absolute age have been made on the rocks of the southern Appalachian region. These determinations partly confirm and partly modify the interpretations made here.

of coarse conglomerate derived from older sedimentary rocks to the southeast (Kellberg and Grant, 1956). The cataclasis of the basement rocks might be part of the disturbance recorded in the Ordovician sedimentary rocks. The possibility of orogeny of this age in the Blue Ridge has been suggested by King (1949a) and Rodgers (1952).

These various lines of evidence, in part contradictory in present detail, suggest an early or middle Paleozoic age for the regional cataclasis of the basement rocks, but do not exclude a late Paleozic age.

STRUCTURES OF LATE PALEOZOIC AGE

The cataclastic and plutonic rocks of the basement were involved in the late Paleozoic deformation that affected the sedimentary rocks of the Unaka Mountains and Appalachian Valley. Both sets of rocks were broken by thrust faults and the fault blocks were themselves folded and internally deformed. The deformation produced a variety of large and small structures superposed on the older plutonic and cataclastic structural features. Other small-scale features, not provably related to the thrust faulting, bear a similar relation to the older structures and perhaps formed during the episode of thrust faulting.

FAULTS AND MYLONITE

Where the basement rocks have been carried over sedimentary and volcanic rocks along the major thrust faults, they have been crushed into mylonite or gouge. These crushed rocks differ from the older rocks of cataclastic origin and are ordinarily distinguishable from them. They form zones a few feet to several hundred feet wide that lie either against or near the faults; the crushing is neither all pervasive nor of regional extent. Their foliation parallels the faults and crosscuts the earlier plutonic and cataclastic foliations that may dip in other directions and at other angles. The mylonite is platy or massive, fine-grained or aphanitic, and contains small crushed quartz and feldspar fragments in a finely crushed groundmass of angular grains. Other crushed rocks include those in which quartz and feldspar grains have been flattened and probably also include some phyllonite. Some of the cataclastic rocks, among them some phyllonite of the basement units of the Lunsford Branch and Forge Creek areas, were probably produced in association with the late Paleozoic faults rather than with the regional cataclasis of the basement rocks, and possibly all of the sheared rocks of the chloritized quartz diorite unit were formed also at the later time. Except for the phyllonite, the younger crushed rocks do not generally show the marked recrystallization, the growth of micas, or the arrangement of quartz and feldspar into lenses and augen that are characteristic of the older cataclastic rocks.

A typical outcrop of younger mylonite was observed in a cut on the road southwest of the Watauga River (the extension into Tennessee of North Carolina State Route 603), where the basement rocks are brought against the Unicoi formation on one of the members of the Stone Mountain fault family. Other characteristic outcrops were seen in the northwest corner of North Carolina, south of Pond Mountain on the road west of the community of Eldreth, where basement rocks lie against volcanic rocks of the Mount Rogers group along another fault of the Stone Mountain fault family. Some details of these and other localities are given in the section on structural geology on pages 75–79.

The different units of basement rocks southeast of the Mountain City window appear to be in fault contact. In places, as between the greenstone and the overlying gneiss near Roan Creek, slivers of Unicoi formation along the contact prove the fault. Besides the contact faults, the units also are faulted internally, as indicated by the following examples:

1. A low-angle fault with an undulating surface is exposed for many hundreds of feet in road cuts along North Carolina State Route 603 about three-quarters of a mile east of Beech Creek. The upper plate, made up of uncrushed quartz monzonite gneiss, overrides flaser gneiss of similar composition whose cataclastic foliation is sharply truncated by the fault (pl. 5*B*). Along the fault is 6 inches to 3 feet of soft, fine-grained, dark gouge (pl. 5*C*).

2. A northwestward-dipping fault is exposed in a quarry on Beaverdam Creek half a mile above the Watauga River. Rocks on both sides of the fault are uncrushed quartz monzonite gneiss, and the fault is marked by 10 feet of blackish-green foliated mylonite and sheared quartz monzonite, containing a lineation that extends down the dip.

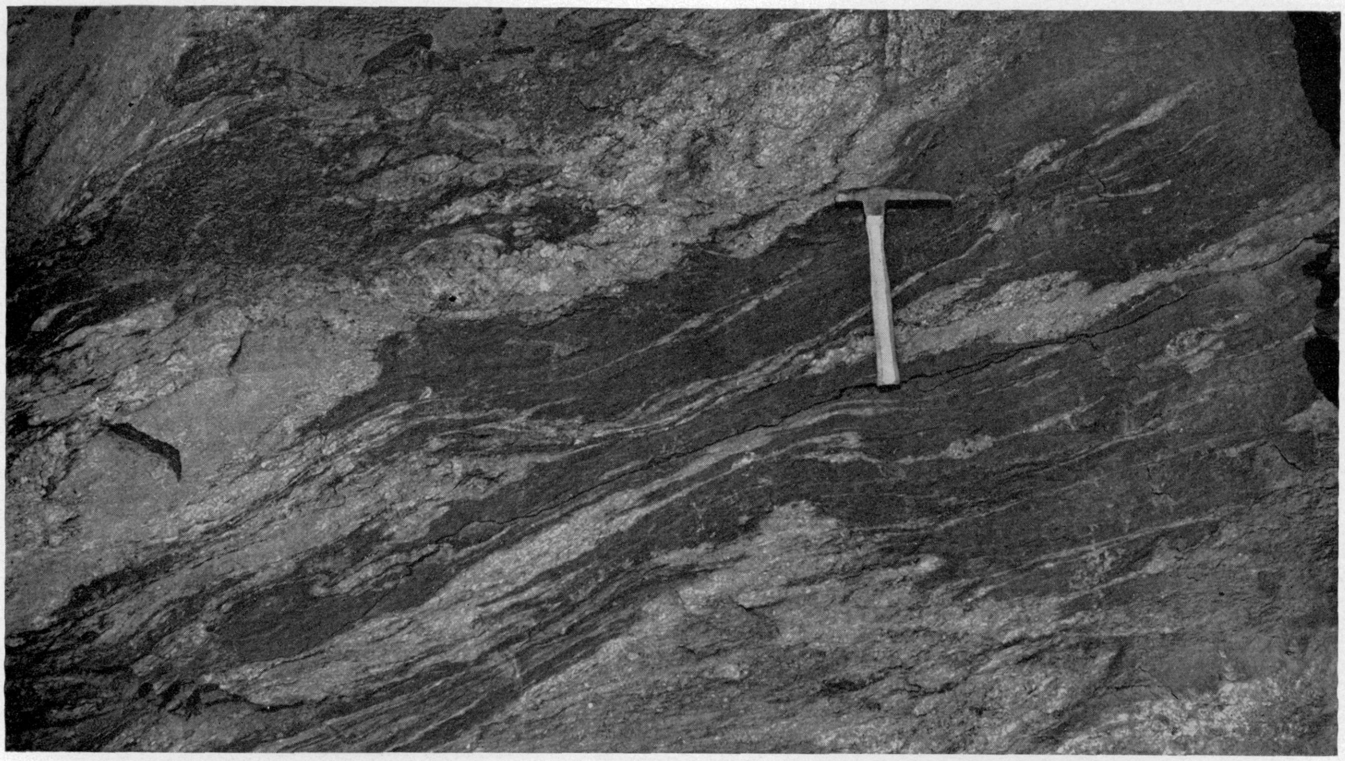
FOLDS

Both the plutonic and cataclastic foliations have been broadly folded, so that in places they depart from their usual southeastward inclinations, as indicated by the reversals shown by the dip symbols on the geologic map (pl. 1). The broad folding was probably produced by warping of the fault blocks during the time of late Paleozoic faulting and folding. Within single outcrops, open folds may be seen in places in the cataclastic gneisses, with axial planes that stand either vertical or dip steeply southeastward; trend of the folds is northeastward.

The change in general inclination of foliation from nearly horizontal in the southeast part of the area to a few degrees southeast in the northwest part of the

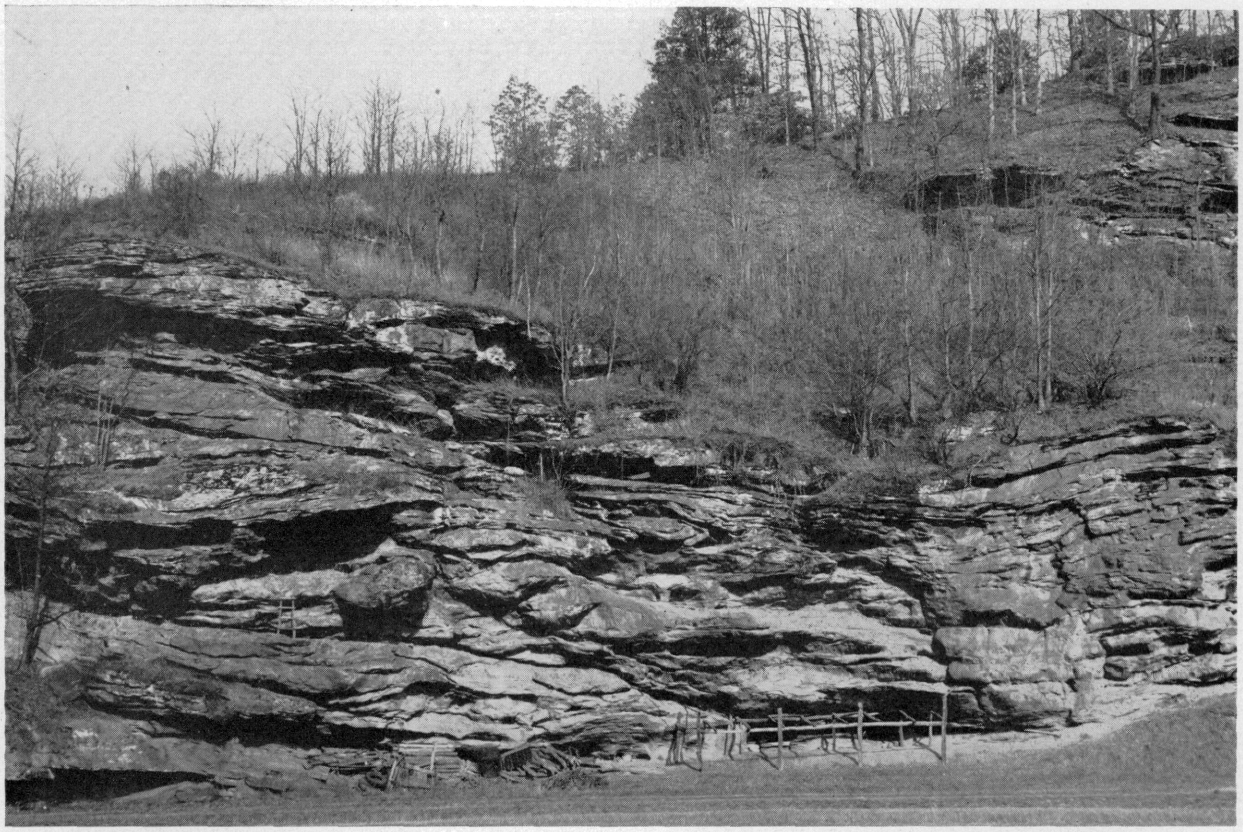
A, GNEISSOSE GRANODIORITE VEINED BY LIGHT-COLORED GRANITIC ROCK

Plutonic foliation of the granodiorite is truncated by the massive light-colored rock. Road cut on North Carolina State Route 603, 0.1 mile east of the Tennessee-North Carolina State line. Photograph by Warren Hamilton.



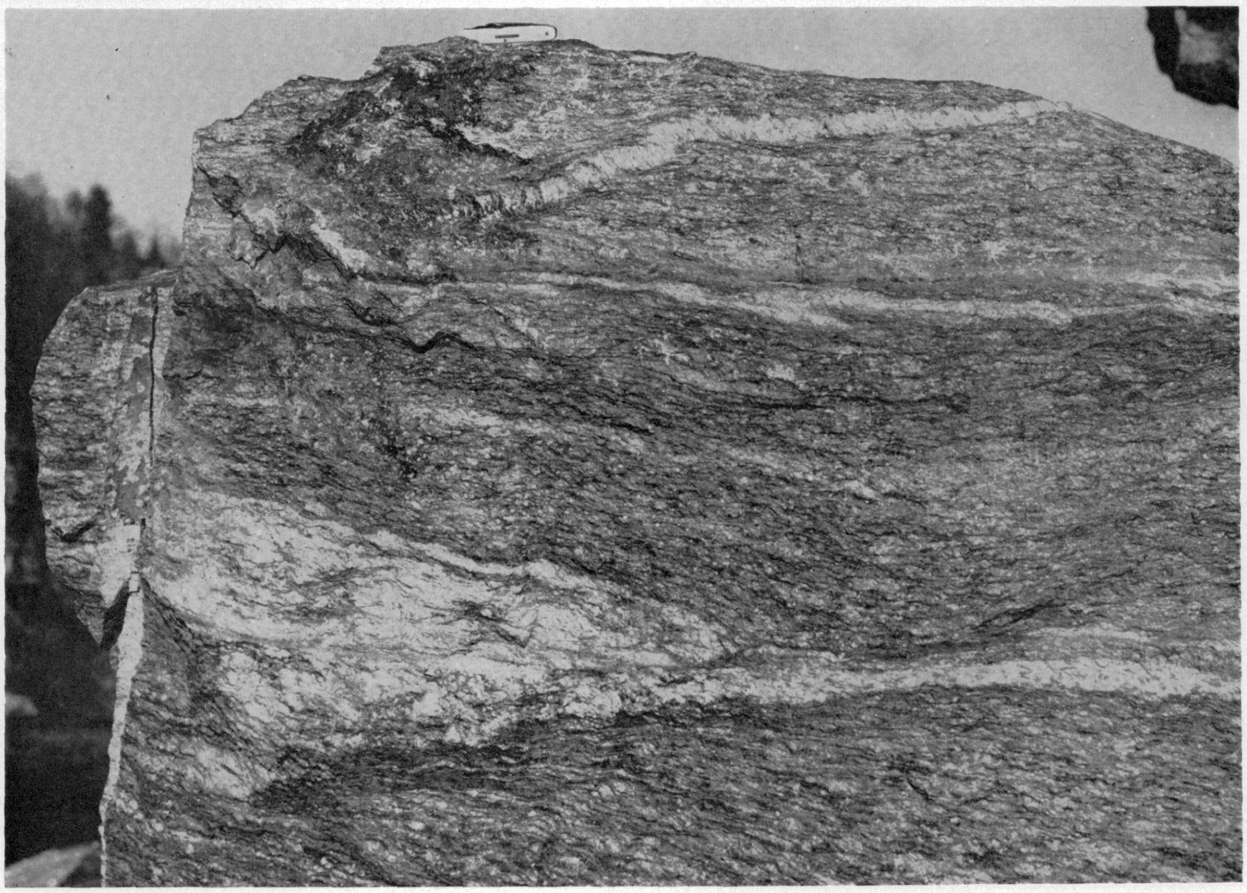
B, VEINED MIGMATTE

Dark fine-grained gneiss, veined and replaced by and enclosed in patchy granitic rock. Road cut on North Carolina State Route 603, on Cove Creek, 0.3 miles west of Phillips Branch. Photograph by Warren Hamilton.



A, CLIFF OUTCROP OF FLASER GNEISS

The large lenses of the exposure are sheared isoclines in banded flaser gneiss. The *b* (axial) lineation of the isoclines, formed during plutonic metamorphism, and the *a* (*slickenside type*) *lineation of the younger cataclastic foliation are roughly parallel*, and plunge gently northeastward under the hill. In Cove Creek valley, 0.15 mile east of Phillips Branch. Photograph by Warren Hamilton.

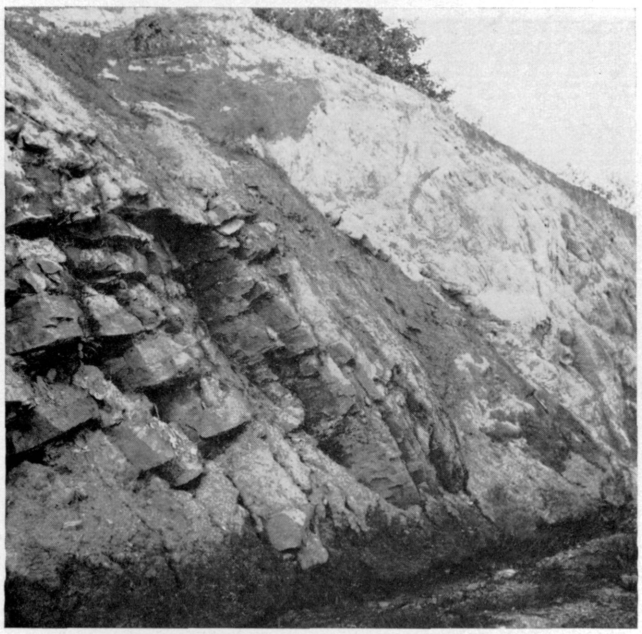


B, FLASER GNEISS

The foliation is cataclastic. Prior to shearing the rock was a layered gneiss containing pegmatites. The pegmatites are less sheared than the gneiss. Note the deflection of cataclastic foliation across the small pegmatite dike near the top of the picture, with foliation refracted through the dike at a high angle to its walls. Knife on top of block is 3 inches long. On North Carolina State Route 603, northeast of Laurel Creek Falls. Photograph by Warren Hamilton.

A, DIKE BROKEN BY BOUDINAGE

A light-colored dike, parallel to the cataclastic foliation of the phyllonite and flaser gneiss, has been broken by boudinage. Lineation *b* of the long axes of the boudins is approximately perpendicular to the outcrop face; lineation *a* in the cataclastic foliation is roughly parallel to the outcrop face. Road cut on Little Beaverdam Creek. Photograph by Warren Hamilton.



B, FAULT BETWEEN FLASER GNEISS AND QUARTZ MONZONITE GNEISS

The fault, marked by the hammer, crosses the picture diagonally, separating dark flaser gneiss (lower left) from uncrushed quartz monzonite gneiss. Cataclastic foliation in the flaser gneiss dips gently to the left and is truncated sharply by the fault. Road cut on North Carolina State Route 603, three-quarters of a mile east of Beech Creek. Photograph by Warren Hamilton.

C, DARK GOUGE ALONG FAULT

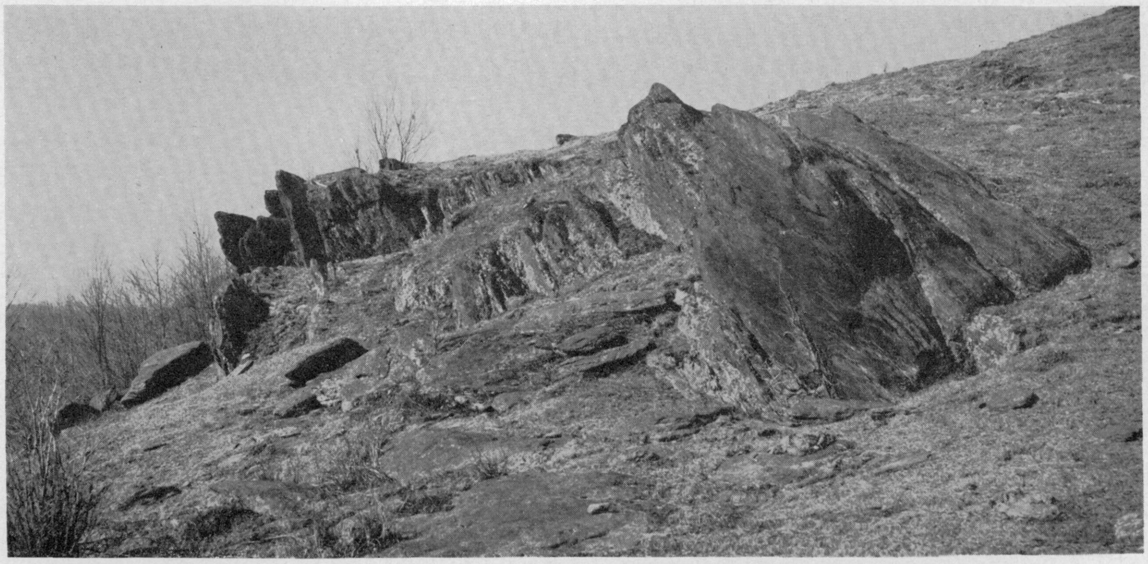
Another view of the fault shown in *B*, showing unsheared quartz monzonite gneiss above the fault on flaser gneiss of similar composition. The fault is traced by a thin irregular zone of gouge. Hammer gives scale. Photograph by Warren Hamilton.

FRACTURE CLEAVAGE IN FLASER GNEISS

The outcrop is crossed by strong cataclastic foliation that extends from upper left to lower right; this foliation is broken at right angles by quartz-filled fracture cleavage veins. Pegmatite, not prominent, extends from just left of the knife to the top of margin of the block and is cross-cut and offset by the cataclastic foliation. The dark area above the center of the picture is a shadow on the irregular rock surface. Knife is 3 inches long. On North Carolina State Route 603, 1½ miles east of Beech Creek. Photograph by Warren Hamilton.

PHYLLONITE DEFORMED BY SLIP CLEAVAGE

Cataclastic foliation, originally parallel to the knife, has been deformed and rotated into a second orientation that crosses the first at a moderate angle, dipping to the right. Road cut on Little Beaverdam Creek 1½ miles north of Beaverdam Creek. Photograph by Warren Hamilton.



A, PHYLLITIC VOLCANIC ROCKS OF MOUNT ROGERS GROUP AT HAW GAP ON TENNESSEE-NORTH CAROLINA DIVIDE, CUT BY SLATY CLEAVAGE THAT DIPS STEEPLY TO THE SOUTHEAST. Photograph by Warren Hamilton.

B, RED BOULDER CONGLOMERATE OF MOUNT ROGERS VOLCANIC GROUP IN CUT ON U. S. HIGHWAY 58

One and one-half miles west of Konnarock, Va. Note lack of bedding and poor sorting. Boulder of granite more than a foot in diameter lies beneath hammer. Photograph by Warren Hamilton.

area represents a regional change in attitude. The axial plane of this broad flexure dips steeply northwestward, and the change in attitude may be due to rotation along the late Paleozoic faults near the northwest side of the province of crystalline rocks.

CLEAVAGE AND OTHER SMALL-SCALE STRUCTURES

At many localities near the Watauga River and elsewhere, vein-filled fracture cleavage crosses the plutonic and cataclastic foliations of the relatively massive gneiss. The fracture cleavage is exposed in road cuts on North Carolina State Route 603 a mile and a half east of Beech Creek (pl. 6), and in a quarry on Beaverdam Creek half a mile upstream from the Watauga River; country rock at the highway exposure is granodiorite gneiss with superposed cataclastic foliation and at the quarry, quartz monzonite gneiss with little cataclastic structure. At both localties, en échelon fractures an inch to several feet apart and a foot or so long in the downdip direction and many feet long parallel to the strike are filled by half-inch veins of quartz, epidote, and magnetite in various proportions. The fractures do not offset the foliation of the wall rocks. Veins and fractures strike northeastward and dip steeply southeastward; at some other localities they stand vertical or dip steeply northwestward. Vein contacts are sharp. The veins are not crushed and show no evidence of subsequent alteration.

At other localities, especially along and near the Watauga River, there are small-scale chevron folds in phyllonite and flaser gneiss. Fold limbs are a few millimeters to several feet across. Thin pegmatites and other layers that escaped severe cataclasis are broken and bent by the folds. Like the fracture cleavage, the chevron folds strike northeast and their axial planes commonly dip steeply southeast.

At several places along Little Beaverdam Creek, a northern tributary of the Watauga River, slip cleavage has formed near the axes of small overturned folds. Cleavage and folds deform the cataclastic foliation of flaser gneiss and phyllonite, so that the rock fabric is a lensing network of several generations of intersecting planar structures (pl. 7).

MINERAL ALTERATION

Late in the history of the basement rocks, parts were altered to minerals of pink and green colors. Southeast of the Mountain City window, the plagioclase of the basement rocks is saussuritized, the ferromagnesian minerals are chloritized, and the potash feldspar is orange pink; the rocks contain thin veins of epidote and blue-purple fluorite and films of hematite. The altered potash feldspars are colored distinctly differently from the probably primary feldspar in the granites south of Pond and Little Pond Mountains; the altered potash feldspars are pale red to orange-pink (hue 10 *R* of the Munsell system), whereas the feldspar grains in the granite are red or pink (hue 5 *R*).

This mineral alteration is conspicuous in a zone a mile to several miles wide in the overriding basement rocks along the southeast edge of the Mountain City window; southeast of this zone, feldspars are fresh and white. The basement rocks of the Shady Valley thrust sheet on Iron Mountains and, sporadically, the plutonic complex of the Mountain City window, show similar alteration. The zone of alteration on the southeast border of the Mountain City window crosses all the basement units indiscriminately, even though they are faulted together, hence must have been produced after the faulting was essentially completed.

STRATIFIED ROCKS

GENERAL CHARACTER OF ROCK FORMATIONS

Lying on the basement rocks is a great succession of stratified rocks that form the mountains of the Unaka province and Appalachian Valley. Within the region of this report the rocks are largely of sedimentary origin and of early Paleozoic age. To the northeast, however, they include at the base volcanic rocks of late Precambrian age, and at various places in the region the lowest Paleozoic formation contains a few interbedded basaltic flows.

The sedimentary rocks of the region include rocks of the Lower, Middle, and Upper Cambrian series, and of the Lower and Middle Ordovician series. Sedimentary rocks below the Middle Ordovician have a thickness of 12,000 to 18,000 feet, of which the lower 6,000 to 10,000 feet is Lower Cambrian. The Middle Ordovician series itself may exceed 5,000 feet in thickness in places. Partly because the Lower Cambrian series is very thick, and partly because the series has been duplicated structurally, it occupies by far the widest area of outcrop. In general, the older sedimentary rocks of the region lie to the southeast, nearest the Precambrian basement, and the younger rocks to the northwest, in and near the Appalachian Valley, but this general relation has been disordered in detail as a result of repetition of the sequence by great low-angle thrusts, and by lesser faults and folds.

The sedimentary rocks include the thick basal Chilhowee group of clastic rocks, followed by a great carbonate sequence, the Shady and Honaker dolomites, and the Conococheague, Jonesboro, and Lenoir limestones. Between the carbonate units are units of shale or limy shale, the Rome formation and Nolichucky shale. The carbonate units are in turn overlain by a thick body of shale and sandstone of Middle Ordovician age, which includes the youngest Paleozoic rocks still preserved in northeasternmost Tennessee.

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Resting on the consolidated rocks are various unconsolidated surficial deposits of Cenozoic age, mostly Quaternary but perhaps in part Tertiary. An account of these deposits is not included in the present chapter as they are closely related to the evolution of the present landscape and are dealt with in a later chapter on "Cenozoic deposits and land forms."

The formations of northeasternmost Tennessee above the basement rocks are summarized in the following stratigraphic table.

Stratified formations exposed in northeasternmost Tennessee

System	Series	Group	Formation	Member	Thickness (feet)
Quaternary	Recent		Alluvium		0–50
	Pleistocene(?)		Older gravel deposits		0–50
Tertiary(?)			Shaly clay and kaolinitic clay		0–100
Ordovician	Middle Ordovician		Sandstone, shale, and conglomerate		3,500
			Shale		200–1,500
			Lenoir limestone		40–200
	Lower Ordovician	Knox	Jonesboro limestone		1,700
Cambrian	Upper Cambrian		Conococheague limestone		2,200
		Conasauga	Nolichucky shale / Elbrook dolomite		0–250
	Middle Cambrian		Honaker dolomite / Elbrook dolomite		2,000–3,000
	Lower Cambrian		Rome formation		1,200–1,800
			Shady dolomite		1,150
		Chilhowee	Erwin formation	Helenmode member Hesse quartzite member Murray shale member Nebo quartzite member	1,200–1,400
			Hampton formation	Cardens Bluff shale member at base	500–1,400
			Unicoi formation	Upper division Lower division	2,000–5,000
Precambrian	Upper Precambrian		Mount Rogers volcanic group		Many thousands of feet
	Lower Precambrian		Basement rocks		

Stratigraphic nomenclature used in the present report is compared in the following table with that used in representative earlier publications.

Development of stratigraphic terminology in northeasternmost Tennessee

Safford, 1869	Keith, 1903, 1907	Butts, 1940	This report
Nash group	Tellico sandstone Athens shale	Athens formation Lenoir limestone	Rocks of Middle Ordovician age (Lenoir limestone at base)
Knox dolomite	Knox dolomite	Beekmantown group Chepultepec limestone Conococheague limestone	Knox group: Jonesboro limestone Conococheague limestone
Knox shale	Nolichucky shale Honaker limestone	Nolichucky shale Honaker and Elbrook dolomites	Conasauga group: Nolichucky shale Honaker and Elbrook dolomites
Knox sandstone	Watauga shale Shady limestone	Rome formation Shady dolomite	Rome formation Shady dolomite
Chilhowee sandstone Ocoee conglomerate and slate	Erwin quartzite Hampton shale Unicoi formation	Chilhowee group: Erwin quartzite Hampton shale Unicoi formation	Chilhowee group: Erwin formation Hampton formation Unicoi formation
Metamorphic group	Beech granite Cranberry granite		Mount Rogers volcanic group
			Basement rocks

PRECAMBRIAN

MOUNT ROGERS VOLCANIC GROUP (UPPER PRECAMBRIAN)

The "Mount Rogers volcanic series" was named by Stose and Stose (1944, p. 410–411) for Mount Rogers, which lies in Virginia a short distance northeast of the present map area. Volcanic rocks of this group were noted by Safford (1869, p. 172) and by Stose and Schrader (1923, p. 45), but the principal work on the group has been done by A. J. and G. W. Stose for the Virginia Geological Survey (Jonas and Stose, 1939, p. 590–591; Stose and Stose, 1944, p. 410–411; Stose and Stose, 1949, p. 311–314). During the present investigation the authors, and others made brief observations of the group, mostly incidental to mapping the northeast end of the Mountain City window. Their traverses were extended northward and northeastward beyond the area of the geologic map (pl. 1); localities mentioned below which are outside the map area are shown on figure 4.

VOLCANIC ROCKS

Volcanic rocks of the Mount Rogers group form the high massif of Whitetop Mountain and Mount Rogers

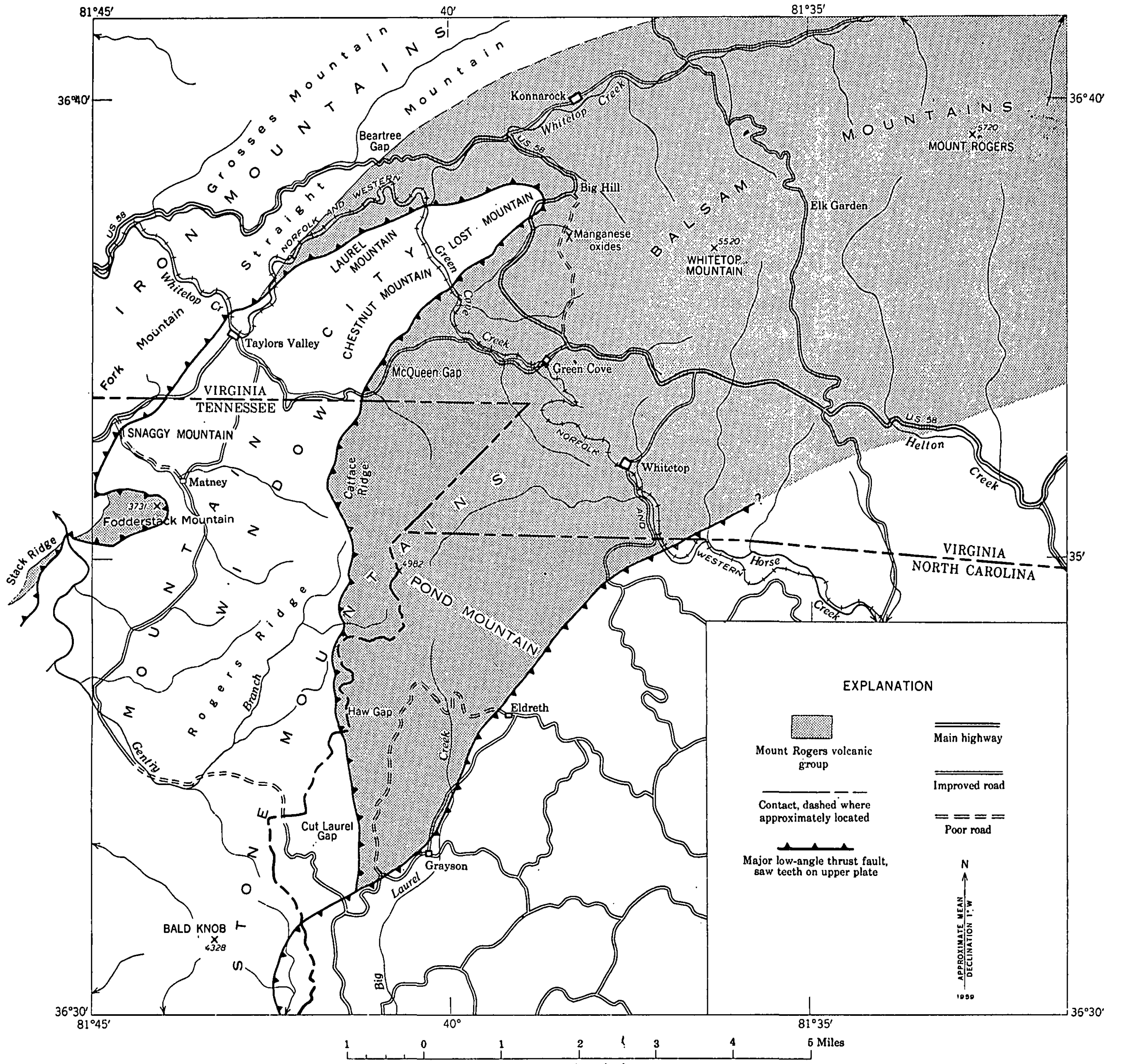


FIGURE 4.—Index map of southern part of Mount Rogers quadrangle, Virginia, Tennessee, and North Carolina, extending north and east beyond the area of the geologic map (pl. 1), to show location of places mentioned in the description of the Mount Rogers volcanic group.

in Virginia, as well as Pond Mountain to the southwest, near the common corner of North Carolina, Tennessee, and Virginia. The two areas apparently are not joined, as sedimentary rocks form the intervening lower ground near the villages of Whitetop and Green Cove. West of Pond Mountain in Tennessee, on the opposite side of the Mountain City window, volcanic rocks form the outlying masses of Fodderstack Mountain and Stack Ridge.

The volcanic rocks are massive lavas and tuffs that form bold ledges on the mountainsides and give rise to great angular blocks in the slope wash and colluvium below. According to Hamilton:

> Most of the volcanic rocks are reddish, maroon, purplish, or bluish gray and are aphanitic or nearly so. Many of the rocks contain pink potash feldspar as phenocrysts or fragments; some quartz is also visible, and less commonly plagioclase; no ferromagnesian minerals were seen. The common occurrence of quartz and potash feldspar in the phenocrysts indicates that the rocks are probably quartz latites and rhyolites. The rocks have commonly been altered, some by recrystallization of the groundmass into finely crystalline material resembling fine-grained quartzite, others by thorough shearing and reconstitution to phyllite. Most of the unsheared rocks appear to represent massive flows.

The rocks at Elk Garden, between Whitetop Mountain and Mount Rogers (fig. 4), are flows, tuff, and agglomerate. According to Hamilton:

> The flows and tuffs are light colored, massive to crudely layered, dense rocks; they are finely crystalline, mostly nonporphyritic, and superficially resemble fine quartzite. Some outcrops contain abundant phenocrysts of dark quartz a millimeter in diameter. Much of the rock is silicified and contains irregular masses of orange chalcedony. A few float blocks at this locality consist of andesitic greenstone, containing minute grains of saussurite and a lesser quantity of fine black material. The agglomerate contains clasts of volcanic material an inch in diameter which lie in a light colored siliceous matrix.

The rocks of Pond Mountain were studied on its southern slope, especially in float blocks. According to Hamilton, they consist of

> phyllitic volcanics of uniform composition, about 10 percent of which consists of phenocrysts, dominantly of red potash feldspar, but with lesser amounts of quartz. The groundmass is finely crystalline and cut by anastomosing shear planes. In part, the shears are inconspicuous and the rock massive, but in part the rocks are crudely phyllitic. In the most strongly sheared rocks the feldspar phenocrysts are changed to knots and stubby augen.

At Haw Gap on the North Carolina-Tennessee divide southwest of Pond Mountain, much of the volcanic rock is schistose and phyllitic (pl. 8*A*), although some of the finely crystalline groundmass is still preserved as lenses between the folia. Phenocrysts of quartz have been reduced to knots and angular fragments, and those of potash feldspar have been altered to ovoids of sericite. Similar rocks occur northwest of Pond Mountain at McQueen Gap.

Fodderstack Mountain to the west is formed largely of massive lavas, which project in ragged ledges. The lava is dull red or purple, with obscure flow structures and phenocrysts, and is irregularly replaced by green minerals and by jasper. On Stack Ridge, across Laurel Creek to the southwest, various pyroclastic and sedimentary rocks are interbedded with the volcanic rocks, including purple slate, arkosic sandstone, and conglomerate that contains slate and sandstone pebbles as much as 2 inches in diameter. The rocks of Stack Ridge must be near the base of the succession as they overlie plutonic basement rocks, apparently unconformably.

The relation between the volcanic rocks and the sedimentary rocks of the Mount Rogers group described below could not be determined in the time available, and the two are not differentiated on the geologic map (pl. 1); at the places where the contact between them was crossed it is concealed by masses of wash and talus.

SEDIMENTARY ROCKS

In Virginia, between the volcanic rocks of Whitetop and Pond Mountains on the southeast and the Unicoi formation of the Iron Mountains on the northwest is a belt of sedimentary rocks about 2 miles broad. The sequence in the belt is interrupted by the Mountain City window, within which rocks of the Chilhowee group emerge anticlinally to form Laurel, Chestnut, and Lost Mountains (pl. 1 and fig. 4). The sedimentary rocks include red boulder conglomerate, red shale, arkosic sandstone, and quartz conglomerate; a representative outcrop showing all these rock types may be observed on U. S. Highway 58 immediately north of Big Hill. Although dips are irregular and erratic, the sequence in the sedimentary rocks appears to be upward away from the Mountain City window on either flank. Sedimentary rocks similar to those in Virginia also occur in the valley of Big Laurel Creek between Eldreth and Grayson, in the northwestern corner of North Carolina.

The most remarkable of the sedimentary rocks is the red boulder conglomerate (pl. 8*B*), which generally lies near or against the rocks of the Mountain City window, as at McQueen Gap and Big Hill on the southeast flank and down Whitetop Creek on the northwest flank. The most prominent outcrops are in cuts on U. S. Highway 58 about 2 miles west of Konnarock. The conglomerate forms thick massive layers and consists of rounded boulders of granitic rocks as much as 3 feet in diameter, and smaller rounded cobbles of aplite, greenstone, and vein quartz, set in a massive, nonbedded red siltstone matrix. In places the fragments are closely packed, in others the rock is mostly siltstone.

The granitic boulders range from granodiorite to granite and have been so altered that the potash feldspars are colored pink and the plagioclase feldspars light green, with most of the ferromagnesian minerals altered to chlorite. Some of the granitic rock is very coarse, with quartz and feldspar grains as much as an inch in diameter. Gneissic structure in the rock, where present, is randomly oriented from boulder to boulder.

The red boulder conglomerate may be the same as the "coarser tuffaceous sediments containing larger rock fragments" described by Stose and Stose (Jonas and Stose, 1939, p. 591) and interpreted by them as ash or mudflow deposits whose fragments were torn loose from the walls of volcanic vents and blown out by explosions. The wide areal extent of the deposit and the lack of any obvious content of volcanic material argues against a volcanic origin and suggests that the fragments were derived by various processes of subaerial erosion, transportation, and deposition.

The higher layers of red conglomerate contain lenses and streaks of red or maroon shale and grade upward into shale. Where the shale is exposed in a continuous sequence, as on U. S. Highway 58 west of Konnarock and north of Big Hill (fig. 4), it is no more than a few hundred feet thick, but it occupies extensive tracts to the southeast, as in the vicinity of Green Cove. The shale is red or maroon, silty, and thinly fissile, flecked in places with greenish spots, and contains occasional thin interbedded layers of arkose and grit. On the west slope of Whitetop Mountain (see fig. 20) at an altitude of about 3,500 feet, prospect pits in the shale disclose interbedded seams of manganese oxides a few inches thick. Superficially, at least, the shale of the Mount Rogers group strongly resembles that of the younger Rome formation. It probably corresponds to the "red tuffaceous shale" of Jonas and Stose (1939, p. 590), although in most places there is no perceptible content of volcanic detritus.

The only volcanic material seen in this part of the section was in road cuts about a mile east of Konnarock, Va., where the shale contains interbedded layers of agglomerate. According to Hamilton this consists of

> angular fragments as much as 3 inches in diameter of quartz, potash feldspar, and aphanitic volcanic rocks in a matrix of coarse maroon tuff; some of the matrix appears to be more sedimentary than pyroclastic.

The agglomerate somewhat resembles the boulder conglomerate previously described, but unlike the conglomerate contains many volcanic fragments and no granitic fragments; the fragments are irregular or angular, rather than rounded as in the conglomerate.

The higher sedimentary rocks of the Mount Rogers group consist largely of brown-weathered, fine- to coarse-grained arkosic sandstone, with interbedded conglomerate made up of well-rounded pebbles, as much as 3 inches in diameter, of quartz and other resistant rocks. The conglomerate differs notably from the red boulder conglomerate, and although both occur in different parts of the same road-cut sections, as north of Big Hill, they are nowhere interbedded; they must have had different origins. These arkosic and conglomeratic rocks considerably resemble those in the lower division of the succeeding Unicoi formation.

THICKNESS AND STRATIGRAPHIC RELATIONS

The thickness of the Mount Rogers volcanic group has not been determined. Stose and Stose (1944, p. 410) state that it "is 1,000 feet or more thick", but this is a minimum estimate and field relations suggest that it is very much thicker. The same authors (Jonas and Stose, 1939, p. 590–591) indicate that the sedimentary part of the group overlies the volcanic part. This was not certainly confirmed during the present investigation, although it was observed that volcanic rocks form the base of the group on Stack Ridge, and that the sedimentary rocks in many places are in contact with the succeeding Unicoi formation.

In most parts of the area studied, the base of the Mount Rogers group is concealed, and where it is in contact with plutonic and metamorphic basement rocks it is separated from them by faults. On Stack Ridge it overlies these rocks, and while the contact is poorly exposed it is apparently unconformable. The red boulder conglomerate of the Mount Rogers group contains fragments of the basement rocks that were undergoing erosion during its deposition.

The Mount Rogers group appears to be unconformable beneath the succeeding Unicoi formation. Stose and Stose (1949, p. 311–314) point out that the Unicoi lies directly on various mappable units of the Mount Rogers group, and that northeast of Mount Rogers in Virginia it lies on basement rocks, with the Mount Rogers group missing; also that the base of the Unicoi truncates rhyolite and diabase dikes, which they believe are syngenetic with the volcanic rocks of the group. During the present investigation it was observed that the Unicoi overlies the lower volcanic rocks on Stack Ridge, where it contains pebbles derived from the erosion of volcanic rocks. Farther northeast, along U. S. Highway 58 between Whitetop Creek and Beartree Gap (fig. 4) the Unicoi lies on the upper arkosic sandstone and quartz conglomerate beds of the Mount Rogers group; here the boundary between the two formations is less plain, and it could not be located accurately on brief investigation.

AGE

Stose and Stose (1944, p. 411) class the Mount Rogers volcanic group as of late Precambrian age, and correlate it with the

> Catoctin basalt, Swift Run tuff, Lynchburg gneiss, and associated intrusives, because they have similar stratigraphic relations to the older and younger rocks and are of the same relative age. Although the Ocoee series contains no extrusive rocks, the writers correlate the Ocoee series with the Mount Rogers series on the basis of their similar stratigraphic position and age, and the resemblance of arkosic beds present in both series.

Rodgers (1953, p. 23), who places the group in the Precambrian with some hesitation, calls attention to the resemblance of the sedimentary rocks of the Mount Rogers group to those in the overlying Unicoi formation.

The units with which the Mount Rogers group have been correlated by Stose and Stose have a similar stratigraphic position above basement rocks and beneath the Unicoi formation and its equivalents. The present authors agree that they are probably all of late Precambrian age, but believe that their mutual relations are dubious, and their lithologic resemblances remote. Both the Mount Rogers group and the Catoctin greenstone contain volcanic rocks, but the former are primarily rhyolitic and latitic, and the latter andesitic and basaltic. The arkose, conglomerates, and shale of the Mount Rogers group do not resemble the clastic rocks of graywacke suite that constitute the Ocoee series. There is, moreover, a possibility, mentioned below, that the lower division of the Unicoi formation contains equivalents of part of the Ocoee series.

CAMBRIAN SYSTEM

CHILHOWEE GROUP (LOWER CAMBRIAN)

GENERAL DISCUSSION

DEFINITION

In northeasternmost Tennessee the clastic rocks of the Chilhowee group constitute the first Paleozoic deposit laid down on the basement rocks. Elsewhere in Tennessee and Virginia, rocks of the Chilhowee group are widely exposed southeast of the Appalachian Valley, and equivalents of the group extend southwestward into Alabama and northeastward beyond Pennsylvania.

The Chilhowee sandstone was named by Safford (1856, p. 152–153; 1869, p. 198–203) for Chilhowee Mountain in Sevier and Blount Counties, central-eastern Tennessee. As it was later divided into various component formations, the term Chilhowee group has come into wide use for the whole, although some reports have referred to it as the "Lower Cambrian quartzites and slates" (U. S. Geological Survey, 1933), the "basal clastic group of the Lower Cambrian series" (King and others, 1944, p. 27), or the "clastic group of Lower Cambrian age" (Ferguson and Jewell, 1951, p. 10–15).

The Chilhowee group has been divided into the Unicoi, Hampton, and Erwin formations, with type localities in the immediate area. Other names have been given to components of the group in Chilhowee Mountain and in northern Virginia, as indicated in the following table.

Formations of Chilhowee group in Tennessee and Virginia

Age		East-central Tennessee, Chilhowee Mountain	Northeasternmost Tennessee, Carter and Johnson Counties (This report)	Northern Virginia, north of Roanoke
Lower Cambrian		Shady dolomite	Shady dolomite	Tomstown dolomite
	Chilhowee group	Hesse sandstone Murray shale Nebo sandstone	Erwin formation	Antietam quartzite
		Nichols shale	Hampton formation	Harpers shale
		Cochran formation	Unicoi formation	Weverton quartzite Loudoun formation
Precambrian		Ocoee series	Mount Rogers volcanic group Basement rocks	Catoctin greenstone Swift Run formation Injection complex

In Keith's reports (1903, 1907) the terms Unicoi formation, Hampton shale, and Erwin quartzite were applied to units supposed to be of relatively constant lithologic character over wide areas. Later experience has shown, however, that the lithologic boundaries are at greatly different levels from place to place, and that different rock types are so interbedded that none of the formations consists dominantly of a single sort of rock. The formations were therefore redefined (King and others, 1944, p. 28) without lithologic implication, the formation boundaries being placed at widely traceable key beds. The units as thus defined are differentiated by tracing individual beds or groups of beds, and by comparing and correlating measured sections from one area to another.

Keith (1907) extended into the Roan Mountain quadrangle the names used on Chilhowee Mountain—Cochran conglomerate, Nichols shale, Nebo quartzite, Murray shale, and Hesse quartzite. The first two names are not used in this report. Cochran conglomerate was applied in places to beds now classed as the upper division of the Unicoi formation in others as the lower part of the Hampton. Nichols is synonymous with Hampton, and hence superfluous. On the other hand, equivalents of the Nebo, Murray, and Hesse can be recognized clearly in the Erwin formation of Holston Mountain and the Iron Mountains and they are here treated as members of that formation.

Keith (1907) also extended the use of the names "Snowbird formation" and "Hiwassee slate" into the Roan Mountain quadrangle where he used them for names of beds as high as the upper division of the Unicoi and the lower part of the Hampton formation of present usage. In their type areas the Snowbird and Hiwassee are part of the Ocoee series, but it is unlikely that the beds called Snowbird and Hiwassee in the Roan Mountain quadrangle are equivalent to any part of the Ocoee series.

Safford (1869, p. 195–196) assigned to the Ocoee series part of the strata in the gorge of Laurel Creek through the Iron Mountains; these strata are here classed as the lower division of the Unicoi formation. This suggested correlation has more to recommend it than Keith's, as the lower division in this area is very thick, and its conglomerate, sandstone, siltstone and shale somewhat resemble those in the upper part of the Ocoee series farther southwest. If the Unicoi formation in this area is wholly younger than the Ocoee series farther southwest it would require that each unit thin out toward the other—the Unicoi southwestward into the thinner Cochran formation and the Ocoee northeastward as a wedge beneath the Cochran and Unicoi.

SECTIONS OF CHILHOWEE GROUP

One of the most accessible and best exposed sections of the Chilhowee group in this area is in the gorge of the Doe River between Gap Creek Mountain and the Iron Mountains between Valley Forge and Hampton—on U. S. Highway 19 E, the abandoned line of the East Tennessee and Western North Carolina Railroad, and the river bed (pl. 12). This section was first described by Safford (1869, p. 201), and was measured in detail during this survey (section 6, pl. 9). It is designated as the type locality of the Hampton formation. Another well exposed but somewhat less accessible section is in the gorge of the Nolichucky River south of Unaka Springs, some miles southwest of the region of this report (section 17, pl. 9). This section is designated as the type locality of the Unicoi and Erwin formations. These and twenty-two other sections of the Chilhowee group were measured in detail or were studied in reconnaissance during this survey. They are shown in graphic form on plate 9 and are further described on p. 102–120.

GENERAL STRATIGRAPHY

The Chilhowee group comprises clastic rocks that lie on a basal unconformity and pass conformably upward into carbonate rocks. Rock types are relatively few and are interbedded in frequent alternation. Basal conglomerate and arkose give place gradually upward to clay shale, siltstone, and vitreous quartzite. The quartzite, arkose, and conglomerate beds stand in ledges that can be traced for considerable distances, but the intervening shale and siltstone are exposed only in places.

The maximum thickness of the Chilhowee group in this region occurs along Iron Mountains where it is as much as 7,500 feet thick; this is also perhaps its maximum for the southern Appalachians. Elsewhere in northeasternmost Tennessee the group averages about 4,000 feet thick. At the type locality on Chilhowee Mountain to the southwest the group is 2,150 to 2,950 feet thick, and similar thicknesses occur in northern Virginia.

The Chilhowee group changes in thickness and lithologic character both along the strike and from one structural block to the next. These changes express variations across the original basin of deposition, but they have been disordered and telescoped subsequently by deformation.

Some of the lithologic changes within single structural blocks are conspicuous, although the overall thickness changes little. Great differences appear, for example, between the sections on the two flanks of the Stony Creek syncline in the Shady Valley area (sections 4 and 10, fig. 5), although the two sequences were originally deposited within a few miles of each other.

Such changes are less profound than those between different structural blocks. Two sections along the Doe River, north and south of Hampton (sections 6 and 18, fig. 5), differ as much or more than those on opposite sides of Shady Valley, but they were originally deposited many miles apart and have been brought together by thrusting along the intervening Iron Mountain fault.

When the arrangement of the deposits before thrusting is restored (fig. 6, right) the pattern of the vari-

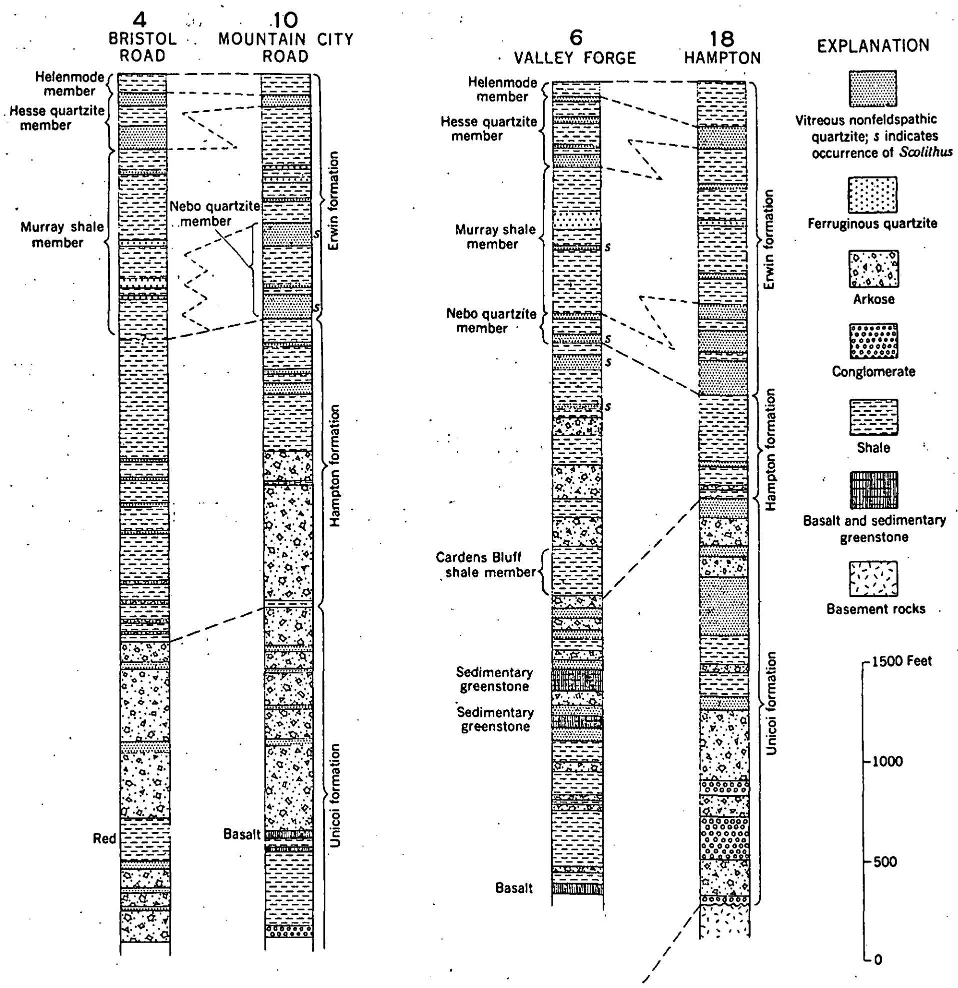


FIGURE 5.—Stratigraphic sections showing lateral variations in Chilhowee group. Each pair of sections is only a few miles apart, yet the members of the pair differ markedly from each other. Sections 4 and 10 (left) are physically connected beneath the syncline of Shady Valley, so that the variation in the original deposit took place within the distance that now separates the sections. Sections 6 and 18 (right) are in different thrust blocks, one in the Shady Valley thrust sheet and the other in the Mountain City window, and the variation in the original deposit probably took place across many miles of the sedimentary basin.

ations in thickness and lithologic character becomes plainer. Thus, rocks of the Chilhowee group in Holston Mountain and the Iron Mountains now lie northwest of those in the Johnson County cove, but have been carried there by the great overthrust of which the Holston Mountain and Iron Mountain faults are a part. These original southeastern deposits are thicker in all their subdivisions than those in the Johnson County cove, and the lower part of the Unicoi formation is very much thicker. Also, they contain lavas of the Unicoi formation that are lacking in most of the Johnson County cove, and lack the thick, nearly continuous bodies of quartzite in the upper part that are characteristic of the cove. The group thinned northwestward across the original basin of deposition, with more quartzite laid down on the northwest in the upper part, and with beds of lava laid down on the southeast in the lower part. The disordering of these original stratigraphic relations supports the conclusion from structural evidence of the existence of far-traveled thrust sheets in northeasternmost Tennessee.

STRATIGRAPHIC RELATIONS

The Chilhowee group lies unconformably on the older rocks. This unconformity is well-marked on the granitic and metamorphic basement rocks, but less definite on the sedimentary rocks and lava flows of the Mount Rogers volcanic group. In many places the unconformity is cut out by thrusting, or is concealed by soil and talus, but it is well exposed at a few places, as at Pardee Point on the Doe River south of Hampton (fig. 7).

At the top, the Chilhowee group passes conformably through the shaly transitional Helenmode member of the Erwin formation, into the Shady dolomite. Although conformable, the upper contact here and else-

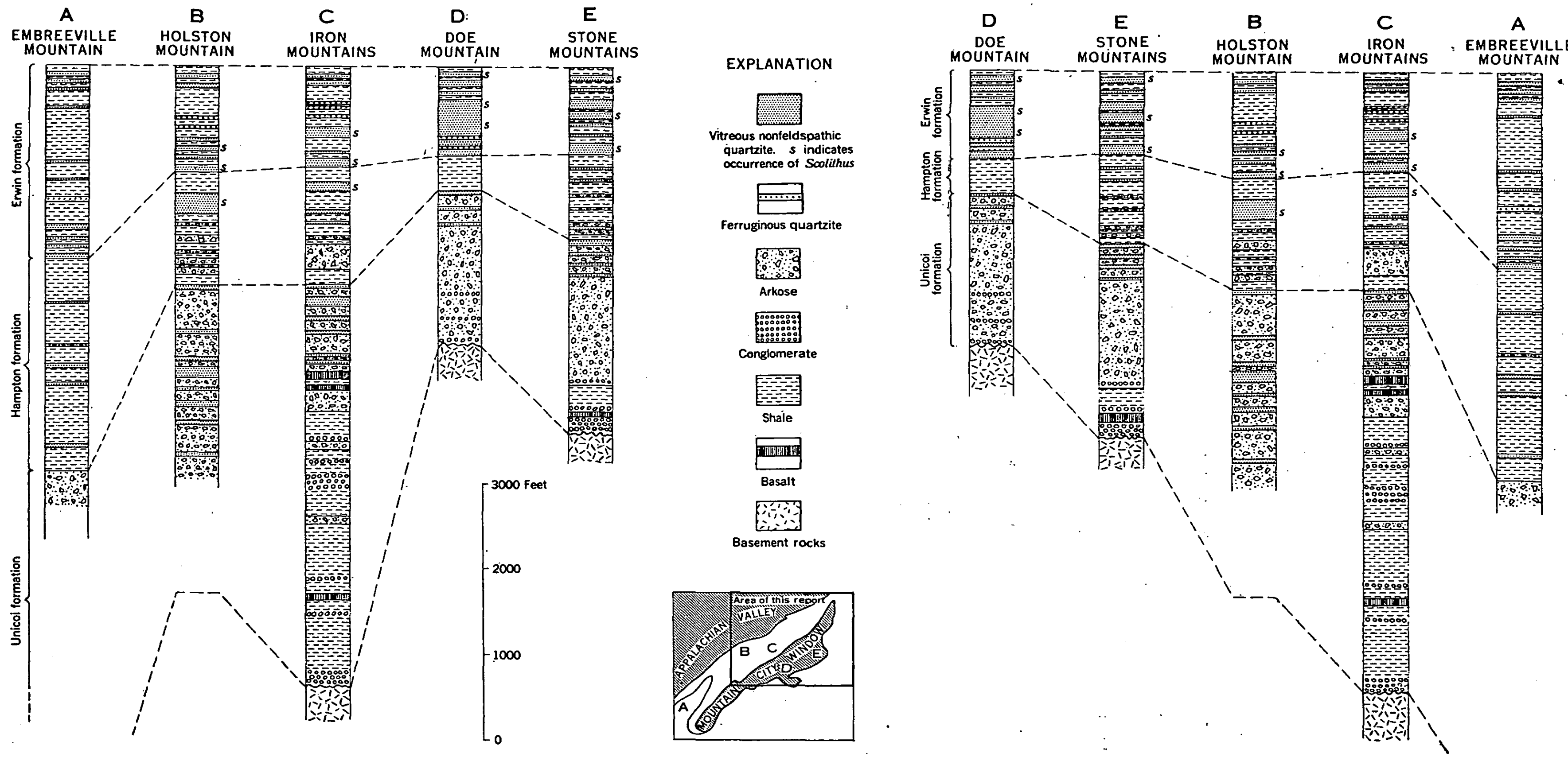


FIGURE 6.—Sections of Chilhowee group, showing sequences in the different thrust sheets. On the left, sections are arranged in present geographic order. On the right, the same sections are rearranged in their probable original order in the basin of deposition. Section *A* is in thrust sheet above Buffalo Mountain fault, southwest of region of this report (King and others, 1944, section *A*, fig. 5). Sections *B* and *C* are in Shady Valley thrust sheet. Sections *D* and *E* are in Mountain City window.

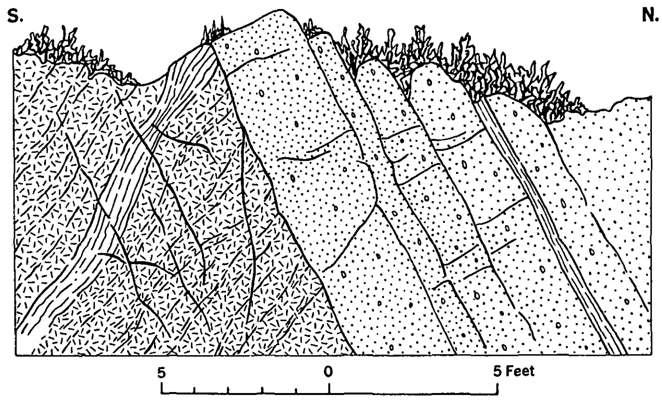


FIGURE 7.—Unconformity at base of Unicoi formation. Sketch of cut on abandoned line of East Tennessee and Western North Carolina Railroad at Pardee Point, south of Hampton, showing basal conglomerate of Unicoi formation (right) overlying and truncating pegmatitic and gneissic granite (left); note truncation by the conglomerate of schistose layer in granite rocks.

where in the southern Appalachians expresses an abrupt change, probably of subcontinental dimensions, from clastic deposition to carbonate deposition. The boundary between the Chilhowee group and the Shady is generally assumed to represent a time-stratigraphic horizon, although there is a possibility that carbonate and clastic rocks may intergrade along the strike, so that the contact may not everywhere be of the same age. Such relations have been proved by McKee (1949, p. 39–42) in the Cambrian and other rocks of the Grand Canyon region. A similar relation cannot be proved within the limits of northeasternmost Tennessee, where there is no interfingering of rock types along the contact, and where the Helenmode member lies beneath the Shady in nearly all parts of the region.

AGE

No diagnostic fossils were found in the Chilhowee group of northeasternmost Tennessee during this survey, but in the Cranberry quadrangle, according to Keith (1903, p. 5),

> Between the quartzite [Erwin] and the overlying Shady limestone are a few feet of sandy shale and thin sandstone [Helenmode member] in which are found a few Lower Cambrian fossils of the *Olenellus* fauna.

From equivalent beds immediately below the Shady in the Little River gap of Chilhowee Mountain, Walcott (1890, p. 570) collected *Olenellus*, *Hyolithus*, and a few other fossils that indicate an Early Cambrian age. Similar scanty remains have been found in the uppermost beds of the Chilhowee group elsewhere (Butts, 1940, p. 36).

The worm tube, *Scolithus*, is abundant in the Erwin formation and in places extends well down into the Hampton formation. Although the presence of *Scolithus* indicates the existence of some form of life during the time, it has no value for correlation purposes.

An age determination by the helium method was made by W. D. Urry on a sample of amygdaloidal basalt from the middle of the Unicoi formation on Laurel Creek immediately south of the Tennessee-Virginia State line (Urry, 1936, p. 1218, 1225). This yielded a figure of 440 to 465 million years; if one accepts the figure of 500 million years conventionally assigned to the beginning of the Cambrian, it would place the Unicoi formation definitely within the Cambrian. However, this determination is of dubious value, as it does not meet modern standards of radiometric analysis.

Great differences of opinion exist as to the position of the base of the Cambrian in this and other regions, where thick bodies of unfossiliferous sediments underlie the lowest fossiliferous Lower Cambrian. Both Howell and others (1944) and Resser (1938) assign the formations of the Chilhowee group below the Erwin to the Precambrian because they lack diagnostic fossils. Other geologists, such as Bloomer and Bloomer (1947, p. 102–106) extend the Cambrian downward to include the Catoctin greenstone and other unfossiliferous formations below the Chilhowee group.

The senior author (1949 a, p. 636–638) concluded earlier that the base of the Cambrian is reasonably placed at the base of the Chilhowee group, and that sediments of the Chilhowee group are the initial deposits of the miogeosyncline in which the Cambrian and Ordovican rocks of the Appalachian Valley were deposited. This interpretation may be doubtful in those parts of the southern Appalachians where the Chilhowee group is underlain by other sedimentary and volcanic rocks, from which it is separated by an obscure or uncertain unconformity, but it applies well in northeasternmost Tennessee where the Chilhowee group lies for them ost part on the deeply eroded surface of the basement rocks.

UNICOI FORMATION

DESCRIPTION

DEFINITION

The Unicoi formation was named "for its strong development in Unicoi County, where there is a fine showing of its strata along the Nolichucky River" (Keith, 1903). In Unicoi County, not far southwest of the region of this report, the Unicoi formation is exposed in many areas, but one of the best sections is that on the Nolichucky River southeast of Unaka Springs (section 17, pl. 9), herewith designated as the type locality.

The Unicoi formation is widely exposed in northeasternmost Tennessee. It commonly lies in high forested mountains and forms much of the crests of Holston Mountain, and the Iron and Stone Mountains.

The upper contact of the Unicoi formation is placed at the top of a sequence of vitreous and arkosic quartzite beds that lies at a rather constant interval of 2,500 to 3,000 feet below the top of the Chilhowee group and is the only persistent key horizon in the middle part of the group. This contact can be easily recognized in most places and is probably of about the same age everywhere.

THICKNESS

The Unicoi formation has a more variable thickness than the other formations of the Chilhowee group. The Precambrian surface on which it was deposited either possessed considerable initial relief, or it subsided unequally during deposition. The thickest sections in the region are on the Iron Mountains, where the only nearly complete measurement suggests a thickness of about 5,000 feet. Similar great thicknesses may occur elsewhere in the area but it is difficult to measure them on account of poor exposures and complex structure. On Holston Mountain in the northwestern part of the same structural block, as much as 2,000 feet of beds occur, but the lower part is cut out against the Holston Mountain fault. Sections of the formation in structural blocks southeast of the Iron Mountains are thinner. At the type section on the Nolichucky River, the beds are a little more than 2,000 feet thick; similar thicknesses occur in the ridges southeast of Hampton and in the Stone Mountains southeast of the Johnson County cove. The rocks of the Unicoi formation exposed in the Doe ridges in the center of the Johnson County cove were probably originally laid down farther northwest than any of the others, but the full thickness of the formation is not exposed.

LITHOLOGIC CHARACTER

The Unicoi formation is a mass of arkosic, coarse-grained, and conglomeratic sandstone, with some beds of vitreous quartzite and of shale, as well as amygdaloidal basalt in parts of the region. All gradations are present from sandstone rich in feldspar to more vitreous quartzite rich in quartz, but even the vitreous rocks are commonly gritty or pebbly. As a whole the sandy rocks are coarser and more feldspathic than similar rocks in the overlying Hampton formation. In the lower part, the coarse sandstone grades into conglomerate with rounded pebbles (a fraction of an inch to 4 inches in diameter) of quartz, feldspar, and fragments of Precambrian rocks. The formation also includes much sandy shale, siltstone, and fine-grained sandstone. They are arkosic, less indurated on weathered surfaces, and lighter colored than the shale and siltstone of the formations above. Red, purple, and green clay shale is present in thin beds. The basalt flows form lenticular beds as much as 100 feet thick. In some sections there is only one bed; in others there are three or more. The basalt is dark green or dull red and commonly amygdaloidal, the amygdules being most abundant at the tops of the flows. At a few localities the basalt possesses an irregular structure suggestive of pillows, but no clearly defined pillow structure was seen.

The basalt lies amidst conglomerate and arkose, and is associated with a peculiar suite of sedimentary rocks that may be partly tuffaceous. They include earthy shale and siltstone that weather red, brown, or orange—that is, to colors brighter than the other rocks of the formation. The suite also includes rocks here termed "sedimentary greenstones" (the "green indurated sediments, probably tuffaceous" of King and others, 1944), which are massive, green or gray green, dense and well indurated, with a marked conchoidal fracture. Megascopically they resemble basalt, but their sedimentary origin is betrayed by faint laminae and by seams of sand and pebbles. In places they seem to occupy the same stratigraphic interval as basalt flows nearby.

Microscopic examination of typical specimens of sedimentary greenstone by J. B. Hadley failed to confirm the inference that the rock contains appreciable quantities of tuffaceous material. The specimens consist of fine-grained feldspathic sandstone or quartzite, with much secondary chlorite in the matrix. According to Rodgers (1953a, p. 37), specimens examined by Jean Lowry contain a large proportion of ilmenite, but no unusual amounts of this mineral were seen in specimens studied by Hadley. Hadley's report is as follows:

Modes of sedimentary greenstones

[Based on examination of thin sections; percentages estimated. Tr, trace]

	Sample Nos.			
	EL-1	CH-3	FS-2	FS-1
Detrital grains	.05-.2 mm	.05-.4 mm	.05-.2 mm	.13-2.5 mm
Primary minerals				
Quartz	50	65	60	95
Microcline and orthoclase	20	15	[1] 20	
Albite	2	5	5	
Biotite [2]	2	Tr.	Tr.	
Muscovite	Tr.	Tr.	Tr.	
Zircon	Tr.	Tr.	Tr.	
Tourmaline	Tr.	Tr.	------	
Leucoxene	1	------	------	
Opaque iron oxides	Tr.	------	------	

[1] Includes 2 percent sericitized grains, probably altered from potash feldspar.
[2] Largely altered to chlorite.

Modes of sedimentary greenstones—Continued

Secondary minerals

Chlorite	20	10	10	5
Sericite	4	5	5	----------
Leucoxene	Tr.	Tr.	Tr.	Tr.
Sphene	Tr.	----------	Tr.	----------
Carbonate	1	----------	----------	----------
Pyrite	----------	----------	Tr.	----------
Opaque iron oxides	Tr.	----------	----------	----------

NOTE.—Description of sample and locality as follows:

E1–1. Sandstone, fine-grained, dark-gray. Outcrop on U. S. Highway 19 E, gorge of the Doe River between Gap Creek Mountain and the Iron Mountains; bed 10, section 6. Elizabethton quadrangle.

CH–3. Sandstone, fine-grained, dark-gray. Gorge of the Nolichucky River south of Unaka Springs; bed 10, section 17. Chestoa quadrangle.

FS–2. Sandstone, fine-grained, dark-gray. At Watauga Dam, horizon not specified. Fish Springs quadrangle.

FS–1. Sandstone, green. From just above big quartzite ledges at Watauga Dam. Bed 9, section 7. Fish Springs quadrangle.

Remarks.—The first three specimens (EL–1, FS–2, and CH–3) are feldspathic sandstones, well-sized, with quartz ranging between 50 and 65 percent. All are characterized by significant amounts of biotite among the detrital grains, but it is chlorite in the matrix that accounts for the dark or greenish color of the rocks. The matrix material is complex and thoroughly recrystallized. It consists largely of secondary chlorite, sericite, and leucoxene, with some carbonate, together with considerable quartz and feldspar. Recrystalized micas commonly penetrate along grain boundaries, and some larger quartz and feldspar grains are partly replaced by micas or carbonate. The grains in all three specimens are small (.05 to 0.20 mm), markedly angular, and tightly packed, with a minimum of matrix.

Specimen FS–1 is somewhat coarser, and a rather pure quartzite. Its grains consist almost entirely of quartz, 0.13 to 2.50 mm in diameter, and were apparently well rounded and with large porosity. Subsequently they have been squeezed so that most grains are strongly flattened against their neighbors and the porosity is reduced to about 5 percent. The remaining pore spaces are now filled with chlorite and smaller amounts of quartz.

In sum, three of these rocks seem to belong to the graywacke clan, and one is a rather pure quartzite. Their compositions probably reflect the pre-Cambrian crystalline complex, modified by factors of weathering and transport. Most of the chlorite that gives these rocks their distinctively green color is probably derived from an original detrital basic paste, but some chlorite may have been added by circulating ground water. This is especially true of FS–1, whose original matrix seems to have been removed and its place taken by chlorite.

There seems to be little connection between the sedimentary greenstones studied and volcanic rocks, unless it be that high concentrations of magnesium and iron were contributed to the ground water during metamorphism by nearby bodies of basalt, and served to build up the chlorite content of the sandstone. Such a possibility seems, however, to be rather far-fetched.

LOCAL FEATURES

IRON MOUNTAINS

On the Iron Mountains the Unicoi formation can be separated on broad lithologic grounds into two divisions, with a rather indefinite boundary between that may not be of the same age from place to place; the two divisions are separately shown on the geologic map (pl. 1).

The upper division, which averages about 1,000 feet thick, consists largely of arkosic sandstone and quartzite, and forms thick ledges that are traceable for long distances along the face of the Iron Mountains. They also stand out prominently in the gorges of the Doe and Watauga Rivers; on the Watauga River three very prominent ledges about 900 feet below the top have been utilized as abutments for Watauga Dam (pls. 10 and 18). The ledge-making beds are five or more in number in individual sections, and each is as much as 50 feet thick; they are more quartzitic than the rest of the division, and at least the upper one contains relatively little feldspar. All contain rounded pebbles, mainly of quartz. The strata between the ledges are partly finer grained, thinner bedded, arkosic sandstone, but between some of the lower ledges are beds of sedimentary greenstone 25 to 50 feet thick. The latter are well exposed near the Watauga Dam and in the gorge of the Doe River south of the Iron Mountains along U. S. Highway 19 E (sections 6 and 7, pl. 9).

The principal beds of amygdaloidal basalt occur either between the lowest ledges of the upper division or near the top of the lower division. They generally form benches or saddles on the southeastern spurs of the Iron Mountains. The basalt is well exposed on Laurel Creek immediately south of the Tennessee-Virginia State line, on Tennessee State Route 91, where two beds are separated by conglomeratic arkose (section 15, pl. 9). The basalt also crops out on U. S. Highway 421 between Shady Valley and Mountain City, but only one bed, 25 feet thick, is present (section 10). Excellent exposures of two or more different beds have been observed at various places on the southeast slope of the mountain between Pandora and Watauga Lake. One of the southwesternmost outcrops of the basalt is on the old line of the East Tennessee and Western North Carolina Railroad, 1,000 feet north of the site of the railroad station at Hampton (section 6, pl. 9; pl. 12). Relations along the Iron Mountains suggest that the basalt is not continuous, but is a series of lenses distributed through a stratigraphic interval of three or four hundred feet.

This habit of the basalt layers presents problems in geologic mapping. Keith (1903, 1907) indicated the basalt as a single layer, but relations observed during this survey make clear that this is merely an idealization. On the present geologic map (pl. 1) the basalt is shown only where observed in field traverses, hence as a series of short, discontinuous outcrops; undoubtedly basalt is also present at many intervening localities.

In steep ravines on the face of the Iron Mountains, 2 miles northeast of Watauga Dam, there appear to be at least four basalt beds, although the section is partly duplicated by folding. Interbedded with the basalt flows are arkosic sandstone and fine conglomerate containing quartz and pink feldspar pebbles with a maximum diameter of a quarter of an inch and several thick beds of green shale or slate, in part schistose, wrinkled, and contorted, in part blebby and possibly tuffaceous. There are also some sheared green massive rocks without amygdules which are either flow basalt, basaltic tuff, or sedimentary greenstone. One ravine contains a 6-inch bed of dark-gray, laminated, crystalline limestone similar to limestone of the Ocoee series farther southwest in Tennessee.

The lower division of the Unicoi formation, beneath the basalt interval, is a great mass of poorly indurated, weak beds that form the lower southeast slopes of Iron Mountains between Watauga Lake and the Tennessee-Virginia State line (pl. 1). These consist largely of thin-bedded arkosic siltstone and sandstone, but also include layers of red and green clay shale and poorly indurated conglomerate containing feldspar and quartz pebbles. In most places the beds are highly disturbed (fig. 15) and poorly exposed. Near Laurel Creek beds of more indurated conglomerate are common, containing rounded pebbles resembling hen's eggs. Most of the pebbles are quartz, but some are fragments of the Precambrian volcanic rocks of the nearby Mount Rogers group. The lower division contains a few lenticular beds of basalt well below the main group, whose exposures were observed on Lyons Branch a mile north-northwest of Laurel Bloomery, and on the Doe Valley-Cross Mountain road 3 miles north of Pandora.

HOLSTON MOUNTAIN

On Holston Mountain as much as 2,000 feet of beds of the Unicoi formation overlie the Holston Mountain fault. Most of the beds are thick-bedded arkosic sandstone and quartzite like that in the upper division on the Iron Mountains. They form prominent ridges such as Delaney Mountain, which is skirted by U. S. Highway 421 between Shady Valley and Bristol (section 4, pl. 9). Along this highway and elsewhere, the lower part of the section contains red arkosic shale; on the mountain face southeast of Denton Valley are also one or more layers of greenish micaceous shale in the upper part (section 5, pl. 9).

During this survey no basalt was seen in the Unicoi formation on Holston Mountain, although beds as low as the basalt interval of the Iron Mountains may be present. Specimens of basalt submitted to the Tennessee Valley Authority by reliable local residents are said to have been collected from the head of the Right Prong of Hatcher Creek, due north of Holston High Point (pl. 1). It is therefore possible that rare lenticular basalt flows are present in the Holston Mountain area.

SOUTHEAST OF THE IRON MOUNTAINS

The type section of the Unicoi formation on the Nolichucky River (section 17, pl. 9) is about 2,000 feet thick; it consists mostly of thick-bedded arkosic sandstone and quartzite but includes two basalt layers. Above the upper basalt are several beds of massive vitreous quartzite and two of sedimentary greenstone. The lower part of the section contains coarse conglomerate and is probably not far above the base of the formation, although during the present investigation the base was interpreted as being cut off by a fault. In subsequent work, Jean Lowry (Rodgers, 1953a, p. 28 and pl. 5) interpreted the basal contact of this section as an unconformity, with an older sedimentary series beneath, to the south.

Similar rocks occur southeast of Hampton, and on Pond and Little Pond Mountains farther east, but no basalt is present. In this area, the formation is well exposed in the gorge of the Doe River (section 18, pl. 9), the basal beds appearing at Pardee Point, where conglomeratic sandstone lies unconformably on the truncated surface of the basement rocks (pl. 9).

Upper strata of the Unicoi formation crop out in a few places in the Doe ridges in the center of the Johnson County cove. Best exposures are on the south face of the southern of the two Sink Mountains, where about 280 feet of coarse crossbedded arkose with layers of fine conglomerate is revealed beneath the Hampton formation (section 20, pl. 9). On Nowhere Ridge farther south, 1,000 feet of Unicoi formation similar to that in the Doe ridges is exposed below the Hampton formation (section 21, fig. 25), but the lowest beds are in fault contact with basement rocks on the east.

In the Stone Mountains, which border the Johnson County cove on the southeast, the Unicoi formation appears to be thicker than 2,000 feet (sections 22 and 23, pl. 9), and more closely resembles the section on the Iron Mountains than any of the other sections in the southeastern area. Its upper beds are coarse conglomeratic arkose, with some strong quartzite ledges, especially near the top. Lower beds on the southeastern slope resemble the lower division of the Iron Mountains and include arkose, coarse conglomerate, and beds of red, purple, and green shale. Amygdaloidal basalt has been observed at a few places near the southeast base of Forge Mountain east of Mountain City and the Stone Mountains southeast of Mountain City (pl. 1). The base of these lower beds is generally cut off by faults of the Stone Mountain family.

Farther north in the Stone Mountains is another exposure of the Unicoi along the Taylors Valley-Green Cove road immediately north of the Virginia-Tennessee State line, but the formation at this place is in a subsidiary fault slice beneath the Catface fault and is more closely related in structural position and facies to the rocks on the Iron Mountains to the west than to those in the Stone Mountains farther south. Amygdaloidal basalt occurs in the eastern part of the exposure; farther west are layers of massive quartzitic sandstone that have been remarkably folded (pl. 11*A*).

Here, and in another fault slice on Snaggy Mountain not far to the west, the quartzitic sandstone has been much altered. Weathered surfaces of the altered rock are vitreous but fresh surfaces show that it is made up of angular quartz grains several millimeters in diameter, lying in a finer grained feldspar matrix, the granulation apparently having been produced by cataclasis during deformation.

HAMPTON FORMATION

DESCRIPTION

DEFINITION

The Hampton formation was named "from the town of Hampton, near which are several fine sections of these strata" (Keith, 1903), in the southwestern part of the region of the present report. The Hampton formation crops out along the Doe River both northwest and southeast of Hampton, the two sections being unlike and lying in different structural blocks (sections 6 and 18, fig. 5). The section to the northwest (pl. 12) is herewith designated as the type locality, as it is characteristic of the formation throughout the Iron Mountains, and also resembles the sequence on Holston Mountain and the Nolichucky River. The section southeast of Hampton is thinner and less representative.

The Hampton formation is composed of interbedded layers of clay shale, siltstone, arkosic sandstone, and vitreous quartzite. Because of its heterogeneity it can best be defined in terms of the more distinctive beds of the Unicoi and Erwin that underlie and overlie it. Keith (1907, p. 6) believed that the strata between these distinctive beds was a single shale unit 100 to 300 feet thick, whereas the strata are actually very much thicker. Therefore, in many places he invoked complex faulting to explain the wide band of outcrop of the formation and the apparent repetition of shaly layers within it.

THICKNESS

As now defined the Hampton formation is 1,200 to 1,400 feet thick in the area of Holston Mountain and the Iron Mountains although it appears to thicken to nearly 2,000 feet immediately south of the Tennessee-Virginia State line (section 15, pl. 9). It is thinner on the Nolichucky River and in the Stone Mountains southeast of the Johnson County cove, and is 500 feet thick or less in the Doe ridges, on Nowhere Ridge, and on the Doe River southeast of Hampton. The Hampton formation of the last three areas was probably deposited farther northwest than that of other localities (fig. 6).

LITHOLOGIC CHARACTER

The Hampton formation is generally thought of as a shaly interval between the more sandy or quartzitic Unicoi and Erwin formations below and above, but this is valid only as a broad generalization. The Hampton is mainly composed of beds weaker than those of the upper part of the Unicoi formation, but it differs from the Erwin formation only in degree. Both Hampton and Erwin consist of interbedded quartzite, sandstone, and shale, with ledge-making quartzite beds more prominently in the Erwin than in the Hampton. No consistent sequence of members is present in the Hampton formation; the amount of shale varies from place to place, and few shale bodies are persistent.

The shaly rocks of the Hampton are generally gray, dark gray, or greenish gray and are darker and more somber than the interbedded sandstone and quartzite beds. Some are truly argillaceous and fissile, with flakes of detrital mica on the bedding surfaces. Others are hard platy rocks made up of alternating argillaceous and silty laminae. Interbedded with them are occasional thicker and more massive layers of siltstone and fine sandstone.

The lower part of the Hampton formation locally includes much arkosic sandstone containing angular feldspar grains and small quantities of dark minerals. Most of the sandstone is medium grained, but parts are coarse grained and even pebbly. On fresh surfaces the sandstone is greenish and vitreous, and the feldspar grains are not apparent. On weathering, the feldspar grains alter to white clay that contrasts with the adjacent vitreous quartz grains. Weathered surfaces are brown, rusty, and pink and commonly earthy. The more feldspathic beds crumble to sand.

In the upper part of the Hampton are some interbedded layers of vitreous white or brown quartzite resembling those in the overlying Erwin formation. Locally two or three of the beds may be traced for many miles along the strike, but most are thinner and less persistent than those in the Erwin.

In places the upper quartzite and the lower arkosic sandstone of the Hampton formation contain *Scolithus*. The tubes in the arkosic sandstone are commonly smaller and shorter than those in the quartzite, and many are bent irregularly. Some of the tubes occur in cross-bedded arkosic sandstone.

LOCAL FEATURES

IRON MOUNTAINS AND HOLSTON MOUNTAIN

The sequence of beds in the type section on the Doe River (section 6, fig. 5) is broadly representative of the Iron Mountains and Holston Mountain area. Shale is prominent in the upper part and at the base, with interbedded thin layers of quartzite above and thick layers of arkosic sandstone below.

The basal shale in the southwest part of the Iron Mountains and Holston Mountain, 100 to 200 feet thick, is sufficiently distinctive to warrant designation as the Cardens Bluff shale member, named for Cardens Bluff on the Watauga River below Watauga Dam (pls. 1 and 18). It is dominantly clay shale, decidedly darker than the usual shale of the unit; on the divides it weathers to bright orange-rusty chips. In the gorges of the Doe and Watauga Rivers through the Iron Mountains, bedding in the shale is crossed by well-marked slaty cleavage (pl. 11*B*), whose peculiar features are discussed on page 67. Along the crest of the Iron Mountains the member forms a well-defined strike valley that continues northeastward as far as U. S. Highway 421, between Shady Valley and Mountain City. The member loses its characteristic features northeastward, either by pinching out between the sandstone layers or by passing into interbedded sandstone and shale.

The succeeding arkosic sandstone is in thin to thick layers interbedded in the shale, or unbroken bodies as much as several hundred feet thick. The top of the arkosic sandstone beds, low in some sections and high in others, is not a definite stratigraphic horizon. The maximum thickness of the sandstone beds is probably on U. S. Highway 421 southeast of Shady Valley (section 10, pl. 9), where they are very coarse, contain little interbedded shale, and are 800 feet thick. This section contrasts with that on the same highway a few miles northwest across Shady Valley (section 4, pl. 9 and fig. 5), where shale dominates the same interval and the arkosic sandstone forms thin sporadic beds. The arkosic sandstone contains *Scolithus* at some localities on the Iron Mountains, notably on the Watauga River below Watauga Dam (section 7, pl. 9), but *Scolithus* is absent at other places.

Toward the southwestern end of Holston Mountain (section 1, pl. 9), the upper part of the Hampton formation contains one or more beds of white, vitreous, *Scolithus*-bearing quartzite, resembling those in the Nebo quartzite member of the Erwin formation above and representing a downward extension of rocks similar to those of the Nebo. These layers thin out northeastward along the strike.

An unusual facies of the Hampton formation occurs along U. S. Highway 421 northwest of Shady Valley on the face of Holston Mountain (section 4, pl. 9) where there are 1,700 feet of dominantly shaly beds. Butts (1940, p. 37), who reports 2,000 feet of shale at this locality, refers to it as "the best exposure of the Hampton." However, the upper part of these shale beds is equivalent to the lower part of the Erwin formation of other sections, the basal or Nebo quartzite member having pinched out at this locality; within the Hampton formation itself the dominantly shaly character is not maintained into adjacent sections.

SOUTHEAST OF THE IRON MOUNTAINS

The Hampton formation on the Nolichucky River (section 17, pl. 9), between the type sections of the Unicoi and Erwin formations, is about 1,100 feet thick; it shows the same succession as on the Iron Mountains and Holston Mountain. *Scolithus* is prominent in the lower arkosic sandstone in the river bed. Sections on the Stone Mountains and Forge Mountain southeast of the Johnson County cove (sections 22 and 23, pl. 9) are probably similar in thickness and lithology but are not well exposed.

Much thinner sections occur southeast of Hampton, in the Doe ridges, and on Nowhere Ridge (sections 18 to 21, pl. 9), where the formation is 360 to 500 feet thick and forms a conspicuous shale break between the sandstone and quartzite below and above. Even here, where the Hampton is more truly a Hampton shale than elsewhere in the region, the shale contains some thin interbedded layers of quartzite and arkosic sandstone.

ERWIN FORMATION

DESCRIPTION

DEFINITION

The Erwin formation was named for the town of Erwin (Keith, 1903, 1907), a short distance southwest of this region. The formation crops out at many places near Erwin, but the best section is that on the Nolichucky River southeast of Unaka Springs (section 17, pl. 9), herewith designated as the type locality.

The Erwin formation forms wide belts of outcrop in Holston Mountain and the Iron Mountains, on the flanks of the Stony Creek syncline (pl. 1). It is also the principal surface rock in the Doe ridges in the center of the Johnson County cove, and crops out at many places in the Stone Mountains southeast of the cove. At the north edge of the map area, north of Damascus, it emerges along the southeastern side of the

Appalachian Valley and extends thence northeastward into Virginia.

The Erwin formation generally lies on the lower slopes of the mountains formed by the Chilhowee group, next to the lowlands underlain by the Shady dolomite. In Stony Creek valley and at many other places its upper beds face the lowlands in broad dip slopes. In the lower part of Beaverdam Creek valley and on the southwest side of Cross Mountain, where the upper beds of the Erwin formation are nearly horizontal, they stand in mesalike outliers.

The Erwin formation is the uppermost unit of the Chilhowee group. It consists of interbedded layers of white vitreous quartzite, dark ferruginous quartzite, siltstone, and shale. The white quartzite beds generally constitute a relatively small part of the formation, but are its most striking and best exposed components, serving to distinguish it from the otherwise similar Hampton formation beneath. At the type locality, and in Holston Mountain and the Iron Mountains, the base is placed beneath widely traceable white quartzite beds that contain *Scolithus* (Nebo quartzite member).

THICKNESS

At the type locality on the Nolichucky River (section 17, pl. 9) the formation is 1,220 feet thick; it is between 1,200 and 1,500 feet thick on Holston Mountain and the Iron Mountains, and about 1,000 feet thick in the Stone Mountains southeast of the Johnson County cove and in the Doe ridges in the center of the cove. On Nowhere Ridge (section 21, pl. 9) the formation is much disturbed so that measurements are uncertain, but it appears to be no more than 600 feet thick.

LITHOLOGIC CHARACTER

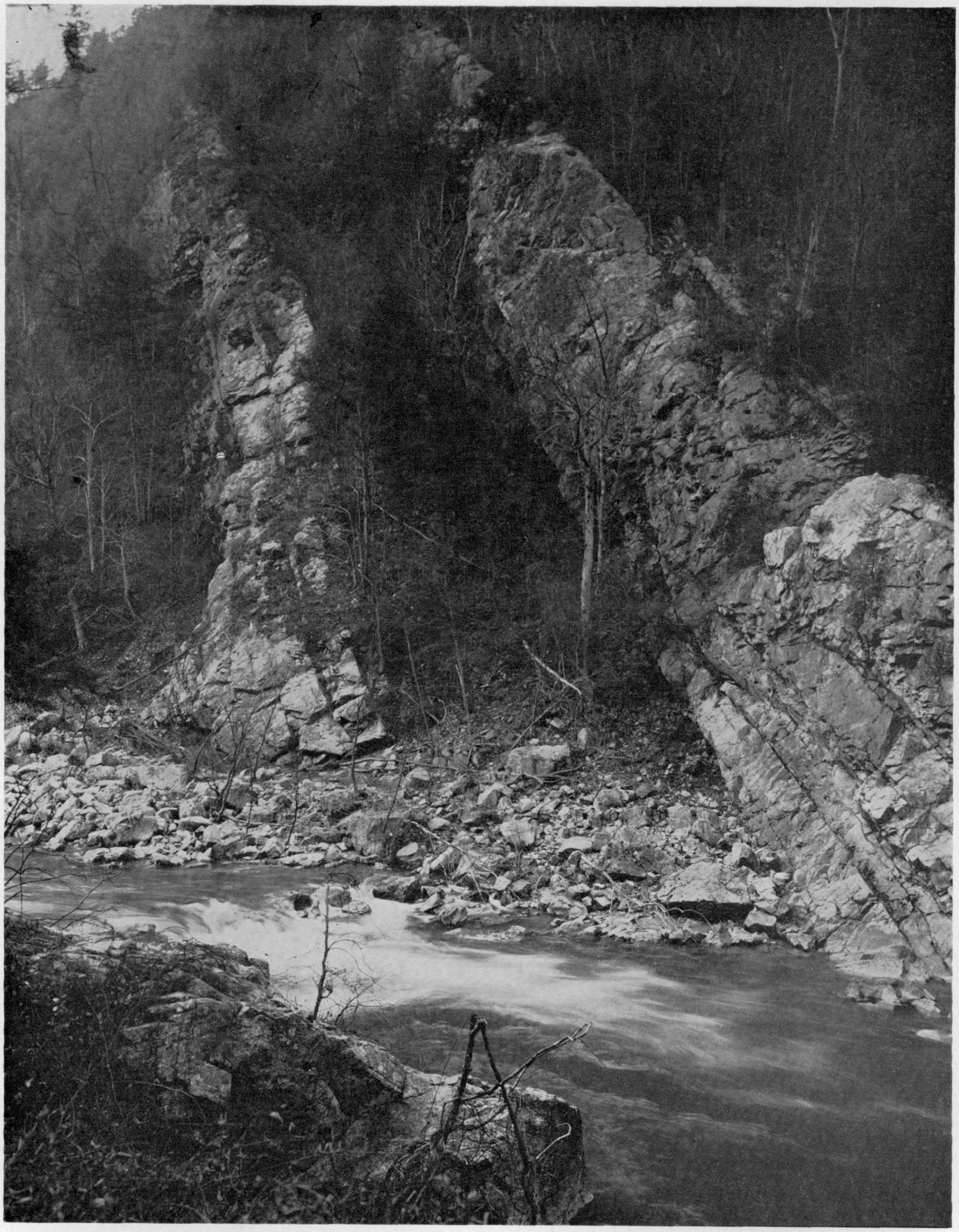
Most of the vitreous quartzite beds of the Erwin formation are white, gray, or buff when fresh, weathering buff. Much of the quartzite is medium-grained, but some is so well cemented and fine textured that the original sand grains are not evident. Most of the sand is almost pure quartz, with practically no feldspar grains; some beds contain scattered grains of glauconite and crystals of pyrite. Individual beds range from a few inches to 25 feet thick. Some massive beds, broken by few bedding planes, reach thicknesses of 50 feet. Except in the Doe ridges, a continuous succession of quartzite beds more than 50 feet thick is rare.

The quartzite beds of the Erwin formation contain the most abundant *Scolithus* in the Chilhowee group. In Holston Mountain and the Iron Mountains *Scolithus* occurs principally in the lower beds (Nebo member), but in the Doe ridges to the southeast in nearly every bed from base to top. *Scolithus* consists of straight, cylindrical tubes, normal to the bedding, thought to have been formed by a burrowing worm and subsequently filled by sand. The tubes are generally closely spaced and extend through beds a few inches to 2 feet thick. In thicker beds they are common in the upper part of the layer, fading out downward. The lowest parts of the thickest beds contain no *Scolithus*, and many are crossbedded. The upper surfaces of the *Scolithus*-bearing beds are dotted by circular nodes that mark the ends of the tubes.

In the upper part of the Weisner formation (Erwin equivalent) of the Cartersville district in Georgia, Kesler (1950, p. 10, pl. 3) describes what appear to be *Scolithus* tubes as "quartz rods" and ascribes them to deformation of the quartzite at the intersections of shear planes. While it is true that in more intensely deformed areas the tubes create a direction of weakness which in many places is followed by planes of cleavage and shearing, there can be no question of the primary origin of the tubes in the less deformed quartzites. It is inconceivable that the nearly cylindrical tubes could have been formed by any combination of shear planes; moreover, in many places the tubes deform and depress the laminae which they penetrated as though they had been bored downward from above while the rocks were still unconsolidated.

The middle part of the Erwin formation contains beds of vitreous dark-bluish or purplish quartzite, colored by finely divided hematite in the cement. The quartzite grades from highly ferruginous to slightly ferruginous. Analyses of ferruginous quartzite given by Jarvis (1912, p. 330, 357) from the Bumpass Cove area southwest of the region of this report indicate a maximum iron content of 40 percent and a minimum silica content of 36 percent. Attempts have been made in the past to mine the ferruginous quartzite as a source of iron ore, but the high silica content has ordinarily discouraged any extensive operations. Most of the ferruginous quartzite is medium-grained, but some is coarse grained or even pebbly. Glauconite grains are present in many of the beds.

In most sections, the greater part of the Erwin formation consists of somber greenish or drab, thin-bedded, silty shale, sandy shale, and earthy siltstone, like those in the Hampton formation. They mostly form thin platy beds consisting of alternating light and dark laminae, the lighter being more silty and the darker more argillaceous. Some thicker beds are of fine-grained earthy sandstone, and there are all gradations between sandstone and vitreous quartzite. In places, layers of argillaceous shale are interbedded with the silty and sandy shale beds, but such layers are subordinate.

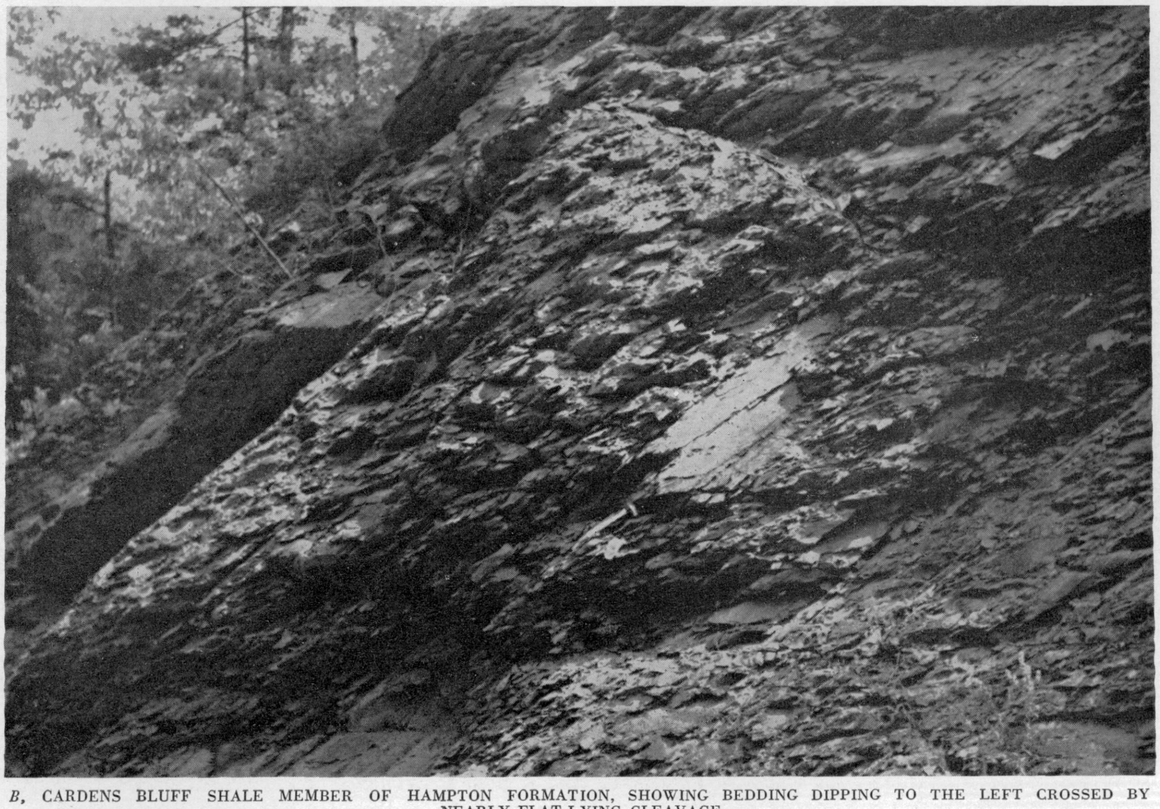


MASSIVE LEDGES OF ARKOSIC QUARTZITE OF UPPER DIVISION OF UNICOI FORMATION, SHOWING CHARACTERISTIC MODE OF OUTCROP

View across Watauga River toward site of west abutment of Watauga Dam, prior to construction of the dam. Photograph by Tennessee Valley Authority.

A, ARKOSIC QUARTZITE OF UPPER DIVISION OF UNICOI FORMATION THROWN INTO A RECUMBENT SYNCLINE OVERTURNED TOWARD THE WEST

Outcrop is in a subsidiary slice of Unicoi formation beneath Catface fault, whose rocks show strong internal deformation. On Taylors Valley-Green Cove road a little north of the Virginia-Tennessee State boundary line and 1½ miles southeast of Taylors Valley. Photograph by P. B. King.



B, CARDENS BLUFF SHALE MEMBER OF HAMPTON FORMATION, SHOWING BEDDING DIPPING TO THE LEFT CROSSED BY NEARLY FLAT-LYING CLEAVAGE

This relation of cleavage to bedding is characteristic of many of the argillaceous layers in Chilhowee group of the Iron Mountains area. Photograph by Warren Hamilton.

LOCAL FEATURES

HOLSTON MOUNTAIN AND THE IRON MOUNTAINS

The Erwin formation of Holston Mountain and the Iron Mountains consists largely of silty and sandy shale. The quartzite beds form only a small part of the formation and differ considerably in thickness from place to place. They are, however, prominently exposed and widely traceable, and the principal ones are separately shown on the geologic map (pl. 1). White quartzite beds close to the top and base are the obvious counterparts of the Hesse and Nebo sandstones of Chilhowee Mountain, farther southwest in Tennessee, the intervening more shaly beds corresponding to the Murray shale of that area.

Four named members are recognized. The Helenmode member comprises generally shaly beds between the Shady dolomite and the upper white quartzite beds; the latter are termed the Hesse quartzite member. The Murray shale member embraces the thick body of strata between the upper and lower white quartzite beds; it is dominantly shaly but includes beds of ferruginous quartzite. The lower white quartzite beds are termed the Nebo quartzite member. The Helenmode member at the top is persistent, but both the Hesse and Nebo quartzite members consists of two or three beds of quartzite in some sections and in some sections of a single bed, the other beds fingering out and disappearing in the Murray shale member.

The Nebo quarzite member consists of several beds of white or gray vitreous quartzite that, in most places, contain abundant *Scolithus*. Individual beds, 10 to 100 feet thick, are separated by shale similar to those in the Murray member. Toward the southwestern end of Holston Mountain the Nebo member includes four *Scolithus*-bearing quartzite beds, and there are similar thinner quartzite beds in the Murray member above and the upper part of the Hampton formation beneath (section 1, pl. 9). Northeastward along Holston Mountain the quartzite dies out. Along U. S. Highway 421 between Shady Valley and Bristol (section 4, pl. 9) they are absent entirely, the whole of the lower part of the Erwin being represented by clay shale indistinguishable from that of the Hampton beneath or the Murray above. Farther northeast, a thin *Scolithus*-bearing quartzite layer reappears (section 5, pl. 9). At most places on Iron Mountains two *Scolithus*-bearing quartzite layers occur in the Nebo member, but these are thin in the section on the Doe River south of Valley Forge (section 6, pl. 9).

The Murray shale member is dominantly sandy shale and siltstone, but argillaceous shale is conspicuous in a few areas. The member also contains one or more beds of ferruginous quartzite in most places. Some of the ferruginous quartzite beds, separately shown on the geologic map (fig. 1), were traced for many miles during the present survey, but other beds are discontinuous. At the southwestern end of Holston Mountain, as noted, the lower part of the member contains thin beds of *Scolithus*-bearing quartzite, comparable to those in the Nebo member. Also, at the northeast end of the Iron Mountains and Holston Mountain, immediately south of Damascus, Va., the upper part of the member contains as many as four beds of white quartzite like those in the Hesse member.

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The Hesse quartzite member is formed of ledge-making quartzite beds exposed in dip slopes on the outer ends of the spurs of Holston Mountain and the Iron Mountains. In places as many as three ledges, each 25 to 50 feet thick, are separated by beds of siltstone (pl. 13). Only the uppermost persists throughout the area. The quartzite is fine to medium grained, vitreous, and generally massive. The upper surfaces in many places are marked by giant ripples a foot or two from crest to crest and a few inches deep. On the surfaces of such beds are small rounded quartz pebbles as much as a quarter of an inch in diameter. No *Scolithus* has been observed in the Hesse member on Iron and Holston Mountains.

The Helenmode member at the top of the formation consists of the so-called transition beds of earlier reports. It was named for the Helenmode pyrite mine near Sadie, in Stony Creek valley, where it is well exposed (King, Ferguson, Craig, and Rodgers, 1944, p. 31). A section of the member at the Helenmode mine was given by Stose and Schrader (1923, fig. 17*B*, p. 68), and the member is described by them as follows:

> These transition beds are exposed in a few places, but in the valley of Stony Creek and in Shady Valley in northeastern Tennessee, also in parts of southwestern Virginia, their character is well shown. They are there about 100 feet thick and embrace yellow finely laminated clays, which evidently were originally calcareous shale, and soft mealy arkosic sandstones, some stained red and purple with iron, others of greenish color, dut to contained glauconite grains. At the top are coarse grits of rounded quartz grains, from which the former calcareous cement has generally been dissolved, leaving a very porous layer or a loosely coherent mass, in many places stained black with manganese oxide or rusty with iron oxide.

In a subsequent paper, Stose (1942, p. 169–171) revised these observations and estimated that the "transition beds" had a thickness of 523 feet in Shady Valley and 270 feet in Stony Creek valley. These revisions resulted from misinterpretation and misunderstanding of the field relations. Stose's section in Shady Valley is accurate, but extends from the middle of the Shady dolomite to the middle of the Erwin formation as here defined. His section in Stony Creek valley was assembled by superimposing short sections of identical beds, measured at various places on the dip slope of Holston Mountain. Observations made during this survey confirm in every respect the earlier observations of Stose and Schrader.

During the present survey the Helenmode member was mapped around the whole periphery of Shady Valley and Stony Creek valley (pl. 1), where it has a thickness of 100 feet or a little less. It is only 67 feet thick in the well-exposed section on U. S. Highway 19 E, south of Valley Forge (section 6, pl. 9, pl. 13). Excellent exposures occur in Stony Creek valley in the vicinity of Sadie and the Helenmode mine (section 28A), but the most accessible is in Shady Valley at the road metal quarry on Beaverdam Creek, half a mile southwest of Crandull.

The silty and shaly beds of the member are hard, strong, and greenish-grey on fresh exposure, where they closely resemble those lower in the Erwin formation, but they break down readily on weathering, perhaps because they are slightly more calcareous, and change into thin-bedded brown clay. In some places the shale contains lenticular beds of white quartzite that can be traced for short distances only.

Keith (1903, p. 5) reported finding "a few Lower Cambrian fossils of the *Olenellus* fauna" in the Cranberry quadrangle in what appears to be the Helenmode member. Bedding surfaces of the shale at the quarry near Crandull, and elsewhere, show obscure impressions that may represent invertebrate trails or seaweed impressions, but diagnostic fossils have not been found in the member during the present investigation.

The "coarser grits" mentioned by Stose and Schrader consist of coarse sandstone with remarkably rounded quartz grains as much as one-sixteenth of an inch in diameter, lying in a finer-grained matrix that is probably siliceous, calcareous, and glauconitic. One layer averaging 4 feet thick forms the top of the member throughout Shady Valley and Stony Creek valley, and seems to be gradational with the Shady dolomite; in places similar thinner layers occur in the shale not far beneath. On weathering the coarse sandstone breaks down to incoherent sand, or is cemented by silica, iron oxides, or manganese oxides, the cement extending only a few inches to a foot beneath the surface. The weathered outcrops have been prospected for siliceous iron and manganese ore in some places.

The coarse sandstone bed here placed at the top of the Helenmode member has been variously classified. In southwest Virginia a similar layer has been called the initial deposit of the Shady dolomite, rather than the last deposit of the Erwin formation (Currier, 1935, p. 19–20; Miller, 1944, p. 19). However, the coarse sandstone is gradational, not only with the Shady above but with the Erwin below. In mapping, it is conveniently grouped with the Erwin formation as it is the uppermost clastic rock in the section, and in areas of pronounced weathering it is also the highest bed that preserves the original structure; at such places the Shady above is represented only by residual clay.

SOUTHEAST OF THE IRON MOUNTAINS

The Erwin formation at the type locality on the Nolichucky River (section 17, pl. 9) closely resembles that in Holston Mountain and the Iron Mountains; it includes the same members and has a similar thickness. Farther northeast in the same strike belt, in the ridges southeast of Hampton (sections 18 and 19, pl. 9), both the Nebo and Hesse quartzite members are thick and prominent, but the Murray shale member persists as a definite break between.

In the Stone Mountains southeast of the Johnson County cove (sections 22, 23, and 24, pl. 9) the sequence in the Erwin formation does not admit of "ledge" mapping, as on Holston Mountain and the Iron Mountains, partly because of complex structure but principally because the Erwin is more uniformally quartzitic and cannot be subdivided into mappable units. The formation appears to be somewhat thinner here than in sections previously described and contains considerably more quartzite. Interbedded shale is prominent only locally, as on Atchinson Branch northeast of Mountain City. *Scolithus* occurs in various beds from the base to the top of the formation, and some of the quartzite beds in the middle and lower parts are ferruginous.

In the Stone Mountains the Helenmode member has been certainly recognized only in the north; elsewhere it is either concealed or faulted out. In the north, between Mountain City and Matney, 50 to 100 feet of sandy shale and sandstone between the uppermost quartzite and the Shady dolomite appears to correspond to the Helenmode member and has been so mapped (section 24, pl. 9). In places in this area, as in the outlying anticline on Dyestone Branch, the sandstone contains *Scolithus*.

The Erwin formation of the Doe ridges and Nowhere Ridge (sections 20 and 21, pl. 9) contains much more quartzite than elswhere in northeasternmost Tennessee, and more closely resembles Erwin section in the Appalachian Valley of southwestern Virginia. Unlike other outcrops in the region, those on the Doe ridges weather to give rise to talus fields made up of quartzite blocks; *Scolithus* occurs throughout and is prominent in the topmost quartzite beds. The lower beds on Sink Mountain and elsewhere in the Doe ridges include quartzite that contains closely spaced ferruginous bands.

The Helenmode member has been recognized at many places in the Doe ridges, but is less than 50 feet thick. It is well exposed at the Young mine on the northwest slope of Dry Run Mountain (Laurence, 1940, p. 396–401); at Ironville, 1¼ miles west of the southwest end of Dry Run Mountain; and on the county road on the north side of Roan Creek just northeast of the sharp bend around Creek Ridge. As in Shady Valley and Stony Creek valley it consists of fine-grained silty shale, weathered buff, with one or two layers of coarse sandstone near the top.

SHADY DOLOMITE (LOWER CAMBRIAN)

DESCRIPTION

DEFINITION

The Shady dolomite was named for Shady Valley (Keith, 1903, p. 5), in the north-central part of this region. Few outcrops occur at the type locality, although the whole unit is probably present beneath the valley. A much better section of the formation is exposed in Stony Creek valley a few miles to the southwest, and this is taken as typical (sections 26, 27, and 28, pl. 14).

The Shady dolomite is the lowest carbonate unit of the Paleozoic section of the Appalachians and consists largely of blue-gray and white dolomite, but includes small amounts of limestone and a few beds of shale.

The Shady is widely distributed and underlies wide areas of the lowlands of Shady Valley, Stony Creek valley, the Johnson County cove, and the Doe River cove. At the north edge of the region of this report, north of Damascus, Va., it crops out in the Appalachian Valley. The Shady is readily weathered and eroded; outcrops of unweathered dolomite are uncommon except near the larger streams, and the formation is generally covered by a thick mantle of residual clay, or by gravel washed from the adjacent mountains.

THICKNESS

The thickness of the Shady can be determined in only a few places. In Stony Creek valley, matching of several measured sections indicates that it is 1,150 feet thick, but it appears to be only 950 feet thick on the Doe River (section 25, pl. 14) to the southwest. In the Doe River cove near Hampton, 1,090 feet has been measured (section 32, pl. 14). Sections near Damascus, Va., (section 29, pl. 14), although incomplete, appear to be about as thick.

LITHOLOGIC CHARACTER

The Shady dolomite includes several distinct rock types, interbedded throughout in rather thick bodies, so that at least locally the formation can be divided into several members. Regionally, these probably form interfingering wedges as the same members cannot be recognized everywhere.

"Blue dolomite" is commonest and most widespread. It is dark to light blue gray and fine grained, the lighter varieties tending to be a little coarser grained than the darker. Some of the blue dolomite is thick bedded and includes massive layers 5 feet or more thick; other parts are thin bedded or laminated and contain silty partings. Nodules of chalcedonic chert are abundant in some layers. Coarsely crystalline white dolomite (termed "sparry" by Rodgers, 1948, p. 5) formed by recrystallization is irregularly distributed through the finer textured blue rock. It forms blebs in the more massive layers, which impart a knobby or "warty" appearance to weathered surfaces (Currier, 1935, p. 21); in the more laminated rock it forms stringers parallel to the bedding, grading into the "ribboned" variety.

The rock termed "white dolomite" is a characteristic but less common rock type in the Shady. It is mostly white but partly light gray, or has a pinkish to yellowish cast, and forms massive beds. Some is compact and fine grained and some is saccharoidal (Currier, 1935, p. 22), with grains a millimeter or more in diameter. Most of the white dolomite is purer than any other in the Shady; analyses from adjacent areas indicate 98 to 99 percent total carbonates. Nevertheless, at a few places it contains some silty layers. Recrystallization has produced veins and stockworks which, though coarsely crystalline, are of about the same color as the surrounding fine-grained dolomite.

"Ribboned dolomite" forms fairly thick units in some areas, notably in Shady Valley and Stony Creek valley. The ribboned appearance (Currier, 1935, p. 20–21) is due to alternating layers, half an inch or less thick, of dark-blue-gray and light-blue-gray dolomite. The darker layers are slightly finer grained than the light-colored layers and probably contain more organic material. The light-colored layers are slightly silty. Throughout much of the region, nearly all the light-colored layers of the ribboned dolomite have been converted to white coarsely crystalline secondary dolomite. Fresh surfaces of the rock are thus marked by a succession of white and dark-blue-gray stripes.

Many of the units of ribboned dolomite also contain a little limestone. Ribboned limestone, like ribboned dolomite, consists of alternating light and dark layers. The dark ribbons are pure limetsone; the light colored are locally limestone but more commonly dolomitic. In many places ribboned limstone and ribboned dolomite form parts of the same outcrops. At such places, the contact is sharp and irregular and may cut the bedding at any angle, so that beds of limestone pass laterally into dolomite. The ribboned rock was probably originally pure limestone and was partly altered to dolomite during its consolidation.

The Shady also contains thin beds of dolomitic shale, especially in the upper part. On fresh surfaces the rock is light-gray thin-bedded shaly dolomite, but on weathering it changes to brown platy shale that forms small benches or spurs on the hillsides. True argillaceous shale occurs in the Shady, but is rare.

LOCAL FEATURES

STONY CREEK VALLEY

Stony Creek valley affords the best exposures of the Shady dolomite in northeasternmost Tennessee. The whole sequence is, however, not exposed at a single locality, but must be pieced together from several sections (sections 26, 27, and 28, fig. 34). Here, six members are recognized. Where practicable, the upper three are differentiated on the geologic map (fig. 1), the lower three being joined in one map unit. The sequence in Stony Creek valley may be summarized as follows:

Generalized section of Shady dolomite in Stony Creek valley

	Average thickness (feet)
Transition beds of Rome formation.	
Shady dolomite:	
6. Upper blue member: Dolomite, blue-gray, medium- to thin-bedded; mostly laminated and silty, with nodules of bluish chert, especially near top and base; near top, at least three beds of shaly dolomite as much as 10 ft thick, the lowest associated with black, slightly dolomitic shale; at base, a 30-ft bed of blue-gray dolomite, with much white chalcedonic chert, overlain by persistent layer of shaly dolomite 5 to 10 ft thick	400
5. Upper white member. Dolomite, white to light-gray, massive, compact to saccharoidal; nearly pure but with a thin layer of laminated silty dolomite 2 ft thick in upper part; contacts sharp at top and bottom	125
4. Middle blue member: Dolomite, blue-gray; mostly thick-bedded to massive; includes some laminated beds and a few ribboned beds	250
3. Ribboned member: Dolomite and limestone, ribboned; dolomite predominating; lighter colored dolomite ribbons partly coarsely crystalline; some lenses of massive blue-gray dolomite; gradational contacts above and below	250
2. Lower blue member: Dolomite, blue-gray, mostly thick bedded to massive; includes some laminated, silty, and ribboned beds; contains many blebs of white, coarsely crystalline dolomite	90
1. Lower white member: Dolomite, white, light-gray, and pink, massive, compact; scattered rounded sand grains and some lenses of dolomitic sandstone near base; grades into overlying member; thickness variable, about	35
Total thickness of Shady dolomite	1,150
Erwin formation:	
Helenmode member: Sandstone coarse-grained, with white or pinkish dolomite cement at top.	

The upper three members are found only in the southwestern half of the valley, the middle blue member extending northeastward about as far as Carter. These upper members are well exposed on the slope northwest of Blue Spring (section 27, pl. 14). Toward the northeast the dolomite remaining on the valley floor is thin, and is locally cut through to the Erwin along Stony Creek. The lower white and lower blue members are well exposed along the creek between Carter and Sadie (section 28, pl. 14). The ribboned member is exposed in the Stoutson quarry, on Blevins Branch near the north end of the valley, where a vertical face, nearly 100 feet high, shows the irregular relations between ribboned dolomite and ribboned limestone.

SHADY VALLEY

In Shady Valley (fig. 8), the type locality, Shady dolomite underlies the upper basin and the basin below Crandull, the two areas being separated by a transverse ridge of the Helenmode member. The whole formation is probably present, as red shale of the Rome formation is exposed along U. S. Highway 421 just east of the main crossroads. Outcrops are sparse, the bedrock being mostly concealed by residuum, alluvial deposits, and marsh land. From the few exposures in the area it may be inferred that the same members as in Stony Creek valley are present and that the thickness is about the same. The exposures of the Shady dolomite in Shady Valley are listed below.

Outcrops of unweathered Shady dolomite in Shady Valley

Rome formation: Deeply weathered red shale, exposed on U. S. Highway 421 a quarter of a mile southeast of the main crossroads in Shady Valley.

Shady dolomite:

Upper blue member:

7. Southwest side of U. S. Highway 421, in sinkhole, 300 ft. southeast of main crossroads in Shady Valley. Blue-gray, medium-bedded dolomite.
6. A quarter of a mile north of main crossroads in Shady Valley at edge of marsh. Silty dolomite, containing rounded sand grains. Probably belongs to lower part of member.

Upper white member:

5. A quarter of a mile northwest of main crossroads in Shady Valley, just north of U. S. Highway 421, on Beaverdam Creek. White compact dolomite.

Middle blue member:

4. One mile southwest of main crossroads in Shady Valley, just west of State Route 91, abandoned quarry at edge of marsh, now filled by water. Blocks from quarry are blue gray laminated and faintly ribboned dolomite. Stratigraphic position of this outcrop less certain than of the others.

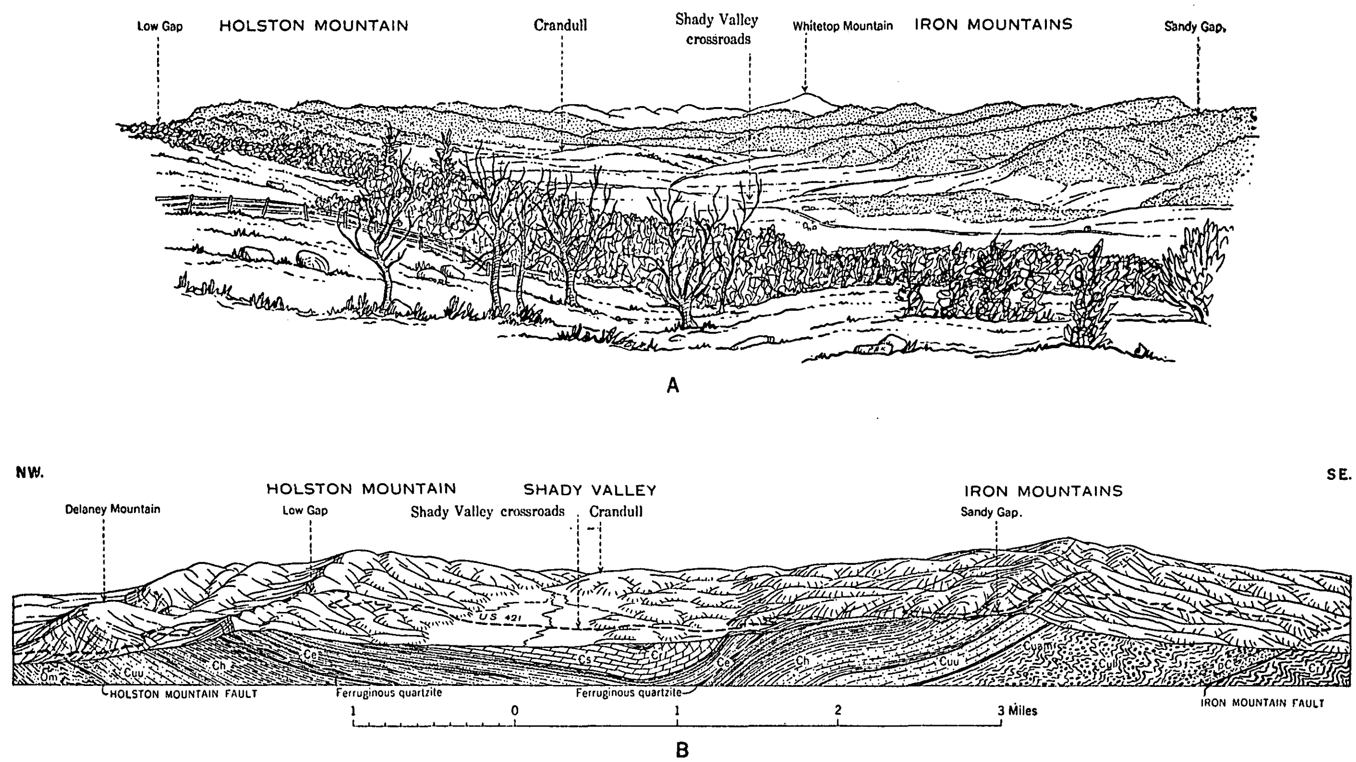

FIGURE 8.—Views of Shady Valley. *A*, Panorama from Buck Ridge on southwest side of valley, looking northeastward down course of Beaverdam Creek. *B*, Block diagram looking northeastward, covering middle ground of panorama, and extending across mountains on either side. Om, Middle Ordovician series; Ꞓr, Rome formation; Ꞓs, Shady dolomite; Ꞓe, Erwin formation; Ꞓh, Hampton formation; Unicoi formation: Ꞓuu, upper division, Ꞓul, lower division with amygdaloidal basalt, Ꞓuam; pꞒ, basement rocks.

Outcrops of unweathered Shady dolomite in Shady Valley—Con.

Shady dolomite—Continued

Ribboned member:

3. North of Crandull and near Ham Greer mine, northwest edge of valley of Beaverdam Creek, and adjacent valleys. Many outcrops of typical ribboned dolomite, much less recrystallized than that in Stony Creek valley.

Lower blue member:

2. Half a mile west of Harmon at northeast end of upper basin of Shady Valley, several quarries on low ridge, nearly at marsh level. Blue massive dolomite, in part silty, in part with blebs of coarsely crystalline dolomite.

Lower white member:

1. A quarter of a mile east of Crandull, bluff on northeast bank of Beaverdam Creek. A section 30 ft. thick of white, compact dolomite. Contains sand grains at base, and grades into light-blue-gray dolomite at top.

Erwin formation:

Helenmode member: On bluff of Beaverdam Creek beneath lower white member of outcrop; also at road metal quarry half a mile southwest of Crandull. Coarse sandstone at top, cemented with dolomite, on dark-greenish silty shale.

Northeastward down Beaverdam Creek toward Damascus, Va., the Erwin formation occurs high on the valley walls, but patches of characteristic residual clay of the Shady dolomite overlies the Helenmode member on the ridge tops (fig. 12). At Sutherland, immediately south of the Tennessee-Virginia State line, the Shady is warped down in a small basin, similar to the upper basin in Shady Valley. As in Shady Valley, there are few outcrops of unweathered dolomite here, but some pinnacles project into the residual clay near the State Line mine.

DAMASCUS AREA

North of Damascus, Va., at the north edge of the region shown on the geologic map (pl. 1), the Shady dolomite emerges from beneath the Holston Mountain fault along the southeast edge of the Appalachian Valley, whence it extends with few interruptions northeastward into the Glade Mountain and Austinville areas (Miller, 1944; Currier, 1935). Sections of the Shady dolomite near Damascus immediately north of Laurel Creek (section 29, pl. 14) demonstate the presence of the same lithologic members as those in Stony Creek valley.

DOE RIVER COVE

Although outcrops are few near Hampton, some fairly long sequences of Shady dolomite are exposed locally (sections 30 and 31, pl. 14), the one on the north side of Laurel Fork being nearly complete (section 32, fig. 34). The Shady dolomite exposed in the Doe River cove lies only 6 miles from that in Stony Creek valley, and even nearer its southwestward extension along the Iron Mountains (section 25, pl. 14), but the subdivisions of Stony Creek valley are obscure or absent, probably because it is in a different structural block. The Shady of the Doe River cove contains much more white dolomite in both the lower and upper parts, and even the "blue" dolomite is mostly light blue gray; no ribboned dolomite is present. Some of the blue dolomite beds are very cherty; others are blebby and contain quartz dolomolds. There are also many interbedded layers of silty dolomite and dolomitic shale.

JOHNSON COUNTY COVE

The Shady dolomite of the larger Johnson County cove to the northeast has been much more deformed and repeated by folding and faulting than that of any other area in the region; in places it has been intimately infolded with the Rome formation. These complex structures are well shown in the deep road cuts on State Route 67 southeast of Watauga Lake (pl. 1).

Although several rock types are present in the Shady, no consistent sequence has been recognized. Most of the formation appears to be blue or blue-gray dolomite in thin to thick beds, but sporadic white dolomite beds are present. Ribboned dolomite was observed only in a few outcrops near Watauga Dam. Interbedded dolomitic shale and shaly dolomite are common in the upper half of the formation, and may have been the source of the phosphate deposits of that area (Jenkins 1916, p. 54, 58, 61, 68–69, and 101). The shale is steel gray to black when fresh, and weathers brown and platy. On the north shore of Watauga Lake west of Meal Camp Hollow, beds of maroon-red shale like those of the Rome formation are interbedded with the dolomite several hundred feet below the top.

On the upper reaches of the Elk River the Shady dolomite that overlies the Nowhere Ridge section of the Chilhowee group (section 21) is mostly blue-gray to light-blue-gray dolomite partly crushed and brecciated, and filled with white crystalline dolomite. One layer of white dolomite was observed near the middle. There are four silty or shaly beds in the upper part, one nearly 50 feet thick, and three near the base, the thickest measuring 15 feet. A similar section occurs about 4 miles to the northeast on Gregg Branch south of an inlier of Erwin formation. Another nearly complete section of the Shady is exposed along the county road near the head of Big Dry Run, southeast of Narrows Knob and east of an inlier of Erwin; nearly half of the formation here is white fine-grained dolomite.

At Ironville, 1¼ miles west of the southwest end of Dry Run Mountain, the basal 2 feet of the Shady, lying on the Helenmode member of the Erwin formation, is light-blue-gray crystalline dolomite, but the dolomite is darker blue and finer grained above. Thirty feet above the base is a lighter gray bed, above which the dolomite is massive and blebby, with a "warty" weathered surface.

In the vicinity of Matney, near the northeast end of the Johnson County cove, the Shady consists mainly of thin to thick beds of blue-gray fine-grained dolomite, in part cherty. No white dolomite or ribboned dolomite has been observed. Some black shaly dolomite layers are interbedded near the top.

The upper part of the Shady in the northwestern belts of outcrop of the Johnson County cove, near the foot of the Iron Mountains, has a peculiar facies. Southwest of the new townsite of Butler, on the north shore of Watauga Lake, a broad anticlinal area of Shady emerges from the Rome (fig. 1). Most of the rock here is poorly bedded conglomerate or breccia, consisting of angular plates and chips of thin-bedded dolomite, as much as 2 inches across, lying in a granular dolomite matrix. This directly underlies the Rome formation; it overlies and is somewhat interbedded with layered dolomite in the anticlinal core. In places the conglomerate fills channels. Similar conglomeratic dolomite also occurs in the long anticlinal belt of Shady northwest of Doe Creek, between Stalcup Branch and the Cross Mountain fault, although here much more dolomite and dolomitic shale is interbedded. The conglomerate was probably formed by reworking by waves and currents of the last Shady deposits in an area of sea floor that was shallower than elsewhere. Shoaling of the sea floor might have resulted from excessive building up of deposits, or from mild tectonic movements.

MANGANESE AND IRON CONTENT

In northeasternmost Tennessee and elsewhere in the southern Appalachians manganese and iron oxides occur in residium of the carbonate rocks, but especially in residuum overlying the lower part of the Shady dolomite. These oxides must have been concentrated during weathering from manganese and iron minerals in the bedrock that were either disseminated components of the original sediment, or were introduced later by hydrothermal activity.

That the source minerals of the manganese oxides were primary rather than hydrothermal is suggested by their widespread rather than localized occurrence (fig. 27) and their concentration over certain parts of the stratigraphic section. It has been suggested that the source of the original minerals was in the lowest beds of the Shady and in the underlying Helenmode member (Stose, Miser, Katz, and Hewett, 1919, p. 54–55; Stose and Schrader, 1923, p. 25; Stose, 1942, p. 172), but later sampling and analysis indicates a modification of this interpretation:

1. Seven samples collected in Shady Valley by P. B. King from the uppermost part of the Helenmode member and from various levels in the Shady dolomite as high as 600 feet above the base are shown by analyses by Cyrus Feldman to contain 0.31 to 2.59 percent manganese carbonate; this indicates the presence of 0.15 to 1.24 percent manganese in carbonate form (King and others, 1944, p. 58). The greatest concentration, yielding the highest figure cited, was not from the lowest beds, but from ribboned dolomite about 200 feet above the base, from rock showing little recrystallization or other alteration.

2. Outcrops of unweathered Shady dolomite were extensively sampled by R. A. Laurence for the Tennessee Valley Authority in 1937 (Rankin and Laurence, 1938; R. A. Laurence, written communication, 1953). Of seven samples from quarries in the lower blue member of the Shady west of Harmon in Shady Valley (outcrop 2, table on p. 47), five yielded no manganese on analysis and the remaining two, 1.05 and 0.76 percent. In a section at Cedar Mountain south of Hampton 42 samples were collected from the Shady between 70 and 564 feet above the base. Many of these samples yielded no manganese on analysis, but quantities averaging 0.65 and 0.77 percent were found between 210–240 feet, and 485–532 feet above the base.

3. Specimens collected from the Shady by John Rodgers (1945, p. 129; 1948, p. 37–40) in Bumpass Cove southwest of the region of the present report indicate "that the percentage of manganese is highest in country-rock dolomite unaffected by hydrothermal action, and that the manganese is present as carbonate." Analyses of samples from a drill hole show that 43 feet of beds about 100 feet above the base of the Shady dolomite average 0.60 percent manganese oxide.

These tests show that various beds in the lower part of the Shady dolomite, mainly well above its base, contain appreciable amounts of manganese in carbonate form, probably as an original constituent. Enough manganese carbonate occurs in some of the beds to provide a source for manganese oxides that have been concentrated in the residuum.

Less definite information exists as to the relation between the iron oxides in the residuum of the Shady dolomite and the source minerals in the bedrock. Keith (1903, p. 8) suggested that they were derived from pyrite disseminated in the upper quartzite layers of the Erwin formation, but Rodgers (1948, p. 42) infers that, like the manganese oxides, they were derived from original carbonate minerals in the lower part of the Shady.

SECONDARY FEATURES

RECRYSTALLIZATION

Dolomite of the Shady has been much jointed, brecciated, and recrystallized as a result of deformation. By recrystallization the original fine-grained or compact dolomite has been changed to aggregates of white crystals 2 or 3 millimeters in diameter ("sparry dolomite" of Rodgers, 1948, p. 5); the limestone is not recrystallized. Recrystallization has taken place not only in such strongly deformed areas as the Johnson County cove, but in less deformed areas such as Stony Creek valley; it is most common in the lower part of the formation and less common above. The most striking change is in the ribboned dolomite where the lighter ribbons are commonly recrystallized and the darker have remained unaltered.

A little new material was introduced during recrystallization. Small cavities lined by dolomite rhombs are common in the coarsely crystalline dolomite, most of which have been filled by quartz in bodies generally an inch or less across. As the quartz is less soluble than the enclosing dolomite, the quartz dolomolds are commonly set free by weathering and form an abundant constituent of the residuum of the Shady. Most of the surfaces of the dolomite consist of imprints of dolomite rhombs, but some imperfect quartz crystal faces are also evident.

Rodgers (1948, p. 13) concludes that

> the close association of breccia, sparry dolomite, and metallic sulfide minerals indicates that the sparry dolomite was formed during the deformation of the region, and by the solutions that introduced the sulfides.

JASPEROID

Jasperoid (Rodgers, 1948, p. 15–16; Kesler, 1950, p. 47–49), a siliceous rock formed by replacement of dolomite, is widely distributed in the outcrop areas of the Shady dolomite in northeasternmost Tennessee and through much of the southern Appalachians. The largest amounts occur immediately south of Mountain City in the Johnson County cove, where jasperoid is found in both the Shady and Rome formations. In Shady and Stony Creek Valleys it is relatively less common and forms only small masses. Some jasperoid is present in the Elbrook dolomite south of Damascus, Va.

Jasperoid is typically yellowish-brown, dull lustered, and flinty or fine grained, but varies widely. The color may be red, gray, white, or black, depending on amounts of iron and manganese oxides. Some jasperoid is granular and resembles medium-grained sandstone; some consists of a closely woven network of siliceous veinlets. Cavities and vugs are common, many lined by mammillary chalcedony or drusy quartz. Jasperiod has sometimes been confused with quartzite or chert, but the three have quite different origins. The nodular chalcedonic chert of the Shady is grayer, more vitreous, and forms smaller concretionary masses; it probably originated earlier than the jasperoid.

Most of the jasperoid has been so thoroughly reconstituted as to obscure the original character of the rock, but relict structures are present in a few places. On Gentry Mountain south of Mountain City, where the jasperoid has formed from dolomite and dolomitic shale of the Rome formation, the original bedding is well marked. In a prospect tunnel on Heaberling Branch in Shady Valley, pieces of jasperoid show the structure of ribboned dolomite; in some other places the jasperoid contains relicts of quartz dolomolds. Similar jasperoid in the Cartersville district, Georgia, contains fossils like those in the adjacent bedrock, and relicts of carbonate cleavage (Kesler, 1950, p. 48).

Nearly all the jasperoid forms isolated masses a few feet to more than 25 feet in diameter, lying in residual clay. Relations of the jasperoid in the clay to the original dolomite are generally not evident, but south of Mountain City, in mine openings on Gentry Mountain, Little Mountain, and Wilson Hill, the jasperoid forms massive ledges that probably extend to the underlying bedrock. Some jasperoid in this area contains clean-cut joints and some is brecciated. Jasperoid ledges on Wilson Hill lie on the trend of one of the faults that cuts the Erwin formation on Dry Run Mountain to the southwest.

The manganese and iron oxides that replace the residual clay have commonly replaced jasperiod also, in irregular areas, botryoidal and frondlike structures, and vein networks; mineralization seems to have worked inward from the surfaces. Some of the nodules of iron oxides, manganese oxides, and jasperoid are coated or veined by thin films of later siliceous material. Kesler (1950, p. 47) believes that the jasperoid was colored during weathering, the original rock having been gray or drab.

While there is little question that the jasperoid formed by replacement of dolomite, it is not clear whether replacement was by hydrothermal solutions of about the same generation as the introduction of the metallic sulfides, or by superficial solutions during weathering. Similar jasperoid is formed near many hydrothermal metallic deposits in the West, and Kesler (1950, p. 48) reports sulfides in the jasperoid at Cartersville, Ga. Conversely, the virtual absence of jasperoid in the bedrock of the Shady suggests that it was not formed at depth in the dolomite, but everywhere near the zone of weathering. This is also suggested by the fact that it is not localized in areas otherwise mineralized, but occurs regionally through the whole outcrop belt of the Shady in the southern Appalachians.

RESIDUAL CLAY

The Shady dolomite is especially susceptible to weathering and is widely blanketed by thick bodies of residual clay. The clay was originally disseminated through the dolomite, especially in the blue dolomite and in the ribboned dolomite and limestone; part of the unweathered dolomite contains as much as 20 percent clay. During weathering, dolomite and calcite were dissolved and the clay was left, along with other insoluble material such as quartz dolomolds, chert, and jasperoid.

Most of the residual clay is brown to buff, tough, dense, and waxy, and has no perceptible granularity. This type is locally called "buckfat." Some of the buckfat is massive and featureless, but other parts are thinly laminated in different colors, the laminae show all degrees of contortion. The buckfat clay contains lenses and thin beds of white kaolinitic clay and yellow silty clay. Streaks of wad and soft ocherous limonite are also common. In places the clay contains nodules of hard manganese and iron oxides, locally so concentrated as to form the manganese and iron ores of the region.

The residual clay is not uniformly distributed over the dolomite. On the lower slopes and near the larger streams, outcrops of unweathered dolomite are extensive and the clay blanket is thin or wanting. On the divides, which are generally remnants of terraces and former valley floors, the blanket may be 50 to 100 feet thick. Most of the clay probably accumulated when wide areas of the valley floors were near base level, for at this time chemical action was profound, and the clay could not be removed by erosion.

Along the dip slopes of the underlying quartzite, weathering of the dolomite may extend deeper than elsewhere, and the residual clay may be thicker. At the southwest end of Bumpass Cove, southwest of the region of this report, drilling indicates the presence of clay bodies 250 feet thick, flanked on one side by a quartzite dip slope, and on the other by a steep face of unweathered dolomite (fig. 9) (Rodgers, 1948, fig. 3, p. 14). Similar relations may exist elsewhere.

The residual clay lies on an irregular, pinnacled surface of the unweathered dolomite, from which it is separated by a sharp contact. The surface of the dolo-

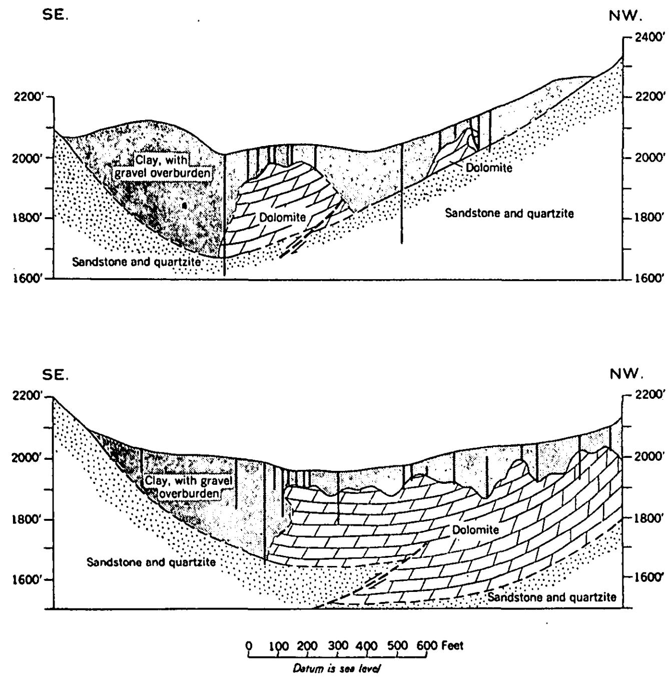

FIGURE 9.—Sections in southwest end of Bumpass Cove, southwest of the region of the present report, showing the relation between unweathered dolomite and residual clay, as revealed by drilling by Embree Iron Co. The habit of the clay to thicken at lower ends of quartzite dip slopes is shown. After Rodgers (1948, fig. 3, p. 14).

mite has been laid bare over wide areas in some of the old hydraulic mine pits, as in Stony Creek valley, in the area south of Mountain City, and especially in Bumpass Cove. There it has a fantastic variety of pinnacles, crevices, and caverns, with a relief of 10 to 100 feet. All these features were formed beneath the clay, rather than in the open; after the clay was mined away some of the pinnacles have fallen for want of support.

Some clay contains intermingled rounded boulders, contorted lenses of sand, and broken fragments of standstone. This material was apparently introduced a relatively long time ago, as the quartzite boulders are deeply weathered, and as both clay and foreign materials have been mineralized by iron and manganese oxides. A considerable part of the foreign material was probably introduced by overfolding and intermixing of residual clay and superficial deposits during downhill creep, slump, and slope wash. Such overfolding has clearly taken place in the clay exposed in the road cut on U. S. Highway 19 E a quarter of a mile south of Valley Forge (pl. 13 B). Some foreign material might have fallen into the clay along cracks produced by drying and slumping.

The surface of the residual clay is widely altered to a red mealy soil which is 6 feet or more thick in places. The soil forms by loss of cohesion of the clay, by washing away of finer material, and by concentration, oxidation, and partial dehydration of the ferruginous material. It generally contains a concentration of the coarser insoluble material in the clay, such as quartz dolomolds, chert, jasperoid, and fragments of iron and manganese oxides. Creep is active in the soil layer, for fragments of manganese oxides derived from a small ore body in the clay may be scattered over several acres and remain in the soil even after the original ore body has been eroded away. The red soil layer is thickest in areas where erosion is not active. It is absent on steep gullied slopes, and also where the clay is overlain by gravel.

CORRELATION AND AGE

MUTUAL RELATIONS OF ROCK TYPES

The different rock types of the Shady dolomite represent a gradational sequence, from white dolomite through blue massive dolomite, blue laminated dolomite, ribboned dolomite, to ribboned limestone. It is significant that rock types far apart in this sequence seldom or never are in contact, so that in passing vertically through any given section the rock types change back and forth in sequential order.

Lateral changes take place in the Shady as well, and probably in the same sequence. Thus, the well-defined lithologic units of the section in Stony Creek valley are poorly recognizable in the Johnson County and Doe River coves, where ribboned carbonate rocks are absent and where there is much more white and blue dolomite. The lithologic units of any area are probably interfingering wedges that thicken and thin in opposite directions from each other.

The sequence of rock types in the Shady represents lateral gradation away from an original shore, probably to the southeast, with ribboned carbonate rocks laid down nearest the shore and white dolomite farthest away. As with the Chilhowee group, the original relations of the Shady in northeasternmost Tennessee have been reversed as a result of thrusting, so that areas with ribboned carbonate now lie to the northwest.

COMPARISON WITH SOUTHWESTERN VIRGINIA

The Shady dolomite is extensively exposed in the southeastern part of the Appalachian Valley of southwestern Virginia and has been studied in detail in the zinc and lead district near Austinville, about 70 miles northeast of the region of this report (Currier, 1935, p. 16–37; Butts, 1940, p. 41–56; Brown, 1953, p. 1217).

The section of the Shady in Stony Creek valley is very similar to that in the north part of the zinc and lead district, north of the Hematite Mountain fault, although the formation is here somewhat thicker (Currier, 1935, pl. 9, sec. II; John Rodgers, written communication, 1953). Members of ribboned carbonate and white dolomite occur in the same positions as the ribboned and upper white members of Stony Creek valley; above the white member is a persistent layer of shaly dolomite like that at the base of the upper blue member. The remainder of the section is blue-gray dolomite, corresponding to the lower, middle, and upper blue members of Stony Creek valley. In outcrop belts farther northwest the Shady consists of irregularly interbedded blue and white dolomite, without well-defined members (Butts, 1940, p. 51), and thus resembles the facies of the Shady in the Johnson County cove of Tennessee.

South of the Hematite Mountain fault, in the main Austinville district, the Shady is 1,550 to 2,050 feet thick (Currier, 1935, pl. 9, secs. III and IV) and consists of ribboned limestone and dolomite below (Patterson member) and white saccharoidal dolomite above (Austinville member of Butts, 1940); the topmost Ivanhoe limestone member, which was included in the Shady by Currier, is only local. The member is now included in the lower part of Rome formation. Blue dolomite is interbedded in part but cannot be designated as distinct members. In the southeastern part of the district these rocks give place to a sequence of more clastic and fossiliferous Lower Cambian carbonate rocks of quite different character.

It is evident that the same rock types occur in the Shady dolomite in both northeasternmost Tennessee and southwestern Virginia and that there is a similar change in facies from northwest to southeast in both regions. Only the clastic fossiliferous facies southeast of Austinville is unrepresented in northeasternmost Tennessee; this may be a near-shore deposit that is an end member of the gradational sequence just outlined (Currier, 1935, p. 35; Stose and Jonas, 1938, p. 30; Butts, 1940, p. 50–51). The sequence of facies is, however, offset to the northwest in relation to northeasternmost Tennessee, as all the outcrops in southwestern Virginia lie northwest of and beneath the extension of the Holston Mountain fault ("Iron Mountain overthrust" of Currier), or in a structural block corresponding to the Mountain City window. Appalachian structural features cross the shoreline of the Shady depositional basin at a wide angle and also the belts of facies that are parallel to it.

FOSSILS

No fossils have been found in the Shady dolomite of northeasternmost Tennessee, and, except for the beds of doubtful relations southeast of Austinville, Va., the Shady in other areas is very sparsely fossiliferous; a few species, including *Archaeocyathus*, *Salterella*, and *Olenellus* definitely fix the age as Early Cambrian. Occurrence of fossils in the Shady dolomite in nearby areas, especially in southwestern Virginia, has been summarized by Resser (1938, p. 24–25) and Butts (1940, p. 54–56).

Both Resser (1938, p. 7) and Kesler (1950, p. 11–12) speak of a Shady fauna as though it were a distinct entity, but such reference is inappropriate. No fauna is known at the type locality, and fossils collected elsewhere are merely suffice to fix the age as Early Cambrian, and not to characterize the whole fauna that must have existed during Shady time. Except for certain forms obviously related to the carbonate facies of the formation, the fossils of the Shady dolomite show no distinctive difference from those of the Lower Cambrian formations below and above it.

ROME FORMATION (LOWER CAMBRIAN)

DEFINITION

The Rome formation was named for Rome, Ga. (Hayes, 1891, p. 143; Walcott, 1891, p. 304). This name is generally used in the southern Appalachians south of Roanoke, Va., for the dominantly red, argillaceous and sandy rocks of the upper part of the Lower Cambrian series, and has supplanted many local names that had come into use for the same unit (Woodward, 1929; Resser, 1938, p. 7–10). Keith, in his earlier work, failed to recognize the resemblance between the red shale along the southeast edge of the Appalachian Valley and the Rome formation that he mapped farther northwest; he referred to the shale as the "shore deposit of the Knox dolomite" (1892, 1895) on the mistaken assumption that the underlying Shady was equivalent to the much younger Knox. After the Shady was recognized in its true position, he termed the unit the Watauga shale (1903, p. 5), from exposures along the Watauga River within the region of this report, although he indicated its general equivalence with the Rome.

In this region the Rome formation is underlain by the Shady dolomite and overlain by the Honaker or Elbrook dolomite; the contact with each is gradational within a few feet. In belts farther northwest the uppermost beds that were formerly called Rome have recently been removed from the formation and termed the Pumpkin Valley shale of the Conasauga group (Rodgers and Kent, 1948, p. 7–9). In the region of the present report, however, the Pumpkin Valley equivalents are probably in the basal part of the Honaker or Elbrook dolomite (Rodgers, 1953a, p. 52), so that the formation does not require redefinition.

OCCURRENCE

The Rome formation is extensively exposed in Johnson County and Doe River coves, where it is the youngest formation (fig. 1). Some of the best exposures are along the Watauga River, the type area of the Watauga shale of former usage. Parts of these are now submerged beneath Watauga Lake, but other good outcrops have been opened in the new deep cuts of Tennessee State Route 67 near its crossing of the lake.

The Rome is also exposed at the southwest end of the syncline of Stony Creek valley, where it plunges under the Honaker dolomite near Elizabethton; a small area of Rome is also preserved in Shady Valley along the same trend to the northeast.

Near Damascus, Va., the Rome emerges from beneath the Holston Mountain fault along the southeastern edge of the Appalachian Valley, the belt of outcrop extending far northeastward into Virginia. Southwestward along the same trend the formation reappears in Denton Valley.

THICKNESS

The whole thickness of the Rome is exposed in only a few places, either the top or base being missing; in most areas it is difficult to estimate the thickness because the structure is complex. Within this region the full thickness of the formation has been determined only near Valley Forge (section 25, pl. 14), where it is about 1,250 feet, and near Damascus, Va. (section 29, pl. 14), where it is about 1,800 feet. Possibly as much as 1,500 feet is exposed in Denton Valley, with the base not visible (section 34, p. 127). The thickness was estimated by L. E. Smith to be 2,100 feet on Jeffrey Branch in the Doe River cove a little southwest of the map area, but this section may have been duplicated by hidden folds and faults, and the top is missing. The Rome formation in the Johnson County cove is much deformed and its thickness has not been determined.

LITHOLOGIC CHARACTER

A large part of the Rome formation is red, maroon, or brown shale, mostly silty and well consolidated. Green argillaceous, sericitic shale also occurs, associated with dolomitic shale and shaly dolomite. Interbedded with the shale is maroon-red, brown, and greenish-brown siltstone that, in places, grades into fine-grained sandstone. The thicker and more sandy beds of siltstone are resistant and stand out as ledges.

Interbedded with the shale, especially with the green shale, are many beds of light-gray shaly dolomite, mostly less than 2 feet thick. Some thicker units, from 15 to 100 feet thick, consist of blue-gray, finely crystalline dolomite in thick to massive layers. In places they contain nodules of vitreous chert. They much resemble the upper beds of the Shady dolomite.

The thinner shale, siltstone, and dolomite beds of the Rome formation are probably lenticular, but the thicker siltstone, dolomite, and limestone beds have great lateral extent. Two prominent dolomite beds in the lower part of the Rome in the southwest part of Stony Creek valley and on the Doe River at Valley Forge are differentiated on the geologic map (pls. 1 and 12).

At the base of the Rome formation at the southwest end of Stony Creek valley, lying on the Shady dolomite, are 75 to 100 feet of transition beds composed of silty and shaly dolomite and dolomitic shale, with a bed of massive blue-gray dolomite near the middle. The transition beds contain very little red shale; the first thick beds of red shale appear at their top.

EFFECTS OF WEATHERING

The Rome formation forms steep-sided knobby hills, many cleared and cultivated. The shale weathers into small chips, and the green shale and dolomitic shale into silty clay. The soil formed on the shale is thin and rocky, but generally blankets most of the surface except along the streams and roads. South of Mountain City, the shale has been silicified into jasperoid in areas of considerable faulting and fracturing.

The dolomite and limestone beds weather to light-yellow clay, which is generally laminated and silty. The thicker dolomite beds form bands of buckfat clay, containing chert nodules. Most of the iron and manganese deposits in the Rome formation occur in residiuum of the thicker dolomite beds. In places, also, siliceous and argillaceous limestone interbedded in the Rome formation has weathered to tripoli, a porous mass of fine-grained angular particles, from which circulating ground water has removed the carbonates (Glenn, 1914). Near Cobb Creek, a little northeast of the present townsite of Butler, five such beds have been prospected; some stand nearly vertical and some are 30 feet or more thick. Altered rock in one layer has been explored to a depth of more than 40 feet.

FOSSILS AND AGE

No fossils have been found in the Rome formation in this region. Elsewhere it contains a sparse fauna, mainly of trilobites, as summarized by Resser (1938, p. 23–24) and Butts (1940, p. 63–67). These include *Olenellus* and other genera of Early Cambrian age. Formerly the Rome was classed as of Early and Middle Cambrian age, but most or all fossils of Middle Cambrian age occur in the upper part, the unit now termed the Pumpkin Valley shale and excluded from the Rome formation. Probably the whole of the Rome formation as now defined is of Early Cambrian age.

CONASAUGA GROUP (MIDDLE AND UPPER CAMBRIAN)

The Conasauga group is an interfingering complex of shale, limestone, and dolomite, mainly of Middle Cambrian but partly of Late Cambrian age, of which the Elbrook dolomite, Honaker dolomite, and Nolichucky shale are the representatives in northeasternmost Tennessee. The broader relations of the different rock units in the Conasauga group are shown in a diagram by Rodgers (1953a, fig. 3, p. 46).

The Elbrook dolomite (Stose, 1906, p. 209) lies mainly to the east and northeast in Virginia. It consists almost entirely of thin-bedded dolomite and is one end member of the complex. Farther west and southwest in Virginia and Tennessee, the place of the upper dolomite beds is taken by the Nolichucky shale (Campbell, 1894, p. 2), but a considerable body of dolomite beneath is termed the Honaker dolomite (Campbell, 1897, p. 2). Still farther west and southwest in Tennessee the carbonate rocks, here mainly limestone, intertongue with shale, the different shale and limestone layers each bearing a formation name. The shale layers eventually merge into a solid body by the fingering out of the limestone layers; this is the typical Conasauga shale (Hayes, 1891, p. 143), which extends from Tennessee into Georgia and Alabama. It is the opposite end member of the interfingering complex.

Within this region the Conasauga group is exposed in two separate areas—one to the north, along the southeast edge of the Appalachian Valley, and the other to the southwest near Elizabethton, in the trough of the Stony Creek syncline. In the northern occurrence the interval is all dolomite, the Elbrook, but to the southwest the Nolichucky shale is at the top and the underlying dolomite is the Honaker.

ELBROOK DOLOMITE

The Elbrook dolomite forms a long belt of outcrop along the southeast side of the Appalachian Valley in Virginia; Laurel Creek crosses it west of Damascus and it is cut out southwestward against the Holston Mountain fault (pl. 1). A few miles to the southwest it reappears in Denton Valley, where it is best exposed near Mill Creek (section 34, p. 127). The Elbrook was studied critically only in the Denton Valley area; in this area it is about 2,000 feet thick, but there is some uncertainty as to the upper contact.

The lower quarter of the formations is thin-bedded or thinly laminated light-gray dolomite, containing many stringers of black chert and occasional heads of *Cryptozoon*. It closely resembles the characteristic Elbrook farther northeast in Virginia.

The upper three-quarters of the formation is less distinctive. It contains some thin-bedded dolomite like that beneath, and other beds of dark fetid dolomite and of dolomite and limestone with argillaceous ribbons like those in the Conococheague limestone above, but the greater part is a succession of dolomite and limestone beds a few feet thick, containing many laminae within the beds. This upper division shares lithologic features of the more characteristic Elbrook and Conococheague below and above; although parts of it resemble the Conococheague, it is placed in the Elbrook mainly because of its low position in the section. The upper contact is tentatively drawn at the base of a set of persistent black fetid dolomite beds, but comparison with the better defined sections elsewhere might prove that it should be placed several hundred feet lower or higher.

HONAKER DOLOMITE

The Honaker dolomite occupies a large area in the trough of the Stony Creek syncline south of Elizabethton, where it stands in prominent knobby hills that culminate in Lynn Mountain east of the Doe River (pl. 1). Between the hills its surface has been cut in places into an intricate sinkhole topography, so that much of its area is drained through underground channels.

Keith (1907) gives a thickness of 1,800 to 2,200 feet for the Honaker in the Roan Mountain quadrangle, of which the Elizabethton area is a part. Estimates by the senior author near Elizabethon suggest a thickness of at least 2,200 feet and possibly 2,500 feet. Farther northwest Rodgers (1953a, p. 51–52) measured 1,300 feet of the upper beds and inferred that the section ended not far above the base; either the Honaker has thinned greatly in this vicinity, or the concealed beds are thicker than supposed.

The lower part of the Honaker dolomite is well exposed in cuts on the county road on the east side of the Doe River north of Valley Forge, and also in a large abandoned quarry at the west end of Lynn Mountain, within the city of Elizabethton. These lower beds are mainly dolomite in layers 1 to 5 feet thick, some massive and others laminated. They also include much shale, mainly as partings between the dolomite layers, but in increasingly thick layers downward toward the Rome formation. In fresh outcrops the dolomite appears only slightly cherty, but chert nodules are moderately abundant on weathered slopes south of Elizabethton.

The middle of the formation is apparently largely slabby light-gray dolomite and limestone with argillaceous ribs and ribbons, and sporadic shaly partings. This part is more susceptible to weathering and solution than parts below or above; it crops out on lower ground and for long distances along the strike has been cut into sinkhole topography.

Near the top, beneath the Nolichucky shale, are many thick beds of dark-gray to black fetid finely crystalline dolomite, which project as rounded ledges on the north slope of Bryant Ridge south of Elizabethton. Keith (1907, p. 7) noted that

Just below the top of the formation are from 25 to 50 feet of a peculiar gray limestone [dolomite] that in many places is seamed with calcite and weathers into knots or balls which are noticeably round. These layers are also sandy in many places, a fact which appears plainly on weathered surfaces.

The supposed "sandy" character probably originates from granular disintegration of the crystalline dolomite. These beds probably correspond to the upper 250-foot unit of the Honaker in the section described by Rodgers (1953a, p. 52).

NOLICHUCKY SHALE

Overlying the Honaker dolomite near Elizabethton are 200 to 250 feet of shaly rocks that probably correspond to the Nolichucky shale. The formation occurs on both flanks of the Stony Creek syncline. Best exposures are to the north near the crest of Bryant Ridge, and along Gap Creek at the west end of the ridge, near Big Spring (section 33, p. 125). On the southeast flank, where dips are steeper and the outcrop narrower, the formation is difficult to recognize although shale layers at the appropriate position were noted in a few road cuts.

Beds of truly argillaceous shale make up relatively little of the Nolichucky. They are prominent at the base, corresponding to part of the basal 150-foot layer in Rodgers' section (1953a, p. 52). At Big Spring, three shale beds were seen, each lying with abrupt contact on underlying limestone and grading upward into fairly solid limestone through interbedded shale and thin-bedded limestone; the same cycle is thus repeated three times. The lowest bed, resting on the Honaker, is 30 feet thick and is dull greenish fissile clay shale containing oboloid brachiopods and other more fragmentary fossils on bedding surfaces. The higher shale beds are thinner and more calcareous. The argillaceous content of the formation is emphasized by weathering; on weathered outcrops both shale and shaly limestone beds appear shaly, and both give rise to yellow or brown shale chips in the soil.

The upper half of the formation consists largely of limestone beds a few inches to several feet thick containing many silty or shaly laminae a fraction of an inch to several inches apart, which project as ribs or ribbons on weathered surfaces; some more granular limestone beds contain fossil fragments. These upper beds probably correspond to the Maynardville limestone member of other areas in the Appalachian Valley. They are overlain with fairly abrupt contact by thicker limestone beds of the Concococheague.

FOSSILS AND AGE

During this study, fosils were seen in the Big Spring section in the upper part of the Honaker and in the shale and limestone of the Nolichucky, the best preserved being oboloid brachiopods on the bedding surfaces of the shale. Diagnostic fossils could no doubt be obtained here at several horizons by thorough collecting. No fossils were seen in most of the Honaker or in the Elbrook, which are very sparsely fossiliferous throughout the southern Appalachians.

The most abundant fossils in the Conasauga group, which establish its age, occur in the intertonguing shale and limestone facies, of which the Nolichucky shale is the sole local representative. The fauna of most of the group is of Middle Cambrian age, but that of the Nolichucky shale and Maynardville limestone is of Late Cambrian age. Occurrence of fossils in the group has been summarized by Resser (1938, p. 26–30) and Butts (1940, p. 67–87).

CAMBRIAN AND ORDOVICIAN SYSTEMS

KNOX GROUP (UPPER CAMBRIAN AND LOWER ORDOVICIAN)

In Tennessee the thick body of upper Cambrian and Lower Ordovician carbonate rocks has long been known as the Knox dolomite (Safford, 1869, p. 204). This has now been subdivided into various formations whose mutual relations are indicated by Rodgers (1953a, table 5, p. 56), but their general kinship justifies retention of the name Knox group.

In the southeastern part of the Appalachian Valley, where the carbonate rocks are dominantly limestone, many of the subdivisions distinguished farther northwest are no longer recognizable, but the beds of Late Cambrian age are still separable from those of Early Ordovician age. These are termed, respectively, the Conococheague limestone (Stose, 1908, p. 701–703) and the Jonesboro limestone (Ulrich, 1911, p. 671–672).

Within the region of this survey the Knox group is fully exposed only in Denton Valley to the north (pl. 1), where it is about 3,900 feet thick, of which 2,200 feet belongs to the Conococheague and 1,700 feet to the Jonesboro. The only other extensive exposure is to the southwest, beyond Elizabethton, where the basal Conococheague is preserved in the trough of the Stony Creek syncline; the full section of the Knox overlies this southwest of the map area, but was not examined.

CONOCOCHEAGUE LIMESTONE

In Denton Valley (section 34, p. 126), the Conococheague limestone is marked at the base by four or five layers, each as much as 6 feet thick, of coarsely crystalline black fetid dolomite that form massive dark ledges; they closely resemble beds in the upper part of the Honaker dolomite of the Elizabethton area and beds in the lower part of the Copper Ridge dolomite of sections farther northwest.

The upper few hundred feet includes four or more sandstone beds, 1 or 2 feet thick, containing rounded quartz grains, generally crumbled by weathering because of removal of the original calcareous cement. These beds have been located at many places entirely across Denton Valley and are the most readily recognizable marker beds in the carbonate sequence there. The sandstone beds are associated with limestone that contains conspicuous crinkled argillaceous laminae or ribbons, a few inches apart, that project as ribs on weathered surfaces. Embedded in the limestone are large *Cryptozoon* reefs. These upper beds closely resemble the characteristic Conococheague limestone farther northeast in Virginia.

The remainder of the formation is less distinctive than the top and base, and consists of limestone and dodomite in beds a few feet thick, generally laminated within the beds, but with few or no argillaceous layers. Parts of the Conococheague limestone in Denton Valley are slightly cherty, and the basal beds in places yield large masses of porous slaggy chert.

The lower part of the Conococheague limestone is preserved in the synclinal trough south of Elizabethton, where it lies nearly horizontal and projects in low knobby hills, which are without systematic pattern and are separated by innumerable sinks. Less than 1,000 feet is preserved within the map area. The lower part of the Conococheague here has fewer distinctive features than that in Denton Valley. One of the best exposures south of Elizabethton is in a quarry on the east side of Gap Creek a mile south of Big Spring, where beds of limestone a few feet thick have argillaceous and dolomitic laminae and interbedded layers of dolomite and shaly limestone. Elsewhere there are some thicker, more massive dolomite beds, and some limestone beds with more prominent argillaceous laminae or ribbons. In places large chert nodules are embedded in the rock or lie on the weathered surfaces.

JONESBORO LIMESTONE

The Jonesboro limestone is fully exposed in Denton Valley, but its top crops out farther southwest in a small anticline at the foot of Holston Mountain between Underwood Springs and Webb Springs. It also crops out extensively immediately northwest of the map area, beyond the South Fork of the Holston River and South Holston Lake. Only the section in Denton Valley was critically studied by the senior author.

In Denton Valley (section 34, p. 126) most of the formation consists of gray to blue-gray limestone in beds a few feet thick, with some interbedded layers of dolomite of about the same thickness. Many of the limestone beds contain thin laminae, in part straight, in part crinkled; toward the base these laminae are marked by increasingly prominent argillaceous ribbons like those in the Conococheague limestone below.

The upper few hundred feet of the formation is mainly dolomite in beds 1 to 5 feet thick, some blue gray and compact, and some light gray, glistening, and thoroughly crystalline. Chert is sparse in the Jonesboro, but is perhaps somewhat more abundant in these upper beds. The upper beds of the Jonesboro closely resemble the Mascot dolomite, which forms the top of the Knox group in belts farther northwest; the crystalline dolomite is similar to the so-called "recrystalline" dolomite of that area.

In the area northwest of South Holston Lake the Jonesboro is reported to be 1,000 to 1,200 feet thick (Tennessee Valley Authority Geologic Branch, 1949, p. 361). In this area it consists of—

> blue-gray, massively bedded, mottled dolomite and magnesian limestone. Zones of shaly and sandy limestone are present throughout the outcrop area but are most common near the top of the formation. Bands of conglomerate with well rounded pebbles occur throughout the formation as deep drilling at the saddle dam [of South Holston Lake] indicates. These bands are composed predominantly of limestone pebbles, but some subangular chert fragments are also present.

RELATIONS OF THE KNOX GROUP TO OVERLYING ROCKS

The top of the Jonesboro limestone was observed by the senior author only in a road cut on the northeast side of Cox Creek at the north edge of Denton Valley, where thick-bedded gray dolomite of the upper part of the Jonesboro is overlain, with slightly irregular contact, by a 1-foot bed of granular clastic limestone that forms the base of the Lenoir limestone.

Elsewhere, thicker conglomerate beds are reported to lie on the Knox and to form the base of the overlying succession. At the saddle dam of South Holston Lake southwest of Denton Valley, these are 12 to 15 feet thick and consist of rounded to subangular limestone and chert pebbles (Tennessee Valley Authority Geologic

Branch, 1949, p. 361). Keith (1907, p. 7) reports "a breccia or angular conglomerate of limestone" in the same position still farther southwest, 4 miles east of Bluff City.

In northeasternmost Tennessee the contact between the Knox group and the overlying beds is probably an erosional unconformity, although this is not everywhere conspicuous. This unconformity, in places marked by deep erosion but without angular discordance, forms the summit of the Knox group throughout Tennessee, Virginia, and adjacent states (Butts, 1940, p. 119: Rodgers, 1953a, p. 59–60; Bridge, 1955, p. 729–730).

FOSSILS AND AGE

Fossils were not collected from the Knox group during this survey. Their occurrence and character in Virginia have been discussed by Butts (1940, p. 89–90, 95, 100–101, 116–119) and in Tennessee by Oder (1934). The lower part of the Knox, or Conococheague and its equivalents, is of Late Cambrian age. The upper part, or Jonesboro and its equivalents, is of Early Ordovician age, and corresponds to the Beekmantown of New York.

ORDOVICIAN SYSTEM

MIDDLE ORDOVICIAN SERIES

GENERAL FEATURES

The Middle Ordovician series occupies a wide belt of knobby, timbered hills along the southeastern edge of the Appalachian Valley between the South Fork of the the Holston River and the base of Holston Mountain, along the whole northwest edge of the map area (pl. 1). The rocks are folded into a synclinorium in which the thickness of beds above the Knox group has been estimated by Butts (1940, p. 165) to be 5,000 to 10,000 feet, and by Kellberg and Grant (1956, p. 701) to be 5,000 to 8,000 feet; these geologists point out, however, that no reliable section can be measured, owing to the complex structure. Decker (1952, p. 38–39) questions these great thicknesses, but he examined only the thinner sections of Middle Ordovician rocks near Bristol farther northwest. The structure sections of plate 17 seem to require at least 5,000 feet of Middle Ordovician rocks between the South Fork of the Holston River and Holston Mountain. Farther northwest toward Bristol, beyond the map area, narrower belts of Middle Ordovician rocks alternate with belts of limestone of the Knox group, and represent lesser synclines in which only the lower part of the sequence is preserved.

This great body of rocks has been variously classified, as indicated in the following table.

Classification of rocks of Middle Ordovician series near South Holston Lake, according to usage by various authors

Campbell (1899) and Keith (1907)	Butts (1940)	TVA reports (1949)	This report
Tellico sandstone	Athens formation (sandstone facies)	Tellico sandstone	Upper unit of sandstone, shale, and conglomerate
Athens shale		Athens shale	Lower unit of shale
(Not recognized)	Lenoir limestone	Stones River (Chicamauga) group	Lenoir limestone

No specific names are given the units above the Lenoir limestone in this report because they are not entirely comparable to facies of the Middle Ordovician rocks in other areas. The Middle Ordovician series is being studied, moreover, by many geologists who are revising its terminology. The shale beds overlying the Lenoir limestone are much like graptolite-bearing shale that has been called Athens elsewhere (Decker, 1952, p. 28–45), but they are lithologically different from the Athens shale at its type locality. The sandstone beds differ greatly from the type Tellico (Neuman, 1955, p. 154–155) and may have had a different origin and age. The extension of the term Athens by Butts to encompass the whole post-Lenoir sequence was probably based on the occurrence of Athens or Normanskill type graptolites throughout. But under proper facies conditions the graptolites might have a wider range.

Only random observations on the rocks of the Middle Ordovician series were made during this survey, and much of the following description is based on work by geologists of the Tennessee Valley Authority (Tennessee Valley Authority Geologic Branch, 1949, p. 357–362; Kellberg and Grant, 1956, p. 700–705). Representation of the series on the geologic map (pl. 1) is based on a map of the South Holston Lake area made by McGavock and Finfrock in 1942. This map appears to be very accurate near South Holston Dam and elsewhere along the northwest side of the outcrop belt, but farther southeast, toward Holston Mountain, where reconnaissance methods of mapping were used, there are discrepancies with later spot observations by Kellberg and Grant and by the senior author. These later observations suggest, for example, that near Lucy and Fishdam Creeks the synclinal axis may lie about a mile farther southeast than mapped. As the later work did not suffice for revising the whole area, it has seemed best to retain the earlier representation on the geologic map (pl. 1) as giving at least a general view of geologic relations.

LENOIR LIMESTONE

The Lenoir limestone, or initial unit of the Middle Ordovician series, is so thin and has been definitely identified at so few places that it is not feasible to represent it on the geologic map (pl. 1). Accordingly it is not differentiated from the rocks above, although it probably occurs everywhere along the basal contact.

The Lenoir limestone is well exposed on the county road on the northeast side of Cox Creek at the north edge of Denton Valley, where it is 40 feet thick (section 34, p. 126). At the base, resting on the Knox, is a thin granular clastic limestone; this is overlain by blue-gray compact limestone that passes in turn into gray cobbly limestone, both crowded with fragments of trilobites and brachiopods. The limestone beds are overlain by shale, with which they have a sharp but probably conformable contact.

Near the old crossing of the South Fork of the Holston River on U. S. Highway 421, about a mile northeast of the present highway, Butts (1932, p. 84) observed 25 feet of Lenoir limestone, but McGavock and Finfrock record nearly 200 feet near the saddle dam of South Holston Lake nearby. (See Tennessee Valley Authority Geologic Branch, 1949, p. 261).

> Here the formation is made up of light to dark gray beds of fine-grained, nodular, argillaceous limestone. It is so uniformally fine-grained in some localities that it resembles a lithographic limestone. Although not common, dolomitization of some of the limestone has taken place to a limited extent. The basal beds of the formation consist of a conglomerate from 12 to 15 feet thick, composed of rounded to subangular fragments of limestone and chert in a limestone matrix.

The contact with the shale above is sharp but conformable. The formation is sparsely fossiliferous on the whole, although some layers contain large numbers of brachiopods. Butts notes the occurrence of *Maclurea magna.*

Farther south, on the anticline between Webb Springs and Underwood Springs, L. C. Craig reports that the basal beds of the Middle Ordovician series are black fissile shale overlain by gray or black, thin-bedded fossiliferous limestone; these are overlain by the main shale body. The relation of these beds to the Lenoir at other localities is uncertain.

LOWER UNIT OF SHALE (ATHENS SHALE OF REPORTS)

The lower unit of shale crops out in a long narrow belt on the northwest flank of the synclinorium of Middle Ordovician rocks, which lies northwest of South Holston Lake south of U. S. Highway 421, and southeast of it to the north (pl. 1). Similar shale crops out on the southeast flank of the synclinorium, near the foot of Holston Mountain, but is much obscured by wash from the Chilhowee group on the mountain. South of Morrill Creek and the Cross Mountain fault only the lower shale unit is probably present in the Middle Ordovician area.

Keith (1907) gives a thickness of 800 to 1,600 feet for the unit in the Roan Mountain quadrangle, but McGavock and Finfrock (Tennessee Valley Authority Geologic Branch, 1949, p. 360) state that it apparently ranges between 200 and 5,000 feet. On Virginia State Route 672 south of Avens Bridge, 2,300 feet of the shale was observed, without sandstone interbeds. Decker (1952, p. 39) measured 1,760 feet of shale farther northwest near Bristol but included some of the overlying sandstone. In the Great Knobs south of Abingdon, Va., not far northwest of the map area, Butts (1940) reports sandstone beds 200 feet above the base. These extreme variations in thickness may in part be due to duplications by folding or to tectonic thickening and thinning. In large part, however, they must result from the fact that the contact between shale below and sandstone above is not at a constant stratigraphic level, and that the two rocks interfinger along the strike.

The shale is characteristically olive green to black, indurated, thinly fissile, and platy. Some bedding surfaces are coated with fine-grained detrital mica, and some of the rock contains pyrite. The shale is remarkably uniform over wide areas and through great thicknesses, but grades into the coarser clastic rocks laterally and upward, and in the upper part sandstone layers of various thicknesses are interbedded. The shale is much contorted, thrown into small folds, and broken by minor faults. In places it contains a weak cleavage and breaks in pencillike fragments.

Butts (1932, p. 84) has collected Athens or Normanskill type graptolites from the basal part of the shale at the old crossing of U. S. Highway 421 over the South Fork of the Holston River, and also from shale outcrops on the same highway to the southeast, 200 feet below the Holston Mountain fault. A large graptolite fauna has been collected by Decker and others from the same unit in a belt farther northwest, along Steeles Creek 3 miles southwest of Bristol (Decker, 1952, p. 39–45).

UPPER UNIT OF SANDSTONE, SHALE AND CONGLOMERATE (TELLICO SANDSTONE OF REPORTS)

GENERAL FEATURES

The upper unit occupies the deeper part of the trough of the synclinorium, forming a belt 3 miles broad near U. S. Highway 421, but narrowing to scarcely half a mile farther north, on Cox Creek north of Denton Valley. The unit may be cut off against the Cross Mountain fault to the southwest; if present beyond it is only as small remnants not differentiated on the geologic map (pl. 1).

McGavock and Finfrock (see table below) recognized four subdivisions of the unit near South Holston Dam and have mapped the subdivisions elsewhere, as shown on the map (pl. 1). The mapping represents, however, a generalization of complexly interfingering beds; according to Kellberg and Grant (1956, p. 701)

along the axis of South Holston Dam, where a complete section was uncovered for a distance of 1,700 feet, the lithologic changes were so great and so rapid that detailed correlation of cores recovered from holes spaced on 12-foot centers was extremely difficult.

Section of upper unit of sandstone, shale, and conglomerate near near South Holston Lake

[After McGavock and Finfrock, 1943. Figures represent thicknesses assumed by the senior author in in constructing the structure sections on plate 10]

	Approximate thickness (feet)
Top of section; no higher beds exposed.	
Upper unit of sandstone, shale, and conglomerate:	
4. Upper shale	500
3. Upper sandstone; similar to lower sandstone	500
2. Middle shale, containing some sandstone beds	1, 200
4. Lower sandstone, containing 2 to 40 percent shale	1, 200
Lower unit of shale, at base of section.	

SANDSTONE AND SHALE

The sandstone makes strong ledges, and the lower sandstone division forms the crest of The Knobs, a prominent range of hills northwest of South Holston Lake; other beds form similar high ridges farther southeast. The sandstone is medium to coarse grained, and the freshly fractured surfaces are compact, hard, and blue gray to greenish gray. Some beds are massive and 5 feet or more thick, others are thinner and interbedded with irregularly distributed layers of shale, a few inches to 60 feet thick. The shale beds are thin and platy, and generally more silty or sandy than those in the underlying unit; Butts reports that some of them contain graptolites.

Butts (1940, p. 163–164) terms the sandstone an arkose, but although the feldspar content may locally be considerable, it is mostly subordinate, and quartz grains are dominant. There is, however, a considerable variety of small rock fragments. The sandstone is more properly a graywacke, and has the characteristic poorly sorted, "dirty" aspect of this type of sandstone.

Two specimens of the sandstone, from Cox Creek between Denton Valley and Avens Bridge (specimen 0–1–A), and from U. S. Highway 421 on Lucy Creek, 2¼ miles east of the bridge over the reservoir (specimen O–3–A), were examined in thin section by Warren Hamilton, who reports as follows:

Both specimens are very poorly sorted and contain fragments, mostly of quartz and limestone, in a matrix of chlorite, sericite, and calcite. The rock fragments range from fine sand to granules. Bedding is shown by orientation of tabular fragments.

The quartz grains are mostly from single crystals, slightly strain-shadowed, presumably from igneous or high-grade metamorphic rocks. Some are vein quartz, and some are metaquartzite. A few of the quartz grains show slight marginal recrystallization, but most retain their detrital shapes; many are slightly elongate, but not as a result of deformation.

The dominant rock fragments are gray microcrystalline calcite limestone, some containing tiny quartz grains and others composed in part of calcite spheriods. There are also a few small fragments of dark siltstone and very fine sandstone.

Grains of sodic or intermediate plagioclase make up a few percent of each slide; orthoclase is present but much less abundant. Both specimens contain traces of detrital biotite, apatite, and zircon. Magnetite makes up 1 percent of the rocks and is mostly detrital.

The groundmass of the sandstones has been partly altered to form crystalline calcite and small grains of sericite and chlorite, the latter probably imparting the greenish tinge to the rock. Secondary minerals in the groundmass have no consistent orientation.

CONGLOMERATE BEDS

The most remarkable rock in the upper unit is the conglomerate, although it forms relatively thin, lenticular beds that make up only a small part of the volume of the unit. The conglomerate beds were first noted by Campbell (1899, p. 3–4) and have been described in more detail by Kellberg and Grant (1956, p. 702–705) from whom part of this account is derived. Thicker conglomerate layers are shown on the geologic map where they were observed (pl. 1), but thinner and finer grained conglomerate beds are widespread.

The conglomerate beds do not lie at any definite stratigraphic position, but occur intermittently through the section. In rockfill and aggregate quarries opened during construction of South Holston Dam, conglomerate beds occur at the base of the upper unit and 960 feet above the base. On Virginia State Route 672 south of Avens Bridge they are 700 feet above the base. Drill holes put down during construction of the bridge of U. S. Highway 421 over South Holston Lake entered conglomerate 1,500 feet above the base of the upper unit. Other outcrops, near the junction of Sulphur Spring Branch and the North Fork of Fishdam Creek, and on U. S. Highway 421 on Lucy Creek, apparently lie near the top of the section, close to the axis of the synclinorium.

In the rockfill and aggregate quarry half a mile below South Holston dam, a conglomerate bed is 30 feet thick and includes quartzite cobbles a foot in diameter, but thins out and disappears within 900 feet along the strike. In the outcrops near the junction of Sulphur Spring Branch and the North Fork of Fishdam Creek several beds of conglomerate occur in a stratigraphic interval of 70 feet and contain quartzite boulders 18 inches in diameter; the beds wedge out in short distances, show great variation in grain size, and penecontemporaneous deformational features. On Virginia State Route 672 south of Avens Bridge as many as seven conglomerate layers, each 3 to 5 feet thick, are interbedded in the sandstone in 50 feet of section, some closely spaced and merging, others widely separated. They appear to be the coarse bottom layers of the sandstone beds, like graded beds in graywacke of other regions.

The typical conglomerate consists of poorly sorted fragments with various degrees of rounding, made up of about 80 percent limestone and 10 percent quartzite, with minor amounts of siltstone, vein quartz, chert, and other rocks. They are closely packed in a matrix of gray green slightly calcareous sandstone or silty shale, full of fine rock fragments. Freshly fractured surfaces break across pebbles and matrix alike, and both have much the same color, but they are prominently differentiated on weathered surfaces where the matrix acquires a brown crust and the limestone pebbles are recessed by solution.

Study of the fragments by Kellberg and Grant suggests that they were derived from most of the older formations of the stratigraphic column. They recognize chert and fossiliferous limestone from the Lenoir, limestones of various types like those in the Jonesboro, Conococheague, and Honaker, red and green siltstone from either the Nolichucky or Rome, quartzites from the Erwin and Unicoi, and greenstone derived from volcanic rocks of either the Unicoi or the Mount Rogers group.

One outcrop observed by the senior author in a highway cut on Lucy Creek, 2¼ miles east of the bridge over South Holston Lake, differs somewhat from the others and deserves special description. The strata here dip at low angles and probably are high in the sequence. Lying between well-bedded sandstone and shale is a layer of massive, poorly sorted siltstone or fine sandstone, 10 feet thick, that contains many small rock fragments and widely spaced, well-rounded cobbles and boulders of quartzite and limestone as much as a foot in diameter (fig. 10). Where the structures are visible in the layer they are tumbled, contorted, and chaotic; occasional lenticular streaks of bedded sandstone and argillite dip at all angles and in places are thrown into recumbent folds. Toward the west end of the exposure the massive layer interfingers abruptly with well-bedded deposits. This massive siltstone with sparse cobbles seems to have been transported as a highly viscous, doughy aggregate and deposited as a mass in its present position.

Two specimens of conglomerate were studied in thin-

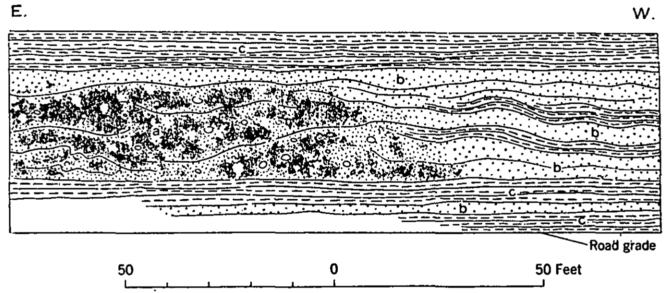

FIGURE 10.—Sketch showing clastic rocks of Middle Ordovician series exposed in a cut on U. S. Highway 421, near Lucy Creek, 2¼ miles east-southeast of bridge over South Holston Lake. *a*, Massive bed of poorly sorted siltstone full of small rock fragments and containing dispersed rounded cobbles of foreign rocks. *b*, Even-textured, medium-grained sandstone. *c*, Fissile argillaceous shale.

section by Warren Hamilton. One (specimen O–3–B) came from a thin layer in sandstone in the highway cut on Lucy Creek from which sandstone specimen O–3–A was collected. According to Hamilton this is:

A fine conglomerate, containing abundant small rock fragments, mostly limestone, embedded in a greenish-gray sandy matrix; the matrix in turn consists of quartz sand and of sand-sized limestone fragments, embedded in calcite, chlorite, sericite, and argillaceous material. The quartz grains are subangular to subrounded, and mostly 0.02 to 0.50 millimeters in diameter, but some, apparently derived from vein quartz and quartzite, are as much as 5 millimeters in diameter. The rock fragments are mostly gray or buff limestone, equidimensional to elongate, ranging from fine sand to as much as 5 millimeters in diameter; there are also a few dark siltstone fragments. The matrix consists dominantly of calcite, which makes up about 30 percent of the rock, but much unoriented secondary chlorite is also present, as well as smaller quantities of sericite and argillaceous material.

A specimen of the massive siltstone layer that contains the sparse large cobbles (specimen O–2), collected from a road cut a few hundred yards to the east is described as follows:

A gritty gray-green siltstone, consisting of subangular to subrounded grains of quartz and rock fragments in a matrix of silt and argillaceous material. It differs from the other specimens described only in having 50 percent of matrix. Quartz grains are mostly less than 1 millimeter in diameter, but some are as large as 2 millimeters; some limestone fragments are slightly larger. In thin section, calcite is less evident as matrix material than in the other specimens, but it is indicated by reaction of the rock to acid.

ORIGIN OF THE UPPER UNIT

As pointed out by Campbell (1899, p. 3–4), the upper unit must have been laid down not far from land to the southeast, in which rocks older than the Middle Ordovician series were exposed. This land evidently extended widely in the southeastern part of the southern Appalachians in Middle Ordovician time, as conglomerate beds have been observed as far northeast as Fincastle, Va., and as far southwest as Cisco, Ga.

(Butts, 1940, p. 159; Kellberg and Grant, 1956 p. 697). The land must have resulted from tectonic movements, as the limestone fragments so abundant in the conglomerate would have remained buried many thousands of feet if not uplifted within reach of erosion. The quartzite, probably derived from the Chilhowee group and the possibly still older rocks, indicates local uplifts high enough to erode all the limestone. Whether the vein quartz pebbles and the feldspar and other mineral grains were derived directly from an exposed plutonic and metamorphic terrane, or secondarily from earlier clastic sediments, has not been determined.

The tectonic structures of these uplifts are probably not the same as any now visible in the sedimentary rocks of the region. Most and perhaps all the folds and faults were produced long after Middle Ordovician time, as the Middle Ordovician rocks are folded equally with the rocks beneath, and are overriden by one of the major low-angle thrusts, the Holston Mountain fault. It is true that the Middle Ordovician series throughout the Appalachian Valley lies unconformably on the Knox group, but where the contact is preserved this unconformity involved only erosion of the underlying beds, and not tilting and folding.

However, as indicated in Hamilton's report on the basement rocks, radioactive age determinations on the pegmatites of the Spruce Pine district, in North Carolina to the southeast, suggest that these were injected between 310 and 370 million years ago, or probably in Ordovician time; Hamilton also suggests that regional cataclasis in the basement rocks occurred slightly earlier during the same epoch of disturbance; emplacement of pegmatites and regional cataclasis may well have been deep-seated manifestations of the same movements that gave rise to the coarse sandstone and conglomerate deposits of the Middle Ordovician series farther northwest.

Butts (1940, p. 159) interpreted the coarse Middle Ordovician deposits as alluvial cones or deltas along the edge of the uplifted land, but in northeasternmost Tennessee they do not have features one would expect in the topset beds of delta deposits, such as crossbedding, lenticular channel fillings, and alternations of marine, brackish water, and continental sediments. Instead, they seem more probably to have been laid down in the deeper parts of a subsiding trough. They were perhaps derived from the tectonic land secondarily, having first accumulated near shore in deltas or otherwise, and later been carried down the slope and spread out in the trough with the aid of turbidity currents.

This origin is particularly compelling for the massive siltstone beds with sparse rounded cobbles exposed on Lucy Creek. The cobbles were clearly rounded in streams or on beaches, but the siltstone enclosing them could have been laid down in no such environment. In comparable sediments in the Jurassic, Cretaceous, and Pliocene of California the origin can be more clearly discerned (Crowell and Winterer, 1953, p. 1502); there "beds of graded conglomerate, laid down on soft water-saturated mud, became unstable and slumped down-slope, mixing the pebbles with the mud." The resultant mixture then moved as a mass, and settled on the bottom in deeper water.

It is true that deposits like those on Lucy Creek form a relatively small part of the mass of the upper unit of the Middle Ordovician series; most of the conglomerate contains more closely packed pebbles and cobbles, and the conglomerate beds themselves are subordinate to the sandstone beds. Nevertheless, these deposits probably formed in a similar environment, although perhaps by slightly different processes. The petrographic similarity between the conglomerate and sandstone, and the abundance of rock fragments in each, indicates that the conglomerate beds do not represent abnormal episodes, but are merely extreme textural variants of the sandstone, into which they grade. Some represent the bottom parts of graded beds, like those in graywacke elsewhere. Here again, some form of turbidity current may have spread each layer of sediment over the floor of the trough.

TECTONICS

STRUCTURAL UNITS

Northeasternmost Tennessee is a segment of the Unaka province and shares with many other parts of that province a dominance of the older rocks of the sedimentary column, the presence of plutonic and metamorphic basement rocks, and of great low-angle thrust faults that have been warped.

The region is divisible into four structural units along the emerging traces of three major low-angle faults—the Holston Mountain, Iron Mountain and Stone Mountain faults (pl. 16). Northwest of the Holston Mountain fault is the Appalachian Valley. Between the Holston Mountain and Iron Mountain faults are Holston Mountain, the Iron Mountains, Shady Valley and Stony Creek valley (pl. 2); these form the Shady Valley thrust sheet, whose center has been downwarped into the Stony Creek syncline. Between the Iron Mountain and Stone Mountain faults are Johnson County cove, Doe River cove, and the Stone Mountains, which together comprise the Mountain City window. Southeast of the Stone Mountain fault are the basement rocks of the Blue Ridge province.

The Holston Mountain and Stone Mountain faults dip southeast, but the Iron Mountain fault dips northwest—an attitude unusual for a major fault in the Appalachians. All three faults appear to be parts of a single system of displacement, a relation which is most evident in the northeast part of the region (section 1, pl. 17). The Iron Mountain fault thus probably connects with the Holston Mountain fault beneath the Shady Valley thrust sheet and, before erosion, was connected with the Stone Mountain fault across the Mountain City window. Two of the four structural units, the Shady Valley thrust sheet and Blue Ridge province, overlie the system of faults; the other two, the Appalachian Valley and Mountain City window, underlie it.

APPALACHIAN VALLEY

The general structure of the Appalachian Valley in Virginia and Tennessee has been set forth by Butts (1940, p. 436–468) and Rodgers (1953a, p. 126–239), but the present report is concerned only with a narrow segment of the southeastern edge lying immediately northwest of the Holston Mountain fault. This segment is made up of folded Cambrian and Early Ordovician carbonate rocks and of Middle Ordovician clastic rocks; structurally it consists of two units. From Denton Valley northeastward the rocks are steeply tilted into a homocline whose sequence is upward to the northwest, away from the Holston Mountain fault (pl. 1). Southwest of Denton Valley, the rocks are downfolded into a synclinorium that preserves an extensive body of Middle Ordovician clastic rocks.

THE HOMOCLINE

Only the southwest end of the homocline lies within the map area; it extends far northeastward into Virginia. Near Damascus at the north edge of the map area the Chilhowee group and Shady dolomite appear along the mountain front at the base of the homocline (section 1, pl. 17), but these lie under the Holston Mountain fault southwestward, where the Rome and Elbrook are the lowest formations exposed. The homocline may represent the northwest flank of an anticline, whose crest is concealed beneath the Shady Valley thrust sheet (fig. 21). The summit of the homocline is 2 or 3 miles northwest of the mountain base, where Middle Ordovician rocks are downfolded in a series of narrow synclines. Along Laurel Creek west of Damascus the rocks of the homocline stand vertical, but farther southwest they dip at diverse angles and are evidently thrown into obscure folds.

DENTON VALLEY

The homocline ends southwestward in Denton Valley, a quadrilateral area 2 miles across, athwart the Virginia-Tennessee boundary, the rocks of this valley being offset to the northwest with respect to those of the main homocline. They are separated from both the homocline to the northeast and the synclinorium to the southwest by nearly vertical transverse faults trending west-northwest, which must possess considerable components of strike-slip displacement. These faults have a complex relation to the Holston Mountain fault on the southeast (p. 64–65).

As in the main homocline, the sequence in Denton Valley begins at the mountain base with the Rome formation and extends northwestward through the carbonate formations into the Middle Ordovician clastic rocks. At the northeast end of the Denton Valley block, the beds are steeply tilted northwestward, without reversals. Southwestward along the strike, the dip steepens and in the southwest part of the block the whole section is overturned (sec. 11, pl. 17). Minor strike faults occur at the southwest end of the block; one thrusts Rome formation over Conococheague limestone and another thrusts Jonesboro limestone over the lower shale of the Middle Ordovician; the Elbrook dolomite and Lenoir limestone have been cut out by the faulting. At the southwest end of the Denton Valley block, at the terminus of the homocline, there must have been greater frictional resistance to northwestward movement than at the northeast end, so that this part of the block was more compressed.

Beyond the cross fault at the southwest end of Denton Valley, carbonate rocks of the Knox group are exposed in a small area near Harr, dipping at a low angle southeastward away from the lower shale of the Middle Ordovician, and dipping beneath shales on the southeast. The structure of this area is puzzling. On the geologic map and section (pl. 1; section 12, pl. 17) the Knox is shown as thrust over the shale on the northwest and passing conformably beneath the shale on the southeast, but some field observations suggest a different possibility. That part of the Knox group on the northwest resembles the Jonesboro and that on the southeast the Conococheague, implying that the rocks are overturned, as they are at the west end of Denton Valley. The Knox and the shale on the southeast are discordant at many places as though the two units are in fault contact.

THE SYNCLINORIUM

Southwest of Denton Valley the Middle Ordovician rocks crop out in a belt 5 miles or more wide between Holston Mountain and South Holston Lake. These rocks form a synclinorium whose deepest trough lies several miles from the mountain base (sections 13 to 21, pl. 17). The synclinorium is probably equivalent to the narrow synclines of Middle Ordovician rocks on the northwest flank of the homocline farther north, but the synclinorium is broader and deeper, and it is displaced southeastward toward Holston Mountain relative to the homocline along the transverse fault at the southwest end of Denton Valley.

Along the northwest flank of the synclinorium, shale and sandstone of the Middle Ordovician series dip regularly southeastward at angles of about 45° away from carbonate rocks of the Knox group that project in an anticline beyond the river. In the interior of the synclinorium the sandstone beds dip steeply and irregularly, and the interbedded shale is highly contorted and broken by minor faults. Details of the structure are incompletely known, but general relations have been determined by the reconnaissance of McGavock and Finfrock. The lower shale reappears to the southeast along the foot of Holston Mountain, on the opposite flank of the synclinorium.

About 6 miles south of U.S. Highway 421, a large transverse fault—the Cross Mountain fault (p. 68)—extends westward into the synclinorium from Holston Mountain. The fault has not been traced through the Middle Ordovician series but may be inferred from offsets in the rocks farther west that resemble offsets on Holston Mountain. Apparently the Cross Mountain fault terminates the deeper part of the synclinorium on the south, as the upper sandstone of the Middle Ordovician series appears to end against it, with little more than the lower shale preserved beyond.

HOLSTON MOUNTAIN FAULT

The Holston Mountain fault (Stose and Jonas, 1938, p. 23) extends for 30 miles across the northwest part of the map area (pl. 1), and far beyond to the northeast and southwest (pl. 16). Through much of the region it follows the base of Holston Mountain, the lower part of the Chilhowee group forming escarpments on the mountain behind it, and Paleozoic rocks as high in the sequence as the Middle Ordovician series forming the Appalachian Valley in front of it. Maximum stratigraphic displacement is thus nearly the whole sedimentary sequence exposed in the region, and marks the fault as of the first order of magnitude.

OUTCROPS OF THE FAULT

Throughout much of its course the fault is concealed by wash from the escarpment behind, but the outcrop pattern of the adjacent rocks indicates that it dips southeast, probably mostly at angles of less than 45°. The actual surface of the fault is exposed at two places.

On U. S. Highway 421 at the southwest end of Delaney Mountain the fault is visible in road cuts for several hundred feet and dips at an average angle of 30° to the southeast (fig. 11). Shale and silty sandstone, at or just beneath the base of the upper division of the

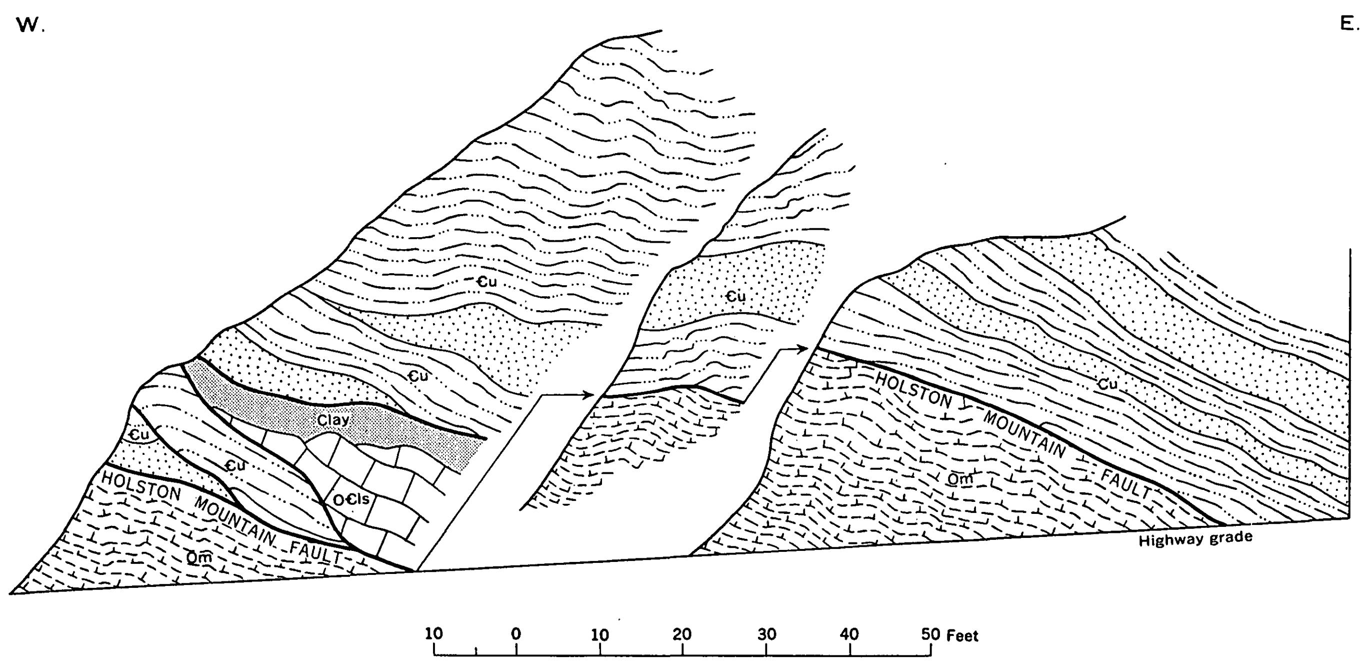

FIGURE 11.—Sketch showing outcrop of the Holston Mountain fault in cut on U. S. Highway 421 at the southwest end of Delaney Mountain. Note the wedge of limestone along the fault at the left. This cut trends for some distance parallel to the strike of the fault; in the sketch, different parts of the cut are projected into a plane nearly parallel to the dip of the fault. Cu—Unicoi formation (shale and sandstone); COls—limestone of uncertain stratigraphic position, probably either Conococheague or Jonesboro limestone, overlain by pink saprolitic clay, probably weathered from the limestone; Om—Middle Ordovician series (shale).

Unicoi formation, override shale of the lower unit of the Middle Ordovician series. At one point along the fault is a slice of limestone 30 feet long and 10 feet thick, probably derived from some part of the Knox group. Both overriding and overridden rocks are only moderately contorted and sliced, and the fault itself is smooth, clean cut, and without brecciation or gouge. Drag folds in the sandstone of the Unicoi formation several hundred feet southeast of the fault along the highway are overturned so as to suggest northwestward movement of the overriding rocks.

Near the southwest end of Holston Mountain the fault is exposed on Licklog Branch at an altitude of 2,360 feet, in a small prospect pit dug in the Middle Ordovician rocks in a fruitless search for coal. Overriding rocks are crumpled siltstone of the Hampton formation, and overriden rocks are folded black platy shale of the lower unit of the Middle Ordovician. The fault surface dips 60° SE and is marked by crumbly gouge 5 inches thick. The steep dip here is anomalous, even for the immediate vicinity, as outcrops of rocks adjacent to the fault on some neighboring ridges indicate dips as low as 5° to the southeast.

OVERRIDING ROCKS

Along most of the Holston Mountain fault in this region the overriding rocks are the massive sandstone beds of the upper division of the Unicoi formation (fig. 20), which dip at low angles southeastward. The sole of the fault is probably at or near the base of the division, with a little of the more shaly lower division preserved in places, as at the outcrop on U. S. Highway 421. Near Damascus, however, the Unicoi is cut out and the overlying Hampton formation rests directly on the fault for several miles; the Unicoi is again the basal overriding formation northeast of Damascus.

A more far-reaching change in habit occurs at the southwest end of Holston Mountain, where the entire Chilhowee group, Shady dolomite, and Rome formation bend abruptly northwestward and are cut off, partly by the main fault and partly by a higher branch fault. From here southwestward to the edge of the map area and beyond, past Johnson City and Jonesboro, the overriding formation is the Honaker dolomite; the fault apparently follows the shaly beds in its lower part. With this change the scarp of Holston Mountain ends and the fault trace lies amidst outcrops of carbonate rocks in the Appalachian Valley.

The Holston Mountain fault does not, therefore, truncate any folds in the overriding block, but mainly follows two stratigraphic horizons, each for long distances, changing abruptly from one to the other at the southwest end of Holston Mountain (fig. 20). Each horizon is characterized by weak shaly beds and is overlain by massive competent beds—the sandstone of the upper division of the Unicoi, and the limestone and dolomite of the upper part of the Honaker and of the Knox group.

OVERRIDDEN ROCKS

As already indicated, the Holston Mountain fault overrides both the homocline of Cambrian and Lower Ordovician rocks from Denton Valley northeastward and the synclinorium of Middle Ordovician rocks to the southwest (fig. 21). These structures are steeply truncated by the fault, as though it overrode beds already deformed. Relations near Sowbed Gap and Denton Valley suggest that at least part of this deformation occurred between earlier and later stages of the thrusting (see below). Truncated folds in the overridden rocks are particularly well shown between Webb Spring and Underwood Spring near the southwest end of Holston Mountain, where the fault overrides an anticline that brings the Knox group to the surface (pl. 1).

SOWBED GAP OFFSET

The trace of the Holston Mountain fault is remarkably straight and is modified only by sinuosities caused by its low dip, and by short offsets on younger transverse faults. Because of the heavy cover it is not everywhere possible to determine the cause of a specific irregularity. Even the Cross Mountain fault offsets the Holston Mountain fault no more than half a mile.

The only major offset is near Sowbed Gap, where the fault is shifted laterally 1½ miles along the transverse fault that bounds Denton Valley on the southwest (pl. 1). This offset is conspicuous topographically, as Little Mountain, an outlying ridge of the Unicoi formation, ends abruptly southwestward against lower hills formed of shale of the Middle Ordovician series.

The nature of this offset is not entirely clear, as the structure of the overriding Unicoi formation has not been worked out in detail. Little Mountain apparently represents a subsidiary slice below the main body on Holston Mountain that repeats the upper part of the Unicoi formation; shale beds exposed at Sowbed Gap may be the same as those on the Denton Valley–Shady Valley road higher on the mountain (beds 2–6, section 5, pl. 9). The main body of the Unicoi formation on the mountain seems to extend without offset over the transverse fault that truncates the Little Mountain slice on the southwest.

These inferred relations suggest that the Unicoi formation of Little Mountain was emplaced during initial movements on the Holston Mountain fault, and that both the Unicoi formation and the rocks of Denton Valley to the northwest were offset by the transverse fault before they were overridden by the main body of Unicoi formation on Holston Mountain. At least part of the structural features of the Appalachian Valley may thus have formed between earlier and later movements on the Holston Mountain fault.

SUBSIDIARY SLICES ALONG HOLSTON MOUNTAIN FAULT

Most major low-angle faults of the southern Appalachians include small to large wedges along the soles, made up of rocks stratigraphically intermediate between the overriding and overridden rocks. Such slices occur on an impressive scale along the Iron Mountain fault to the southeast. They appear to be fewer on the Holston Mountain fault, although much of its trace has not been thoroughly searched.

The large slice of Unicoi formation on Little Mountain and the small slice of limestone of the Knox group on U.S. Highway 421 have been mentioned, the first being part of the overriding block that became detached during later movements, and the second plucked from the overridden block at some point behind the present fault trace. Along the north slope of Little Mountain at the edge of Denton Valley are other slices similar to the last, made up either of Shady dolomite or of quartzite from the Erwin formation. They are mostly represented by boulders and float blocks, two areas of which are large enough to show on the map (pl. 1). These slices probably did not move far from their sources in the overridden block as the beds beneath the fault here belong to the next succeeding unit, the Rome formation.

SHADY VALLEY THRUST SHEET

The Shady Valley thrust sheet extends for 36 miles from northeast to southwest across the region and averages 8 miles in width (pl. 1). It is bordered on the northwest and southeast by the Holston Mountain and Iron Mountain faults that dip inward and probably connect beneath it, both strata and faults being warped down gently in the center to form the Stony Creek syncline. This broad, gently folded syncline, lying amidst otherwise strongly deformed rocks, is prominent on the structure sections (pl. 17).

The base of the Shady Valley thrust sheet is formed mainly by the Chilhowee group, although basement rocks are present in small areas on the southeastern side. The clastic rocks of the Chilhowee group are exposed in Holston Mountain, and the Iron Mountains, and across the central axis in several places toward the north, notably on the high ridge of Cross Mountain. Along the central trough, remnants of the overlying Shady dolomite are preserved; to the southwest, beginning near the Watauga River, the still higher Rome, Honaker, Nolichucky, and Conococheague formations appear. The overlying Jonesboro limestone and basal part of the Middle Ordovician series are preserved a short distance farther southwest, beyond the map area.

STONY CREEK SYNCLINE

Throughout Holston Mountain and the Iron Mountains the rocks of the Chilhowee group dip toward the axis of the Stony Creek syncline at angles of 20° to 50°. Dips are commonly greatest on the southeastern, or Iron Mountains side; near the southwest corner of the map area they steepen to vertical, and high dips continue southwestward past the town of Erwin. Near Shady Valley the rocks close to the axis are broken by a few small high-angle thrust or normal faults of short length and unsystematic pattern. Small normal faults are prominent in the flat-lying Helenmode member of the Erwin formation in the quarry southwest of Crandull.

This rather open structure appears to be based on the massive competent sandstone of the upper division of the Unicoi formation, which forms the sole of most of the thrust sheet. The less competent lower division of the Unicoi formation, which forms the sole of the thrust sheet on the southeast slope of Iron Mountains, has a highly contorted, crumpled structure, very different from that of the rocks above (fig. 15 *B*).

From the Cross Mountain fault southwestward, to and beyond the edge of the map area, the trough of the Stony Creek syncline plunges steadily southwestward, at an average rate of about 335 feet per mile, bringing down formations above the Shady dolomite near and beyond the Watauga River. Northeast of the Cross Mountain fault the plunge is much less regular. Immediately north of the fault the Chilhowee group extends across the synclinal axis in the high plateaus of Cross Mountain, but it plunges steeply northeastward beneath the Shady in the upper basin of Shady Valley. The upper basin is separated from the Crandull basin to the northeast by a transverse warp that brings the top of the Chilhowee group to the surface entirely across the valley. Northeast of the Crandull basin for 5 miles down Beaverdam Creek the Chilhowee group stands high along the synclinal trough, so that the Shady is preserved only as remnants on the ridge tops (fig. 12), but immediately south of the Tennessee-Virginia line the Chilhowee again plunges beneath the Shady in the Sutherland basin, a small replica of the upper basin of Shady Valley.

WATAUGA RIVER ZONE

The broad simplicity of the structure of the Shady Valley thrust sheet is broken near the Watauga River at the southwest end of Stony Creek valley by a belt of complex faulting and folding (pl. 1). Two nearly

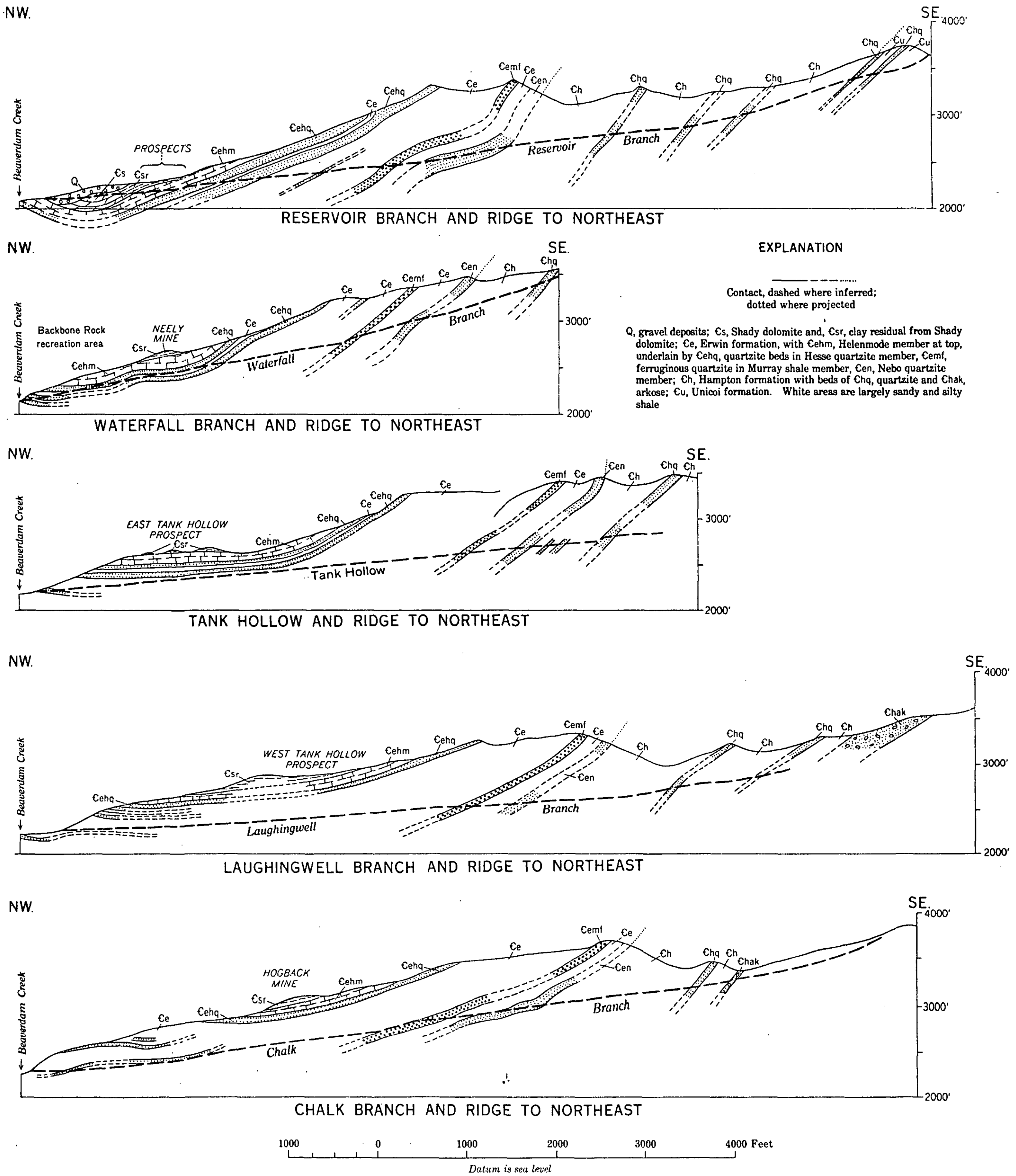

Figure 12.—Profiles on southeast side of Beaverdam Creek valley between Shady Valley and Sutherland, showing relation of clay residual from Shady dolomite to underlying rocks of Chilhowee group. The clay has been mined and prospected for manganese ore at many places. The area lies on northwest slope of Iron Mountains, and on southeast flank of Stony Creek syncline. Each profile shows gradient of a northwestward-flowing stream, and structure of the northeast slope of stream valley, up to the adjacent ridge crest. Prepared by L. E. Smith.

vertical transverse faults occur, each with a component of left-lateral strike-slip displacement. The southeastern fault begins at the Iron Mountain fault and extends northwestward, a little northeast of the Watauga River (pl. 18). The northwestern branches off the Holston Mountain fault as a low-angle thrust, but shortly veers south-southeastward, changing to a high-angle transverse fault across the plunging end of Holston Mountain. Toward the axis of the Stony Creek syncline both faults lie under the wide alluvial area along the Watauga River; they probably do not join beneath the alluvium, yet they seem to be part of the same system of movement.

The structures on the two sides of the southeastern fault differ greatly. The northeastern side is a homocline in which the Chilhowee group and Shady dolomite dip regularly 20° to 45° northwestward (sec. 29, pl. 17). The southwestern side, by contrast, is thrown into recumbent folds and broken by thrust faults directed to the northwest (section 30, 31, and 32, pl. 17; section *A–A′*, pl. 18). At the abutments of Watauga Dam, the Unicoi formation dips about 50° northwest, but higher on the walls of the gorge the same beds are overturned and dip 50° or less southeastward, indicating a great recumbent syncline. Farther down the Watauga River the Erwin, Shady, and Rome formations lie in recumbent folds whose lower limbs are broken by low-angle faults, each fold being moved northwestward over the rocks below it. Prominent exposures of this structure may be seen in the bluff on the north side of the Watauga River a mile below Wilbur Dam (fig. 13). The faults dip northwest like the main Iron Mountain fault beneath, but being smaller, their displacements are more readily apparent.

On the southeast slope of Holston Mountain, several miles northeast of the northwestern transverse fault, the upper beds of the Erwin are broken by a complex system of small interlacing thrusts, on which the maximum displacement is no more than a few hundred feet. Faults of this system were mapped in a generalized manner by Keith (1907), who also showed complementary small northwestward-dipping thrusts on the Iron

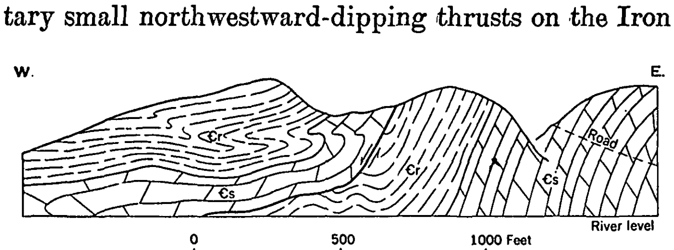

FIGURE 13.—Sketch showing structure of Rome formation (Ꞓr) and Shady dolomite (Ꞓs) as exposed in bluff on north side of Watauga River three-quarters of a mile northwest of Wilbur Dam. Note thrust fault and recumbent folds, indicating differential movement of rocks toward northwest. Area of sketch lies near northwest end of section *A–A′* (pl. 18), but extends somewhat farther northwest.

Mountains side of the syncline (fig. 1 *B*). The latter do not exist, and were inferred because of misinterpretation of the stratigraphy of the Hampton and Erwin formations; there is here no single thin bed of "Hampton shale" repeated many times by faulting, but several shale beds at different levels.

Probably all these features of the Watauga River zone are manifestations of a greater northwestward displacement of that part of the Shady Valley thrust sheet northeast of the zone with respect to the part southwest of it. The northeastern side advanced further, but broke into thrust slices along the present slope of Holston Mountain. The southwestern block lagged behind, but was crowded into recumbent folds and broken by low-angle thrusts near the present site of the Iron Mountains.

Significantly, this zone coincides with the ending of the Unicoi as the basal formation of the thrust block on the Holston Mountain side, the sole of the fault there shifting abruptly from the bottom of the upper division of the Unicoi to the lower part of the Honaker dolomite (fig. 20). Perhaps the transverse structures of the Watauga River zone were localized where this major change in habit affected the thrust sheet.

CLEAVAGE

Most of the rocks of the Shady Valley thrust sheet show little internal deformation and, except for consolidation, appear almost unmetamorphosed. The higher formations were shielded from internal movement by the competent sandstone beds of the upper Unicoi beneath. Also, movement of the thrust sheet itself liberated the rocks from the confining pressures to which they would otherwise have been subjected.

On the Iron Mountains near the Watauga and Doe Rivers the shale units in the Chilhowee group have, however, a well-marked cleavage that lies horizontal or dips northwestward at a lower angle than the bedding (pl. 11 *B*). This cleavage is anomalous, as most cleavage in the southern Appalachians dips southeast. Moreover, cleavage that dips at a lower angle than bedding ordinarily indicates that the beds are overturned, whereas stratigraphic evidence shows plainly that the beds are not. It is more than coincidence that this cleavage with anomalous relations occurs not far from the Iron Mountain fault with anomalous dip; both cleavage and fault probably originated with a different attitude and have since been rotated, probably during downwarping of the Stony Creek syncline. The northwestward-dipping cleavage is in places crossed by another, cruder, more widely spaced fracture cleavage, which dips southeast; this might have been produced during downwarping of the syncline.

CROSS MOUNTAIN FAULT

About 10 miles northeast of the Watauga River zone the Shady Valley thrust sheet is broken by the Cross Mountain fault. Unlike the Watauga River zone, the Cross Mountain fault is younger than emplacement of the Shady Valley thrust sheet, as it offsets not only the rocks of the sheet, but the sole faults and the overridden rocks (pl. 1, 15, 16).

The Cross Mountain fault is named for Cross Mountain, the high transverse ridge that connects Holston Mountain and the Iron Mountains between Stony Creek and Shady Valleys. The fault trends nearly due east along the south side of Cross Mountain, cutting off Stony Creek valley abruptly at its head. The fault raised the rocks on the north relative to those on the south, so that the high mesas of Cross Mountain, composed of the middle and upper parts of the Erwin formation, adjoin the lowlands of Shady dolomite in Stony Creek valley. The Erwin on the north lies nearly flat up to the fault line, but the Shady on the south is dragged sharply in a narrow zone, with the underlying Helenmode member emerging in places along the fault. The apparent vertical movement on the fault is more probably due to right-lateral strike-slip displacement, for the axis of the Stony Creek syncline in Stony Creek valley fails to join that in Shady Valley by nearly 4 miles.

The Cross Mountain fault is exposed at the head of Stony Creek Valley, in the bed of the North Fork of Stony Creek 1¼ miles northeast of Buladeen (fig. 14). Here it stands nearly vertical and brings gently dipping beds of the middle part of the Erwin formation on the north against steeply dipping beds of the upper part of the Erwin formation on the south.

On the Iron Mountains east of Stony Creek valley, amygdaloidal basalt of the middle part of the Unicoi on the south abuts against ferruginous quartzite of the middle part of the Erwin on the north. The trace

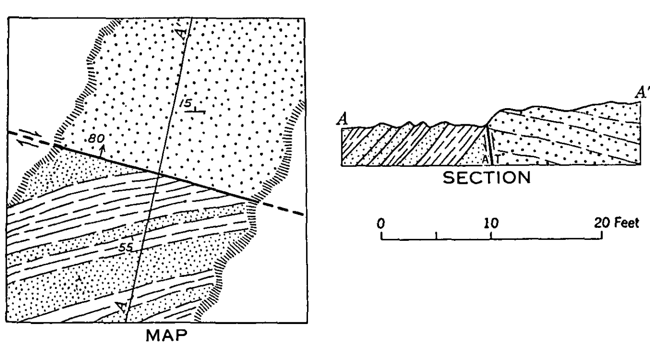

FIGURE 14.—Map and section showing outcrop of Cross Mountain fault in channel of North Fork of Stony Creek, 1¼ mile northeast of Buladeen at upper end of Stony Creek valley. Rocks north of fault are ferruginous quartzite of middle part of Erwin formation. Rocks south of fault are sandy shale and thin-bedded quartzite of upper part of Erwin formation.

of the Iron Mountain fault at the foot of the mountain is offset 2 miles along the Cross Mountain fault. Beyond, to the east, the Cross Mountain fault passes into the homogeneous Rome formation of the Mountain City window, in which displacements are difficult to detect. However, several long reefs of brecciated jasperoid extend out from the foot of the mountain at least 4 miles toward Mountain City, bending into parallelism with the strike; they were probably localized by the faulting. Nothing comparable to the Cross Mountain fault has been observed farther east and the structures on the southeast side of the Mountain City window appear to be unrelated to it.

Westward to the crest of Holston Mountain at Flint Mill Gap, the rocks of the Chilhowee group show strong right-lateral offsets as on the Iron Mountains, but the Holston Mountain fault is offset no more than half a mile. Farther west the Cross Mountain fault runs out into the synclinorium of clastic rocks of the Middle Ordovician series, where its position has not been traced, but beyond, in the Appalachian Valley, Rodgers (1953a, pl. 5) has found evidence for right-lateral offsets of formations by the fault for at least 22 miles west of Holston Mountain (pl. 16).

IRON MOUNTAIN FAULT

The Iron Mountain fault (Keith, 1903, p. 6) extends for 44 miles across the central part of the map area (pl. 1). At the north, in Virginia, it is traceable around the end of the Mountain City window into the Catface fault. It extends at least 16 miles southwestward beyond the map area across the Nolichucky River south of Erwin, beyond which it bends around the southwest end of the Mountain City window (pl. 16) (Rodgers, 1953a, pl. 5). The fault follows the southeast base of Iron Mountains; rocks of the lower part of the Chilhowee group form the escarpment behind the fault and rise above lowlands in front, which are formed of the Shady dolomite and Rome formation.

The Iron Mountain fault dips northwest. In the northern half it dips at very low angles so that near Pandora and elsewhere the overriding rocks project in promontories on the ridges between valleys cut in the overridden rocks. Farther southwest, its surface steepens gradually as a result of subsequent deformation, and at the southwest corner of the map area it probably is nearly vertical.

OUTCROPS OF THE FAULT

Unlike the Holston Mountain fault, the Iron Mountain fault is separated from the mountain escarpment by foothills of overriding rocks and is therefore much less masked by wash, so that natural outcrops are rather common. A typical natural outcrop near a lime kiln on Timothy Branch, 1¼ miles northeast of Pandora, consists of much shattered dolomite of the Rome formation overlain nearly horizontally by arkose and siltstone of the lower division of the Unicoi formation.

The best and most accessible exposures of the fault occur, however, in artificial openings:

The fault is thus revealed in a cut on U. S. Highway 421, 3 miles west of Mountain City (fig. 15 *A*), where it dips about 30° northwest. The overriding rocks are quartz monzonite gneiss of the pre-Unicoi basement. About 50 feet above the fault this retains its primary gneissic structure and the pegmatites are not crushed. Immediately above the fault, however, is a 10-foot layer of deeply weathered and decayed gneiss that appears to have been highly sheared. This lies on brecciated blue limestone and sheared shaly limestone derived either from the Shady or the Rome; normal red shale of the Rome formation is exposed a few hundred feet below the fault.

Extensive exposures of the fault on the Watauga River were made during construction of Watauga Dam. Most of them are now covered by the reservoir or by the engineering works of the dam, but the fault is still exposed in the spillway plaza (section *C–C'*, fig. 16; pl. 19). During construction of the dam, outcrops along the Watauga River were studied in detail by L. F. Grant, J. M. Kellberg, and C. B. McGavock, Jr., geologists of the TVA, on whose work the following description (Tennessee Valley Authority, 1949, p. 379) and

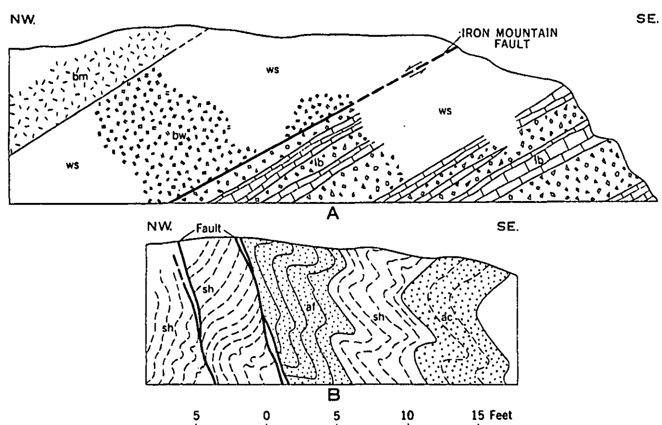

FIGURE 15.—Structures near Iron Mountain fault in road cuts on U. S. Highway 421 northwest of Mountain City. *A*, Structure near Iron Mountain fault 3 miles west-northwest of Mountain City. *B*, Structure about three-quarters of a mile northwest of *A*, showing characteristic complex deformation of lower division of Unicoi formation. *bm*, basement rocks (quartz monzonite gneiss), massive and unaltered; *bw*, basement rocks, sheared and weathered, forming gouge zone immediately above Iron Mountain fault; *lb*, brecciated blue-gray limestone, interbedded with sheared shaly limestone, derived from Rome formation or Shady delomite; *ws*, wash and slump; *sh*, shale; *af*, fine-grained arkose; *ac*, coarse-grained arkose, in part conglomeratic.

accompanying illustrations (figs. 16 and pl. 19) are based.

The strike of the fault at the dam site is N. 52° E., very slightly oblique to the strike of the bedding * * *. The dip is 42° to the northwest, in the same direction as the bedding [of the overriding rocks] but at a lower angle by 7°. The fault plane has an unusually smooth surface, devoid of most of the common markings of fault surfaces; and at this locality there is only slight curvature. In the places where it has been exposed in excavations there is from 6 to 12 inches of soft greenish-gray fault gouge, but this was not obtained from all drill holes which penetrated it * * *.

The minor faults are related to the large Iron Mountain fault. The Shady dolomite which forms the footwall is highly fractured by many small faults, the most persistent group of which strikes N. 30° E. and dips at about 50° to the northwest. The dolomite between these faults is so badly brecciated that original structures such as bedding planes have been completely obliterated; however, the mass has been thoroughly recemented by calcite and dolomite vein material. This brecciated condition extends for some 300 feet away from the main fault.

In the quartzite [above the fault, near the base of the upper division of the Unicoi formation] the original structures have not been completely obliterated. Many small faults are found branching off from the main fault, but they are of small displacement. Several of these faults were encountered in the tunnels and in drill holes near the large fault. * * * Joints are present in the quartzite at the dam site in great numbers. The very brittle quartzite broke readily under the stresses applied to it during the folding and faulting, reducing the whole mass to a body of interlocking blocks.

OVERRIDING ROCKS

Through much of its course the Iron Mountain fault is overlain by the lower division of the Unicoi formation (fig. 20), a body of incompetent arkose, shale, and conglomerate that in most places is strongly contorted. Northeast of Watauga Lake, bodies of Precambrian rocks appear along the fault and increase in extent northeastward (pl. 1).

Although the lower division of the Unicoi formation is much contorted, its persistence as the first unit above the fault suggests that the overriding rocks as a whole were not conspicuously folded before the faulting. However, the fault rises stratigraphically northwestward in the overriding sequence, as the equivalent Holston Mountain fault to the northwest lies at or near the base of the upper division of the Unicoi formation. That the northwestward rise may be abrupt and take place only a short distance northwest of the fault outcrop is suggested by relations near the window north of Mountain City (section *A–A'*, fig. 20). Along the main trace southeast of the window, basement rocks lie on the fault, but these are overlain to the northwest by the lower division of the Unicoi. In the window, 2 miles to the northwest, the beds above the fault are stratigraphically a short distance below the amygdaloidal basalt, or near the top of the lower division.

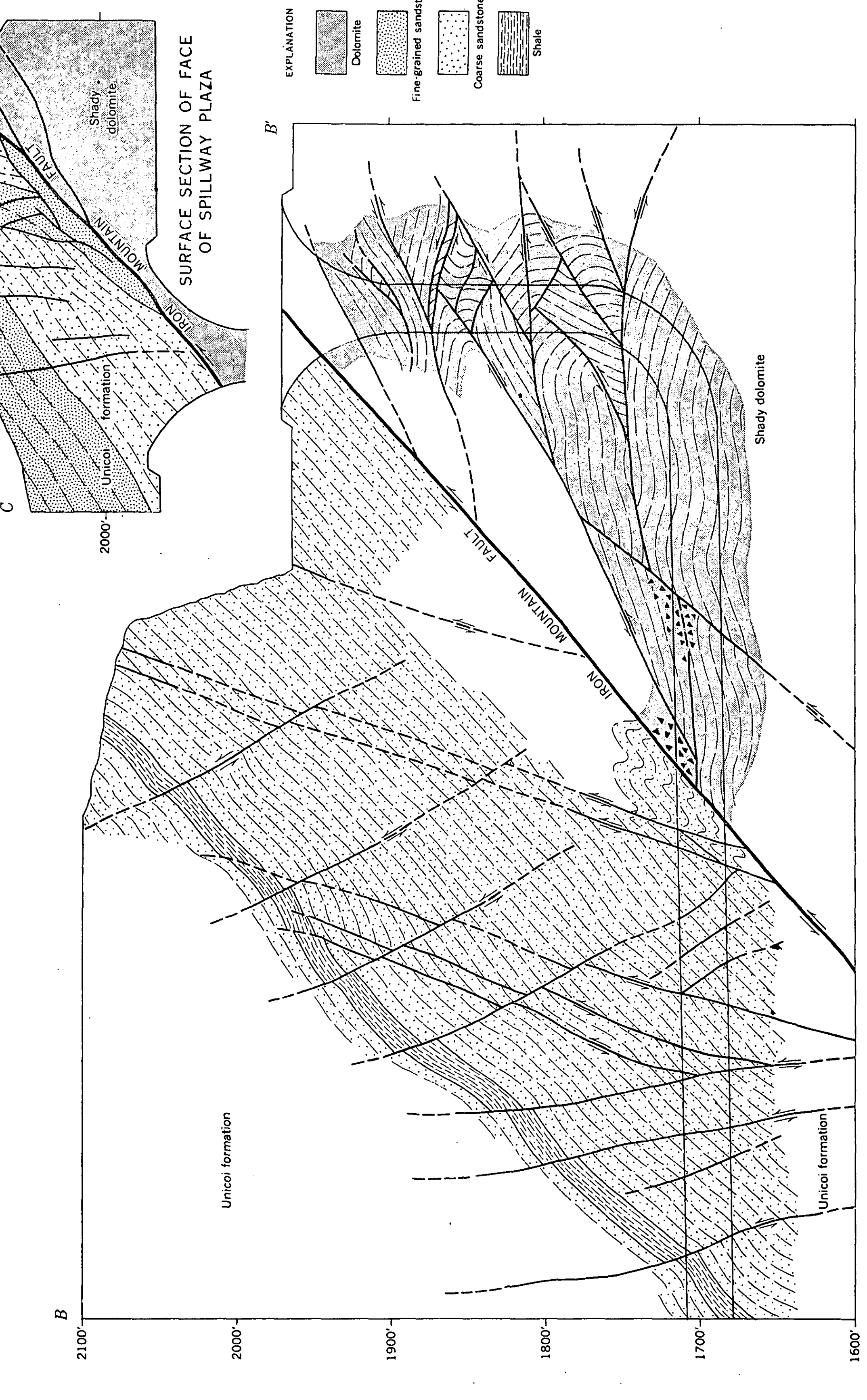

Figure 16.—Sections showing detailed features of Iron Mountain fault at Watauga Dam; for location see plate 18. Section *B–B'* by L. F. Grant and J. M. Kellberg; published by permission of TVA. Section *C–C'* by P. B. King.

OVERRIDDEN ROCKS

The Iron Mountain fault mainly overrides shale of the Rome formation, but in places it truncates sharp anticlines of Shady dolomite (fig. 21). At Watauga Dam the fault for the most part lies on strongly deformed Shady, but not far to the southwest narrow belts of downfolded or downfaulted Rome formation extend up to and pass under the Iron Mountain fault (pl. 18). Evidently the fault truncates strongly deformed overridden rocks.

WINDOW NORTH OF MOUNTAIN CITY

Between Corum Branch and McCann Branch north of Mountain City, low foothills of the basement rocks and lower division of the Unicoi formation rise behind the Iron Mountain fault. Between the foothills and the main escarpment of the Iron Mountains is a long, narrow, covelike area, heavily covered by wash. Near the northeast end Laurence (1939) discovered small outcrops of limestone and shale of the Rome formation amidst the wash, and similar outcrops were found later at intervals for nearly the whole length of the cove, indicating that it is an elongate window in the Shady Valley thrust sheet (pl. 1).

The fault in the window lies nearly 400 feet higher than it does to the southeast, although it there dips gently toward the window; the fault surface is thus notably irregular. The structural rise of the fault coincides with a stratigraphic rise in the rocks that overlie it, from a level in the basement rocks to one near the top of the lower division of the Unicoi formation. On the map and sections (pl. 1 and sections 6, 7, and 8, pl. 17) the Iron Mountain fault is shown as dropped along a normal fault along the southeast side of the window; a high-angle fault is suggested but not proved by the straight line of hills bordering the cove on this side.

SUBSIDIARY SLICES ALONG IRON MOUNTAIN FAULT

Many large subsidiary slices occur along the Iron Mountain fault, made up of rocks intermediate stratigraphically between the overriding and overridden rocks. For consistency, the fault above the slices is indicated on the map (pl. 1) as the Iron Mountain fault, regardless of whether the slice is more closely related to the rocks below or above.

North of Watauga Lake, immediately northwest of the new townsite of Butler, one slice extends 1½ miles along the fault, and is overlain by basement rocks and the lower division of the Unicoi formation, and underlain by Shady dolomite and Rome formation. This slice contains Unicoi, Erwin, and Shady formations, with the Hampton cut out along a minor fault. The rocks of the slice are related to overridden rocks exposed in the Mountain City window a short distance to the southeast.

All the slices to the northeast are parts of the upper division of the Unicoi formation and no doubt broke from the overriding block and lagged behind during its forward motion. One such slice extends a mile along the fault near Spruce Branch and another for 2 miles at Snaggy Mountain. Both are made up of vitreous feldspathic quartzite, cataclastically broken; the rock on Spruce Branch is so shattered that it is quarried for crushed aggregate.

The slice on Snaggy Mountain is only a few miles from a still larger slice along the Catface fault southeast of the Mountain City window; this also consists of quartzite of the upper division of the Unicoi formation. Along the Taylors Valley-Green Cove road near the Tennessee-Virginia State line this slice exposes amygdaloidal basalt at the base; the overlying quartzite beds are remarkably folded and contorted for rocks so competent (pl. 11 *A*), and contain local cataclastic zones as on Snaggy Mountain.

MOUNTAIN CITY WINDOW

The Mountain City window (King and others, 1944, p. 13) extends 44 miles across the southeastern part of the map area and continues 18 miles farther southwest, so that its total length is 62 miles (pl. 16); it is thus one of the largest in the southern Appalachians. The northeast end of the window is at the north edge of the map area near Konnarock, Va. (fig. 4); the southwest end is south of the Nolichucky River (Rodgers, 1953 a, pl. 5). The window is generally 2 to 5 miles broad, but widens to about 10 miles in the central segment between Mountain City and Butler.

The Mountain City window has been produced by a great arching of the thrust structure southeast of the downwarp in the Stony Creek syncline. The arching has permitted erosion of the overridden rocks along the crest, and caused the low-angle faults above to dip away from the window on each flank, and to plunge away from it at the ends.

Much of the window is formed by the Rome formation and Shady dolomite, which have been carved into the Johnson County cove and Doe River cove (pl. 1). These formations are bordered nearly continuously on the southeast by the Chilhowee group, which form the Stone Mountains; the Chilhowee group also emerges farther northwest in the Doe ridges in the wide central segment between Mountain City and Butler. The basement rocks that border the Stone Mountains on the southeast are mainly in the overriding block, but southwest of the Elk River part of them lie within the window.

The rocks of the Mountain City window are strongly folded and faulted, in contrast with the very gentle folding of the same formations in the Shady Valley thrust sheet to the northwest (see structure sections, pl. 17). The structure of the Chilhowee group in the window was mapped in great detail by Ferguson. Local crumpling and poor exposures prevented working out the structure of the Shady and Rome in comparable detail; structure of these formations is shown schematically on the structure sections (pl. 17), and is mentioned only incidentally in the following descriptions.

NORTHEASTERN SEGMENT

The northeastern segment of the window extends 16 miles northeast from Mountain City to a point near Konnarock, Va. Near Mountain City the window is 5 miles wide, but it narrows northeastward and ends by convergence of the Iron Mountain and Catface faults from the two sides (pl. 15). The overridden rocks of the segment are a homoclinal sequence, from the Chilhowee group on the Stone Mountains to the southeast, along the Stone Mountain and Catface faults, to the Shady and Rome formations in the Johnson County cove on the northwest, next to the Iron Mountain fault. There are, however, many minor folds and warps in all the formations, and the incompetent beds are much contorted in places.

The Shady and Rome formations of the main overridden block are cut off by the Iron Mountain fault near Taylors Valley, a mile north of the Virginia-Tennessee line. Farther northeast the window exposes the Hampton and Erwin formations in the main overridden block, and intermediate slices of Unicoi formation that overlie and border them. These rocks rise above lower bordering hills carved from the overriding Mount Rogers volcanic group in the rugged ridges of Chestnut, Laurel, and Lost Mountains (fig. 4). The mountains are archlike in form, declining to the northeast, and reflecting the structural surface of the window. They end near Big Hill, southwest of Konnarock, where the overlying low-angle fault plunges northeastward beneath the surface. At the northeast end, on U. S. Highway 58 half a mile southwest of Big Hill, a small roadside outcrop of quartzite of the Unicoi formation, which is the upper part of an intermediate slice, intervenes between other outcrops of the Mount Rogers volcanic group, which overlie the slice.

To the southwest, the Chilhowee ridges extend into Forge Mountain, which ends abruptly southeast of Mountain City. South of U. S. Highway 421 and Roan Creek, in the central segment of the window, the analogous Chilhowee belt is offset about 4 miles southeastward to the Stone Mountains. Where the rocks of

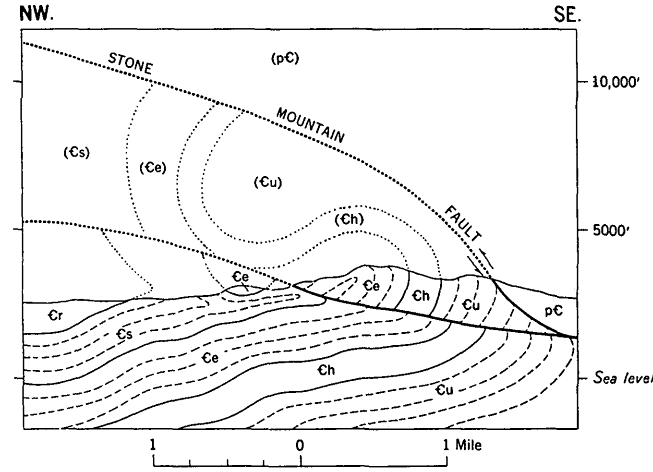

FIGURE 17.—Interpretation of structure of Forge Mountain east of Mountain City, showing origin of the extensive overturning of Erwin formation that has been observed on the mountain. By H. W. Ferguson. €r—Rome formation; €s—Shady dolomite; €e—Erwin formation; €h—Hampton formation; €u—Unicoi formation; p€—basement rocks.

the Chilhowee group enter Forge Mountain from the north, their strike veers toward the west, and a complex series of thrusts occur along their northwestern edge. Thus they are no longer in sequence beneath the Shady and Rome formations as they are farther north, but are broken free from their roots and carried northwestward a mile or two over the Shady and Rome. The roots of the Chilhowee group, perhaps with more southerly strike, may join beneath the surface with the Chilhowee group of the Stone Mountains, in the central segment of the window. The detachment of the rocks of Forge Mountain from their roots may be related to the northwestward offset of the Stone Mountain fault along Roan Creek nearby.

In the main body of Forge Mountain the rocks of the Chilhowee group are largely overturned. The Unicoi and Hampton formations next to the Stone Mountain fault are nearly vertical, but beds in the Erwin on the northwest dip at much lower angles in various directions, and the beds have been rotated 180° or more from their original position. The Erwin must form the lower limb of a great recumbent fold beneath the overriding Stone Mountain thrust sheet, the upper limb being eroded (fig. 17).

That the rocks of Forge Mountain are detached from their roots is clearest at the southwest end, where the summit of Gentry Mountain, the terminal knob of Forge Mountain, is formed of quartzite of the Erwin that rests on shale of the Rome. These shale beds have been extensively silicified to jasperoid, exposed in many old iron-ore cuts on the lower slopes of the mountain. The outlier of quartzite is almost a klippe, but is still lightly connected with the rocks of Forge Mountain by a narrow strip of quartzite that extends across the county road east of Shouns. About a mile east of Gentry Mountain on Forge Creek a small window in the plutonic rocks of the Stone Mountains exposes Shady dolomite and the upper beds of the Erwin formation. The rocks of the window lie southeast of the highly disturbed and transported Chilhowee group on Forge Mountain and probably are part of the roots from which the rocks of the mountain were derived.

CENTRAL SEGMENT

Immediately southwest of Forge Mountain the Mountain City window widens abruptly to 10 miles, a width which it maintains nearly to Butler and the Elk River (pl. 1). The widening is due to offset of the Stone Mountain fault 4 miles southeastward along Roan Creek, and, on the opposite side of the window, to offset of the Iron Mountain fault 2 miles northwestward by strike-slip movements on the Cross Mountain fault.

In the central segment of the window, as in the northeastern segment, the Chilhowee group forms the southeastern edge and projects in the Stone Mountains. To the northwest, however, the structure is not homoclinal, as the Chilhowee group is exposed in the center amidst the Shady and Rome formations, in the complex uplift of the Doe ridges.

Many of the Doe ridges are crudely anticlinal. Doe Mountain to the northwest is an especially massive uplift a mile wide, plunging northeastward and southwestward at the ends, which exposes Unicoi and Hampton formations in the core but is elsewhere sheeted over by quartzite of the Erwin. Anticlinal structure is also largely preserved in the southwest part of Little Dry Run Mountain, and fragments of anticlinal folds may be discerned in many other places. The uplift of the Doe ridges is, however, dominated by a complex system of closely spaced strike faults along which the outcrops of the upper part of the Erwin formation and lower part of the Shady dolomite are repeated many times.

Most of these faults are high-angle thrusts, downthrown to the northwest. A major thrust bounds the northwest foot of Doe Mountain, where the Erwin and older formations are raised against the Rome formation, but most of the thrusts to the southeast have displacements of a thousand feet or less. These thrusts are most conspicuous on Dry Run Mountain where there are four or more slices within less than a mile across the strike, each composed of the topmost part of the Erwin formation and the lowermost part of the Shady dolomite. Dry Run Mountain was originally supposed to be a relatively simple anticline (Keith, 1903), and first intimation of its sliced structure was obtained when Laurence (1940, p. 398) recognized an anomalous strip of residuum of the Shady amidst the Erwin near the core of the mountain at the Young mine; details have since been worked out by Ferguson.

Besides the thrust faults downthrown to the northwest there are, extending through the middle part of the Doe ridges, many faults downthrown to the southeast. These, like the thrust faults, trend northeastward and dip to the southeast; they are therefore normal faults. The normal fault on the southeast side of Gipson Mountain was seen on the former county road along Cobb Creek (now submerged by Watauga Lake) and dips 75° SE. The normal fault on the southeast side of the southern Sink Mountain is exposed in wall-like faces in many ravines that drain into Dry Branch Hollow, and dips 60° SE. Near Cave Ridge and Peak Ridge southeast of Doe Mountain, the normal faults occur singly (section 17, pl. 17), but generally they are intercalated between the thrust faults without apparent order. At a few localities, narrow slivers of Unicoi formation lie amidst the Erwin formation and Shady dolomite. These slivers have been greatly uplifted with respect to the formations in which they lie, by movement along thrust faults on the northwest side and along normal faults on the southeast side. The parallelism of the normal faults with the thrusts and folds in plan and section, their frequent branching from the thrusts, and their consistent downthrow to the southeast suggests that they were formed at the same time and by the same forces as the other structures of the Doe ridges.

The structure of the Doe ridges is remarkably like that of Glade and Lick Mountains in the Appalachian Valley of southwestern Virginia (Stead and Stose, 1943; Miller, 1944; Stose, 1946). These mountains, too, are uplifts in which the Chilhowee group projects through a cover of Shady dolomite and Rome formation, and are composed of parallel folds greatly disrupted and almost obliterated by closely spaced faults. Most of the faults are thrusts, but normal faults like those on the Doe ridges are also present.

The origin of all three of these extraordinary structures is somewhat problematical. Miller (1944, p. 41–45) attributes both thrust and normal faults in Glade Mountain to shingling above the Pulaski (Seven Springs) fault which lies not far beneath. Rodgers (1953 a, p. 140), extending the idea, suggests that the Pulaski fault similarly lies not far beneath the Doe ridges. The senior writer is skeptical of this suggestion, especially as the emerged trace of the Pulaski fault lies beyond Bristol, some 40 miles to the northwest (pl. 16); there is no convincing evidence that the Pulaski fault extends this far southeastward beneath the surface, at least at shallow depth. The senior author regards as much more likely the interpretation by Stose (1946, p. 199) that the structures were produced by essentially vertical uplifts of fractured competent beds, overlying a deep-seated incompetent unit that was undergoing compression. In the Doe ridges these incompetent beds, if present, would lie above the basement rocks in the lower part of the Chilhowee group. Incompetent beds of this sort form the lower part of the Unicoi formation in Stone Mountains southeast of the Doe ridges.

The belt of rocks of the Chilhowee group on the southeast edge of the Mountain City window extends along the Stone Mountains for 14 miles, from Roan Creek to the vicinity of the Watauga River. Like the Chilhowee belt on the southeast side of the window farther north, there is a general homoclinal sequence, with Unicoi formation on the southeast and Hampton and Erwin formations on the northwest, but the structure is greatly complicated by folds and thrust faults, some dipping gently southeast. The Chilhowee group, with a strip of the overlying Shady in places, is thrust over the Rome formation along the entire mountain front, and other smaller thrusts offset the rocks within the Chilhowee group. From the head of Vaught Creek northeastward the Erwin is folded down in synclines southeast of its main outcrop and near the mountain crest; at some other localities the Hampton is upfolded close to the mountain front.

The rocks of the Chilhowee group in the Stone Mountains are of higher metamorphic rank than those elsewhere in the region, perhaps because they have been overridden farther and subjected to greater confining pressures than any other parts of the group now exposed. The argillaceous and silty rocks have been converted to slate and phyllite, in which foliation is well marked at many places. The arkose and quartzite of the Unicoi formation are likewise split by coarse cleavage, and the pebbles in the conglomerate are elongated—the quartz grains flattened and stretched and the feldspar grains shattered and drawn out. In several of the cuts on U.S. Highway 421 along Roan Creek, within a few feet of the Stone Mountain fault, grains are elongated in a northwestward direction; this is probably an *a* lineation parallel to the direction of transport.

Between the Watauga and Elk Rivers, on Dye Leaf Ridge, the Chilhowee group is overlapped by a projection of overriding basement rocks of the Stone Mountain thrust sheet (see p. 77–78). The main belt of the Chilhowee reappears along the Elk River near Nowhere Ridge, striking nearly south, with its rocks conformably beneath the Shady dolomite, rather than in thrust relation as to the northeast. Immediately beyond the Elk River the belt passes beneath basement rocks that lie above the northwestward-trending Unaka Mountain fault.

SOUTHWESTERN SEGMENT

Southwest of the Elk River the central segment of the window terminates against the Unaka Mountain and Little Pond Mountain faults, which together form a line of displacement that extends entirely across the window (pl. 1).

The Unaka Mountain fault, a member of the Stone Mountain fault family, trends northwest for 5 miles and dips gently southwestward (fig. 19), but it turns southwestward, wholly in the basement rocks, before the south side of Little Pond Mountain is reached. The Little Pond Mountain fault, which branches where the Unaka Mountain fault turns southwest, begins as a low-angle fault but steepens progressively northwestward and dips 80° southwest where crossed by Tennessee State Route 67 west of Stony Creek. At Stony Creek it leaves the edge of the Chilhowee group and extends out into the Shady dolomite and Rome formation of Doe River cove, where its course is uncertain. Offsets between the Rome and Shady suggest that it may extend northwestward across the window and under the Iron Mountain fault. Rodgers (1953a, p. 140) interprets the Little Pond Mountain fault as forming the sole of a thrust slice within the Mountain City window higher than the core rocks of the central and northeastern segments, but the senior author believes it is dominantly a transcurrent fault with right-lateral strike-slip displacement, and that it does not extend far southwestward beneath the rocks of the southwestern segment of the window. The strike-slip displacement has offset the rocks of the Chilhowee group of Little Pond Mountain at least 5 miles northwestward, probably from the Stone Mountain trend last seen on Nowhere Ridge. The right-lateral strike-slip displacement on the Little Pond Mountain fault contrasts with the left-lateral displacement of the faults of the Watauga River zone, which lie in seeming alinement to the northwest.

The southwestern segment of the Mountain City window begins at the Little Pond Mountain fault and extends 12 miles southwestward to the southwest corner of the map area (pl. 1). The rocks of the window form a northwestward-dipping homocline, as in the northeastern segment. Here, however, the bounding fault on the southeast side of the window, the Unaka Mountain fault, is not in contact with the Chilhowee group, but lies in the Precambrian basement rocks to the southeast. Thus a band of basement rocks a mile or more wide forms part of the window and lies unconformably but in normal stratigraphic order beneath the Chilhowee group. These rocks constitute the

SURFACE OF IRON MOUNTAIN FAULT EXPOSED IN SPILLWAY PLAZA OF WATAUGA DAM, AS IT APPEARED DURING CONSTRUCTION OF THE DAM

Light-colored Shady dolomite on right is separated from and overridden by the darker-colored Unicoi formation on the left along the clean-cut surface of the fault. Photograph by Tennessee Valley Authority.

"plutonic complex of Pardee Point and Buck Ridge" and the "granitic rocks south of Pond and Little Pond Mountains" as described by Hamilton, on pages 14–16.

Northwest of the basement rocks the Chilhowee group is exposed in Little Pond, Pond, Black, Cedar, and Fork Mountains, units of the Stone Mountains; the Shady dolomite and Rome formation form the Doe River cove beyond, next to the Iron Mountain fault. The sedimentary rocks dip northwest, in part at fairly low angles, but complex isoclinal folding in the Shady and Rome has been revealed by excavations near Watauga Dam (pl. 18). Southwestward the beds steepen to vertical as does the Iron Mountain fault to the northwest; this has resulted from warping after the thrusting.

The most prominent features of the southwestern segment of the Mountain City window are two large transcurrent faults, each with a considerable component of right-lateral strike-slip movement (pl. 1). One passes through Dennis Cove and across the Stone Mountains in the gap between Black Mountain and Cedar Mountain; the other passes along the southwest end of Fork Mountain near U. S. Highway 19 E. Topographic scarps and alined drainage of Laurel Fork and Doe River suggest that the faults extend for some miles southeast of the Stone Mountains in the basement rocks. The southwestern fault, like the Cross Mountain fault farther north, is certainly younger than the thrusting, for it offsets the Iron Mountain fault. The northeastern fault is lost in the alluvium of the Doe River cove near Hampton apparently without offsetting the Iron Mountain fault; it may lose displacement and die out within the Doe River cove before reaching the Iron Mountain fault. Keith (1907, p. 9) stated that "the only places at which the main fault appears to have been actually offset by the later [shear or wedge] faults are near Hampton." The faults that offset the thrust here are the transverse faults just described, but they do not have the habit, form, or manner of displacement inferred by Keith.

STONE MOUNTAIN FAULT FAMILY

The low-angle faults that bound the Mountain City window on the southeast have been termed the Stone Mountain fault (Keith, 1903, p. 6; King and others, 1944, p. 11) but they are considerably more complex than the Holston Mountain and Iron Mountain faults. They do not represent a single break, but are a family of several major breaks, probably of more than one age, that branch and interlace. The Holston Mountain and Iron Mountain faults are probably equivalent to one of the lower branches of the family; the higher branches are probably equivalent to the several major faults nested in the Stony Creek syncline on Buffalo Mountain, southwest of the region of this report (pl. 17). For some members of the family individual names have been proposed by Rodgers (1953, pls. 5 and 6); others are as yet unnamed.

SEGMENT NORTHEAST OF CUT LAUREL GAP

Northeast of Cut Laurel Gap, on the Tennessee-North Carolina divide, 7 miles northeast of Mountain City, the Stone Mountain family consists of two faults, the Catface fault, which bounds the Mountain City window, and the Stone Mountain fault proper, which separates the Mount Rogers volcanic group from the basement rocks on the southeast (pls. 1 and 15).

The Catface fault generally lies near or a little west of the crests of Pond Mountain and Catface Ridge; the crests are formed by the overriding rocks of the Mount Rogers volcanic group, and the lower slopes by the overridden rocks of the Chilhowee group. The Catface fault closely resembles the Iron Mountain fault on the opposite side of the Mountain City window a few miles to the northwest; both have rocks of the Mount Rogers volcanic group on their upper plates and both are underlain by intermediate slices of Unicoi formation with cataclastic structure. Reconnaissance observations indicate that the two connect at the northeast end of the window.

Southward, the Catface fault joins the Stone Mountain fault proper at a point about a mile southeast of Cut Laurel Gap. The surfaces of the two faults are not exposed, but their positions can be accurately located in cleared fields from outcrops of the bordering formations. The Stone Mountain fault crosses the end of the Catface fault at a blunt angle (pl. 1), suggesting that the two faults are not branches, but that the Stone Mountain fault overrides the Catface fault.

The Stone Mountain fault has been traced in reconnaissance northeastward from its intersection with the Catface fault across the northwest corner of North Carolina as far as a point on the North Carolina-Virginia line south of Whitetop, Va. On the south slope of Pond Mountain the fault passes half a mile west of Eldreth, where it is marked by a zone of mylonite several hundred yards wide, formed of overridden volcanic rocks and overriding basement rocks, and containing abundant small fragments, mostly of quartz. The mylonitic structure contrasts with the regional low-grade slaty cleavage of the volcanic rocks and the sheared structure of the basement rocks. The latter contain quartz and feldspar in lenses rather than fragments, and their micaceous folia have a brighter luster; their shearing is probably older than the Stone Mountain thrusting and unrelated to it.

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SEGMENT FROM CUT LAUREL GAP TO ROAN CREEK

For 7 miles southwest of its intersection with the Catface fault the Stone Mountain fault trends along the southeast base of Forge Mountain, and along it basement rocks are thrust over the lower part of the Chilhowee group. On stratigraphic evidence, displacement on the fault thus appears to be slight, but pebbles in the lower conglomerate of the Unicoi formation nearby are flattened and elongated, and the overriding rocks belong to the "gneiss of the Forge Creek area" as described by Hamilton, with metamorphic features unlike those in basement rocks occurring in place beneath the Unicoi.

In parts of this segment the trace of the Stone Mountain fault is relatively straight and it must dip steeply, but it evidently flattens southwestward near the window on Forge Creek, where the Shady and Erwin emerge from beneath the basement rocks. According to Ferguson the fault in this segment is offset several times by transverse faults.

SEGMENT ALONG ROAN CREEK

South of Forge Mountain the Stone Mountain fault turns abruptly southward and south-southeastward for 4 miles, the offset being accompanied by a similar offset in the flanking outcrop belt of the Chilhowee group and by a widening of the Mountain City window. In an earlier report (King and others, 1944, p. 144) it was suggested that the fault in this segment was not the Stone Mountain fault, but a left-lateral transverse fault. Later mapping by Ferguson failed to confirm such a transverse fault and shows that the fault here dips northeast. Nevertheless, fault movements in this segment were probably more nearly parallel to the strike than to the dip as shown by the northwestward elongation of pebbles in the overridden Unicoi formation close to the fault.

Throughout much of this segment the fault follows the deep and narrow valley of Roan Creek, whose eastern slope is made up of overriding basement rocks and the western slope of overridden rocks of the Chilhowee group, broken into slices that extend northeastward beneath the main fault. In the valley, the fault surface is well exposed at several places near U. S. Highway 421, and it has an average dip of 50° to the east.

Southeast of the fault that bounds the Chilhowee group discontinuous narrow slivers of quartzite and conglomerate of the Unicoi formation are embedded in the overriding basement rocks, as discovered by Keith (1903). One sliver lies east of Roan Creek, half a mile north of Key Station, and another west of Roan Creek near the lower end of Bulldog Creek. The rock of the slivers has been crushed and sheared, but much less than the basement rocks adjacent to the southeast. The basement rocks above and southeast of the slivers are part of the "gneiss of the Forge Creek area" and those below are the "chloritized quartz diorite of the Roan Creek area", as described by Hamilton. The contact between the two units can be traced beyond the ends of the slivers; it converges both northward and southwestward with the fault bounding the Chilhowee group of the Mountain City window.

The slivers and the contact between the two basement rock units are evidently on a low-angle fault above that at the edge of the window. Keith mapped the Unicoi of the slivers as bounded by a fault above, but as unconformable on the quartz diorite beneath. However, the slivers of Unicoi formation may be bordered below, as well as above, by a low-angle fault and be carried up from the overridden Chilhowee group beneath the faults of the Stone Mountain family (sections 13 and 14, pl. 17).

SEGMENT FROM ROAN CREEK TO WATAUGA RIVER

Between Roan Creek and the Watauga River, the Stone Mountain fault follows the southeast side of Stone Mountains for 11 miles. The structure here resembles that southeast of Forge Mountain. Only one break has been identified, that between the Chilhowee group and the basement rocks, which here consist mainly of "migmatites of the Watauga River area" as described by Hamilton. The basement rocks abut the lower division of the Unicoi, so that there is little apparent stratigraphic displacement. Detailed mapping by Ferguson shows, however, that the overridden lower part of the Unicoi formation, containing red shale and amygdaloidal basalt, cuts in and out against the fault. Near the head of Rube Creek, Ferguson has identified a small area of basement rocks believed to be in normal order under the Unicoi formation and to be overridden by the Stone Mountain fault. In the overriding basement rocks near State Line Gap, Hamilton has seen zones of mylonite that he attributes to the thrusting.

In this segment the Stone Mountain fault evidently dips steeply southeast, as indicated by its straight course and the steep dip of the foliation in the overridden rocks. Offsets in the fault are attributed by Ferguson to later transverse faulting rather than to low dip. The fault surface flattens somewhat to the southwest, to an average dip of 45° southeastward where it is crossed by the meanders of the Watauga River.

The Stone Mountain fault is exposed immediately south of the Watauga River on the county road in Tennessee that is the extension of North Carolina State Route 603. The fault is marked by 50 feet of mylonite,

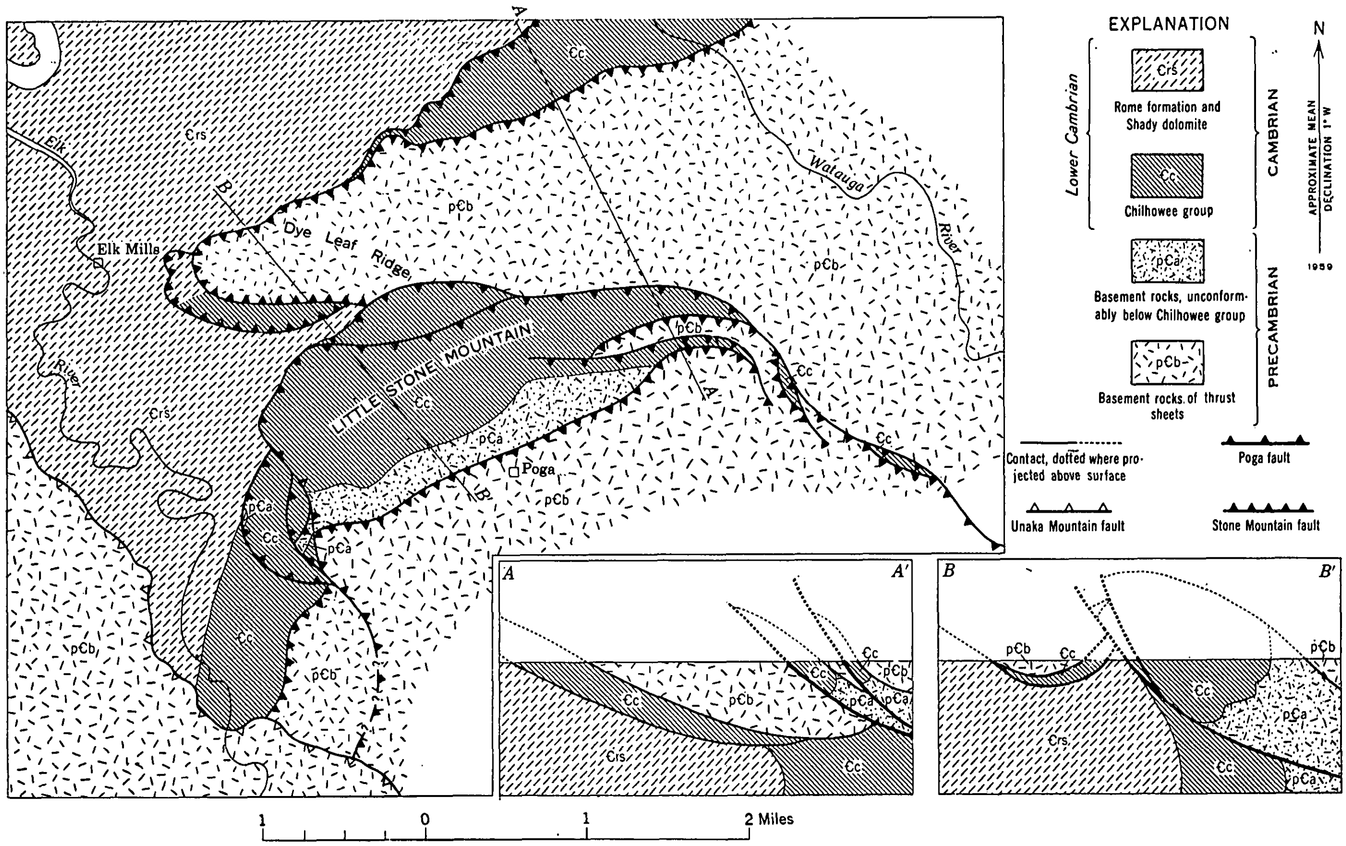

FIGURE 18.—Map and sections of Little Stone Mountain area, showing interpretation of complex structures there, on the assumption that the rocks have been broken successively by three faults of the Stone Mountain fault family—the Stone Mountain fault, the Poga fault, and the Unaka Mountain fault.

consisting of fragmented quartz and feldspar in a fine-grained, aphanitic matrix. The fault dips steeply southeast and truncates the cataclastic foliation of the gneiss, which dips steeply northwestward.

SEGMENT BETWEEN WATAUGA AND ELK RIVERS

Southwest of the Watauga River the Stone Mountain fault family is more complex than it is farther northeast. Keith (1903) mapped a long tongue of overriding basement rocks extending westward along Dye Leaf Ridge, bordered both north and south by overridden sedimentary rocks. He also indicated that the basement rocks in a wide area southeast of Little Stone Mountain (the "curious appendix" of Rodgers, 1953a, p. 140) were in normal unconformable position below the Unicoi and were part of the overridden block.

Later mapping by Ferguson confirms the existence of the tongue of basement rocks on Dye Leaf Ridge, but indicates that there is a much more complex structure of the sedimentary rocks than was originally supposed. Hamilton concludes that most of the basement rocks southeast of Little Stone Mountain are migmatite and gneiss like those along the Watauga River. They show regional shearing as in rocks that elsewhere overlie the Stone Mountain fault family; and it is very unlikely that basement rocks with this structure are in the overridden block. The earlier mapping thus requires revision, but a complete review has not been possible during the present survey. A possible but speculative explanation, set forth below and illustrated in figure 18, was worked out by the senior author with the aid of suggestions from Hamilton. The complex structure here may record more than one major break in the Stone Mountain fault family, with younger faults offsetting and overriding the earlier. Such inferred superposition of faults can be proved in some places.

The oldest fault of the family, here called the Stone Mountain fault proper, forms the sole of the basement rocks on Dye Leaf Ridge (fig. 18). Farther south, its equivalents may be upthrown along the southeast edge of Little Stone Mountain and Nowhere Ridge. On Nowhere Ridge the "migmatites of the Watauga River area" are faulted against the upper division of the Unicoi (section 21, pl. 9); mylonite is present in the basement rocks within a hundred feet or so of the contact. On the south slope of Little Stone Mountain, however, the lower part of the Unicoi formation may lie unconformably on overridden basement rocks; on Buck Ridge, a southeastern spur, Hamilton found a plutonic complex like that which is unconformably below the

Unicoi at Pardee Point. The plutonic complex occupies a narrow strip south of the mountain and is overridden on the south, probably along the Stone Mountain fault proper, by the migmatites.

The Stone Mountain fault proper is apparently offset by a younger break, here called the Poga fault, which raises the overridden rocks of the Unicoi formation on Little Stone Mountain against the tongue of basement rocks on Dye Leaf Ridge to the north. Beneath this fault toward the west, especially in the valley north of Nowhere Ridge, the Chilhowee group and the basement rocks are intricately sliced. Southeast of Little Stone Mountain the fault can be traced in the basement rocks as far as Beech Creek by many narrow slivers of Unicoi formation, probably brought up from the overridden rocks beneath the Stone Mountain fault family.

Southeastward, near the Elk River, both the Stone Mountain fault proper and the Poga fault lie beneath the northwestward-trending Unaka Mountain fault, probably the youngest member of the Stone Mountain fault family in this vicinity. The basement rocks above the Unaka Mountain fault form the "complex of the Lunsford Branch area," as described by Hamilton, which differs recognizably from the "migmatites of the Watauga River area" that it overrides.

To explain the southeastward ending of the supposedly overridden basement rocks south of Little Stone Mountain, Rodgers (1953a, p. 143) postulated a hypothetical "Snow Mountain fault." Our survey was not extended far enough southeastward to test this feature, but as it is now known that there is no contact between basement rocks of the window and those of the Stone Mountain thrust sheet in this area, the necessity for invoking a Snow Mountain fault is no longer compelling.

SEGMENT SOUTHWEST OF ELK RIVER

For 5 miles in the south part of the map area the Elk River is bordered on the southwest by the northwestward-trending segment of the Unaka Mountain fault; farther northwest the same trend is continued across the Mountain City window by the Little Pond Mountain fault. In an earlier report (King and others, 1944, p. 144) these features, like the segment of the Stone Mountain fault along Roan Creek, were attributed to a transverse fault that offsets the Stone Mountain fault family. Later mapping by Ferguson shows that the Unaka Mountain fault and part of the Little Pond Mountain fault dip at low angles to the southwest, and that no separate transverse fault exists. Nevertheless, movement on these faults was probably more nearly parallel to their strike than to their dip.

In the northwestward-trending segment of the Unaka Mountain fault the overriding basement rocks form high forested ridges, and lie indiscriminately on northeastward-trending folds and faults in the Chilhowee, Shady, and Rome of the lower slopes. The fault surface is exposed in Lunsford Branch and Black Branch, one of the best outcrops being in a road cut on the north side of Lunsford Branch (fig. 19). At

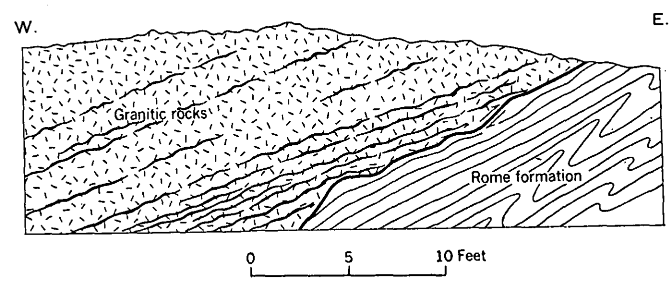

FIGURE 19.—Outcrop of Unaka Mountain fault in a road cut on north side of Lunsford Branch, 1 mile southwest of Elk Mills. The overriding basement rocks contain shear planes that are smoother and dip at a lower angle than the fault surface; they are interpreted as being part of regional shearing that is considerably older than the faulting.

both localities the fault dips at a low angle to the southwest, with contorted shale beds of the Rome formation beneath, and the "complex of the Lunsford Branch area" above. The foliation in the overriding complex dips more regularly and less steeply than the fault plane, and is probably related to the earlier regional shearing.

Southeastward, near Twisting Falls on the Elk River, the fault crosses the base of the Chilhowee group and passes into the basement rocks where it has been traced for 2 miles by superposition of the "complex of the Lunsford Branch area" on the "migmatite of the Watauga River area," and by the prominent topographic scrap of Dark Ridge. Its further continuation has not been determined.

Northwestward, the Unaka Mountain fault splits from the Little Pond Mountain fault before reaching the foot of Little Pond Mountain and passes southwestward into the basement rocks, in which it lies as far as Limestone Cove, southwest of the map area (Rodgers, 1953a, pl. 5). Keith (1907) clearly had difficulty in deciding on the position of the fault here, and locally included parts of the Unicoi formation in the overriding block, an interpretation for which no justification has been found in later work. According to Hamilton the fault can be located with considerable precision by juxtaposition of the "granitic rocks south of Pond and Little Pond Mountains," a part of the overriden block, with the "complex of the Lunsford Branch area" of the overriding block. The overridden granitic rocks are massive and nonfoliated, with inclusions of low-rank phyllite; they lie in normal unconformable order beneath the Unicoi formation of Pond and Little Pond Mountains and are part of the Mountain City window.

GENERAL INTERPRETATION AND SYNTHESIS

Details of the structure of northeasternmost Tennessee having been described, it remains to assemble these details into a regional synthesis. In this account, little attention will be given to the theory of large-scale low-angle thrusting and its application to the southern Appalachians. A useful discussion of this subject has been presented by Campbell and Holden (1925, p. 30-96) which would require little revision to bring up to date; some of the more modern concepts have been stated by Rodgers (1953b, p. 160–165). Consideration of the ultimate causes of deformation in the southern Appalachians and elsewhere is beyond the scope of this report.

RECONSTRUCTION OF THE THRUST COMPLEX

At several places in the preceding text the grand design of the structure has been mentioned, although without proof—the existence of a great thrust sheet, now warped, bounded below by the Holston Mountain, Iron Mountain, and Stone Mountain faults. Many features are in harmony with this interpretation, but specific proof is afforded by the following:

1. Evidence that the Shady Valley thrust sheet is a traveled mass, with the Holston Mountain and Iron Mountain faults connected beneath it, and that it was not an uplifted wedge as believed by Keith (1907; see fig. 1 B of this report): The gentle folding of the rocks of the thrust sheet contrasts with the strong deformation of the rocks that flank it on each side and pass under its edges. The Chilhowee group and Shady dolomite of the thrust sheet differ in facies from the same units in the Mountain City window on the southeast and the Appalachian Valley on the northwest, so as to suggest that the rocks of the thrust sheet originally lay southeast of the window.

2. Evidence that the rocks above the Iron Mountain fault were displaced northwestward like those above the Holston Mountain and Stone Mountain faults, rather than southeastward up the present dip of the fault: Northwestward overriding is indicated by the recumbent folds and minor low-angle thrusts of the Watauga River zone and implied by the attitude of the slaty cleavage in the argillaceous layers of the Chilhowee group.

3. Evidence that the Iron Mountain fault is connected with the Stone Mountain fault family across the Mountain City window: The Iron Mountain and Catface faults in the northeast part of the window are clearly related; they have many statigraphic and structural features in common, and they appear to be traceable into each other. The Iron Mountain fault is less definitely related to other members of the Stone Mountain fault family farther south, but these members are probably upper branches of the thrust complex.

4. Evidence of profound movement on members of the Stone Mountain fault family: In many places, overriding basement rocks lie against the lower Chilhowee rocks, so that there is little stratigraphic hiatus, but these basement rocks have a regional shearing not found in basement rocks in place beneath the Chilhowee group; where basement rocks emerge normally from beneath the Chilhowee group of the Mountain City window they are quite different. Near the Watauga and Elk Rivers the plutonic rocks above the Stone Mountain fault family have clearly ridden several miles northwestward over the sedimentary rocks of the Mountain City window.

The Shady Valley thrust sheet is merely a lower slice of a much more extensive thrust complex (pl. 17) that extends far beyond this region, both along and across the strike (Rodgers, 1953a, p. 139–143). Southwestward beyond the map area, down the plunge of the Stony Creek syncline, upper slices occur on Buffalo Mountain (Keith, 1907; Rodgers, 1953a, pl. 5). Some members of the Stone Mountain fault family southeast of the Mountain City window form the soles of thrust slices above the Shady Valley sheet; these may in part be equivalent to the upper slices on Buffalo Mountain.

Southeast of the region of this report and across the strike, between Boone and Marion, N. C., the Shady dolomite and Chilhowee group come to the surface again in the Grandfather Mountain window (pl. 17), which extends down the Blue Ridge scarp to the edge of the Piedmont. Doubtless the Grandfather Mountain structure is somehow related to the thrust complex discussed here.

STRUCTURE OF THE BASE OF THE SHADY VALLEY THRUST SHEET

In order to illustrate the relations between the rocks of the Shady Valley thrust sheet and the fault at its base a map has been prepared to show the areal geology of the hanging wall of the fault (fig. 20). This map shows that three of the many overriding units cover most of the fault surface—the Precambrian, the upper division of the Unicoi formation, and the Honaker dolomite. The map also brings into order many minor and otherwise inexplicable features, such as the short segment southwest of the map area where the Rome formation comes down against the Iron Mountain fault.

The gentle warping of the Shady Valley thrust sheet and the general parallelism of its strata to the Holston

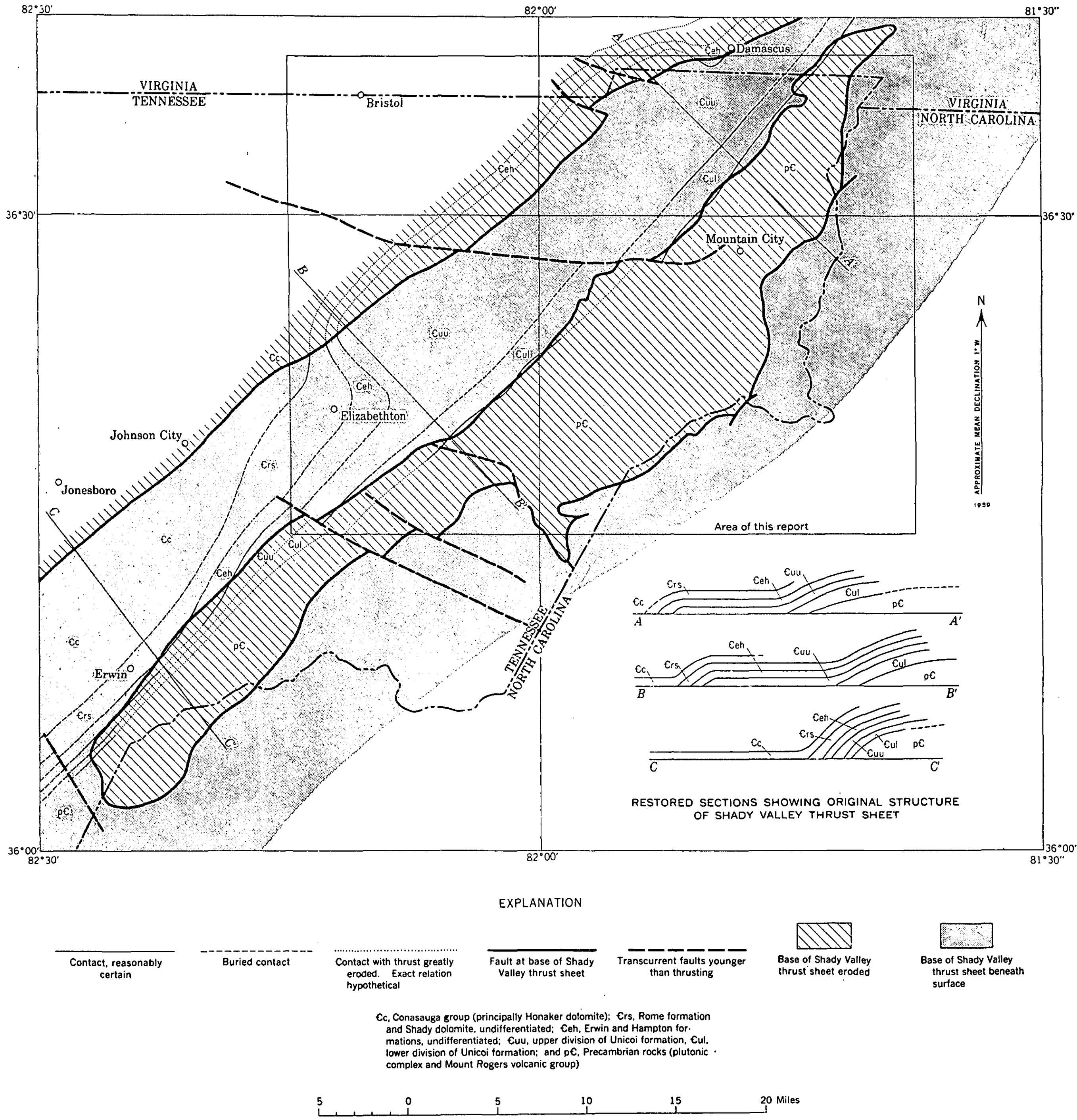

FIGURE 20.—Interpretative map and sections showing geology of the hanging wall of the Holston Mountain–Iron Mountain–Stone Mountain fault complex, and the areal pattern of the formations that lie at the base of the Shady Valley thrust sheet.

Mountain and Iron Mountain faults suggest that prior to the thrusting the rocks had been little deformed. The break along which the thrust developed ascends northwestward through these little deformed overriding formations. Along the Iron Mountains side it lies near the base of the Unicoi formation, or in the Precambrian rocks just beneath. Along the Holston Mountain side the fault lies well up in the Unicoi formation, and in the much higher Honaker dolomite.

The fault did not, however, cut through all the formations without deflection, as suggested by Keith (1907, fig. 3), who pictured the thrusts as simple planes of low-angle shearing. Over wide areas, as shown on figure 20, the fault follows single horizons in the overriding block, and passes abruptly from one to another. These horizons are relatively incompetent, and were no doubt connected by steep planes of shear, as in the much simpler Pine Mountain fault farther northwest (Rich, 1934, p. 1589–1591). After the thrust sheet had moved forward over a relatively flat surface, the rocks above the steep parts of the break would be warped into flexures, as shown in the sections on figure 20. The structure of the thrust sheet gives some indication of such flexures, especially at the abrupt southwest termination of Holston Mountain, where the thrust rises from the Unicoi formation to the Honaker dolomite; the flexure here seems to have localized the faulting of the Watauga River zone.

Southeast of the Iron Mountains the original relations of the thrust to the structure of the overriding rocks cannot be determined, as these rocks belong to the nonstratified Precambrian basement. Here, if anywhere, the thrust may be a low-angle shear as envisioned by earlier geologists.

STRUCTURE OF THE ROCKS BENEATH THE SHADY VALLEY THRUST SHEET

The probable structure of the rocks overridden by the Shady Valley thrust sheet is indicated on a map that shows the areal geology of the footwall of the fault (fig. 21). This is more generalized and speculative than figure 20, because there is little evidence of the relations where the fault has been removed by erosion or is deeply covered, and because it is uncertain to what extent the structures of the overridden formations were formed before, during, or subsequent to the faulting. This difficulty is especially great in structures exposed some distance from the fault trace, as those in the Appalachian Valley and the Doe ridges.

In general, the break ascends northwestward through the overridden rocks, as it does in the overriding rocks. Precambrian rocks, or rocks in the lower part of the Unicoi formation lie beneath the fault along the Stone Mountains; the Shady dolomite and Rome formation lie beneath it along the Iron Mountains; the Knox group and Middle Ordovician series lie beneath it along much of Holston Mountain.

Besides this broader structure, the fault truncates many lesser structures, such as the anticline of the Knox group near Webb Spring and Underwood Spring at the foot of Holston Mountain, isoclinal folds in the Shady and Rome formations at the foot of the Iron Mountains, and the folded and faulted belt of Chilhowee group in the Stone Mountains. It also overlaps the upper end of the homocline at the southeast edge of the Appalachian Valley between Damascus and Denton Valley, the lowest formation emerging from beneath the Holston Mountain fault being the Erwin near Damascus, and the Rome and Elbrook farther southwest. This homocline must be the northwest flank of an uplift on which the Chilhowee group is extensively in contact with the fault, and whose crest is concealed by the Shady Valley thrust sheet; on the opposite side of the thrust sheet near Laurel Bloomery the Iron Mountain fault again lies on the higher Rome formation (fig. 21).

Clearly the fault overrode considerably deformed rocks. This fact is significant in the history of the evolution of the structural features (see p. 85).

RELATION BETWEEN ROCK FACIES AND THRUST STRUCTURE

The distribution of rock facies in the Precambrian basement and the Cambrian formations aids in proving the great extent and displacement of the low-angle thrust faults. The basement rocks above the Stone Mountain faults differ from those in the Shady Valley thrust sheet and Mountain City window, and the Cambrian rocks of the Shady Valley thrust sheet differ from those in the Mountain City window and Appalachian Valley.

As shown by Hamilton, the basement rocks of the Mountain City window include massive granitic intrusives south of Pond and Little Pond Mountains, and at Beauty Spot southwest of the map area; at some other localities the basement is a plutonic complex. A somewhat similar plutonic complex is present at the base of the Shady Valley thrust sheet southeast of the Iron Mountains. The structures of all these rocks were largely older than deposition of the unconformably overlying Unicoi formation; subsequent deformation is represented at most by minor shearing related to the thrusting. By contrast, the basement rocks southeast of and above the Stone Mountain faults are gneiss and migmatite produced by plutonic metamorphism of an earlier terrane, which have in turn been altered profoundly by pervasive regional shear, perhaps in early Paleozoic time. They obviously have had a different history from the basement rocks of the Mountain City window and Shady Valley thrust sheet and before thrusting lay a considerable distance southeast of their present positions.

The Chilhowee group of the Shady Valley thrust sheet is thicker in all its subdivisions than in the Mountain City window, and the lower division of the Unicoi is very much thicker (fig. 6). Also, the Unicoi formation of the thrust sheet contains characteristic lavas that are lacking in much of the window, and the Erwin formation of the thrust sheet lacks the thick and nearly continuous bodies of quartzite characteristic of the formation in the window and the Appalachian Valley. The Chilhowee group of the window is somewhat more like that of the thrust sheet toward the southeast, in the Stone Mountains but even here it is not as thick. If the Chilhowee sections of the Shady Valley thrust sheet were restored to their original relative positions southeast of the Mountain City window the group

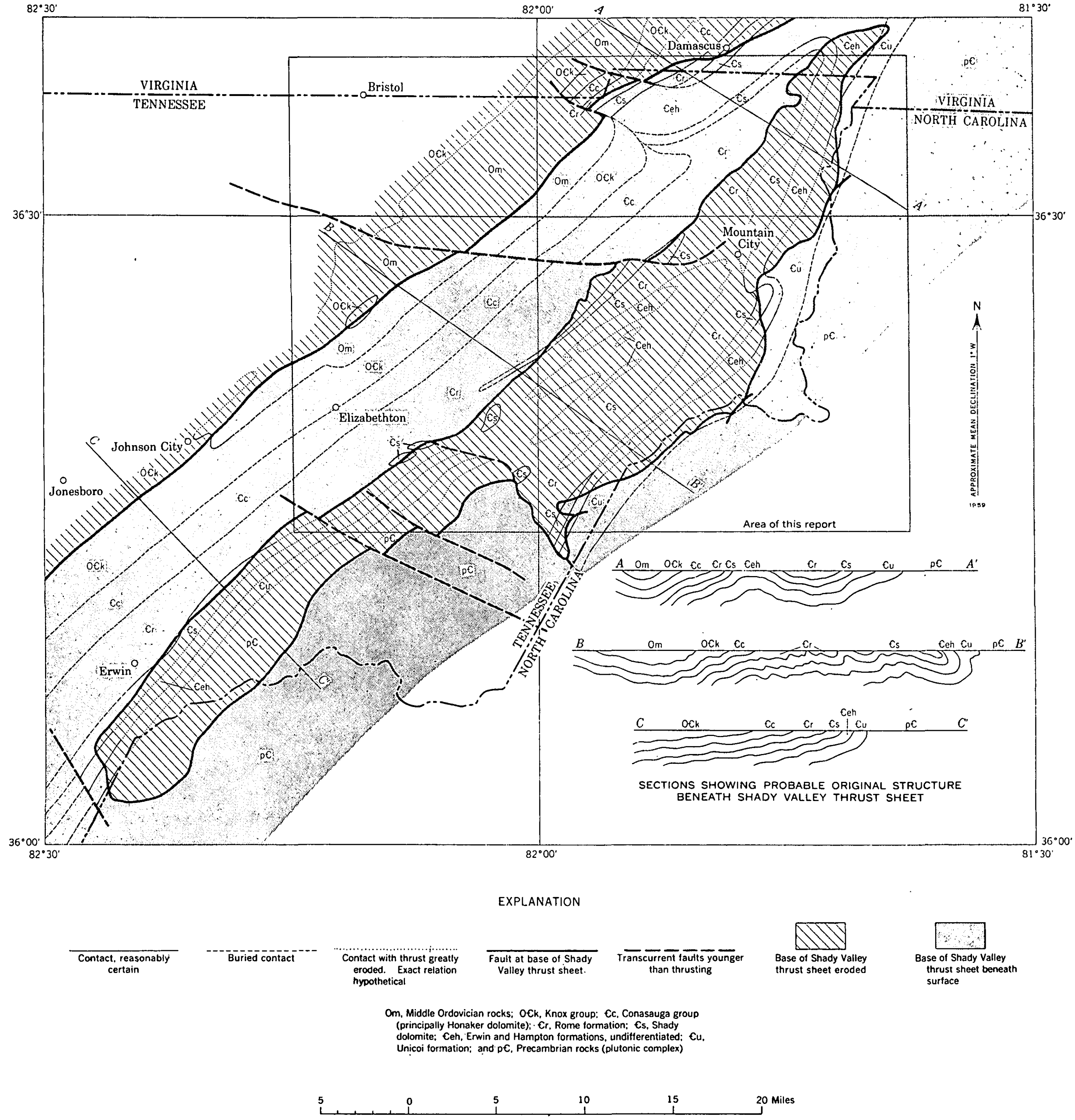

Figure 21.—Interpretative map and sections showing geology of footwall of Holston Mountain-Iron Mountain-Stone Mountain fault complex and the areal pattern of formations overridden by Shady Valley thrust sheet, which are now exposed in the Mountain City window and Appalachian Valley.

would thin in an orderly manner toward the northwest, with beds of lava wedging out in the lower part and with quartzite thickening in the upper part (fig. 6 *B*).

The Shady dolomite of the Shady Valley thrust sheet contains considerable ribboned dolomite and limestone, which are a southeastern facies; ribboned carbonates are lacking in the Mountain City window, which now lies southeast of the thrust sheet. Conversely there is much more white dolomite, a northwestern facies, in the Mountain City window than in the Shady Valley thrust sheet. Facies boundaries in the Shady must originally have extended nearly north-south across the basin of deposition, diverging widely from the trend of structures later superimposed on it, for in the Austinville area in the Appalachian Valley of southwestern Virgina the Shady dolomite beneath the thrust sheet contains ribboned carbonates and a clastic fossiliferous near-shore facies that is not represented in Tennessee.

In the Conasauga group there is evidently still greater divergence between facies boundaries and the present strike, as the Nolichucky shale occurs above the Honaker dolomite in the southwest part of the Shady Valley thrust sheet and also across the Appalachian Valley to the town of Honaker in southwestern Virginia; to the east, the Conasauga group is represented by the Elbrook dolomite alone.

DISPLACEMENT OF THE SHADY VALLEY THRUST SHEET

The faults at the base of the Shady Valley and related thrust sheets are exposed across the strike for 10 to 18 miles. This breadth of exposure is, of course, not a measure of the fault displacement. The Pine Mountain fault farther northwest has a known breadth of at least 20 miles, but its net displacement at about midlength, in the Rose Hill area of southwestern Virginia, has been determined by matching beds on opposite sides as 5.8 miles (Miller and Fuller, 1947). On the Shady Valley thrust sheet, however, no rock unit or structure in the overriding block can be matched with any in the overridden across the entire breadth of exposure, and hence the thrust sheet traveled at least this distance and probably more. Thus, the Chilhowee group of Holston Mountain at the northwest edge of the thrust sheet must have been deposited southeast of the Chilhowee group of the Stone Mountains at the southeast edge of the Mountain City window. How far southeast of the Stone Mountains the Shady Valley thrust sheet originated is a matter for conjecture. Further evidence may be obtained from work in the Grandfather Mountain window farther southeast.

Variations in displacement of the Shady Valley thrust sheet along its strike are unknown, although the left-lateral movement on the faults on the Watauga River zone suggests that displacement may increase from southwest to northeast. Perhaps maximum lateral displacement took place near the area of maximum stratigraphic displacement on Holston Mountain, where the lower part of the Chilhowee group overrides the Middle Ordovician series. Southwestward, where the Honaker dolomite forms the base of the thrust sheet, equivalent carbonate formations form both the overriding and overridden block, the displacement might be relatively less. The Shady Valley thrust sheet may thus have advanced counterclockwise around a pivotal area located somewhere southwest of the region of the present report.

Another question remains—what has become of the strata that once overlay the Rome and Shady formations of the Mountain City window? Higher formations are preserved, not only in the Appalachian Valley to the northwest, but in the Shady Valley thrust sheet that originally lay to the southeast; in the window they were surely once present also. In the Mountain City window the sedimentary sequence extends upward into the incompetent beds of the Rome formation but no higher; in the Appalachian Valley the sedimentary sequence in each thrust sheet extends down into the Honaker dolomite or Rome formation, but no lower. The thrust sheets in the Appalachian Valley were thus derived by wholesale stripping of the rocks above the Rome formation from some area to the southeast. The rocks that once overlay the Mountain City window probably formed a thrust sheet in the Appalachian Valley similar to those now preserved there, but it was probably higher and has been long since eroded; the thrust sheets still remaining are believed to be beneath and to be independent of the Shady Valley thrust sheet.

STRUCTURES YOUNGER THAN THE THRUST COMPLEX

Emplacement of the Shady Valley thrust sheet took place fairly early in the orogenic history as its features have themselves been deformed. The folding of the Shady Valley thrust sheet into the Stony Creek syncline and Mountain City window does not reflect its original configuration, for it is unlikely that the thrust sheet could have moved forward on so irregular a surface, at least without more slicing than is now visible. In places, it is true, the slope of the thrust plane is very gentle, but in most places it dips more than 30°; near the southwest corner of the map area it is nearly vertical on the northwest flank of the Mountain City window. Where the fault dips steeply it must have been rotated as much as 90° from its original position. This rotation seems to be confirmed by the northwestward dips of the slaty cleavage in nearby argillaceous layers.

The Shady Valley thrust sheet and other parts of the thrust complex have been broken by later high-angle transcurrent faults. The largest of these are the Cross Mountain fault and the two transverse faults near Hampton, but many smaller breaks offset the low-angle faults. The transcurrent faults are among the youngest features of the region, as they displace not only the low-angle thrusts but the warped structures into which these faults and their thrust sheets were shaped. It is significant that the major transcurrent faults show a right-lateral displacement, opposite to that of the Watauga River zone that formed during the thrusting. This suggests that the more active segment of this part of the southern Appalachians lay to the northeast during emplacement of the Shady Valley thrust sheet, but later shifted to the southwest. Farther southwest, folds and thrusts may have continued to advance after thrusting had ceased in northeasternmost Tennessee.

CHRONOLOGY OF DEFORMATION

The structures of northeasternmost Tennessee developed over a long period. Besides the large, evident structures that are younger than any of the rocks now exposed in the region, other features suggest that disturbances took place in or near the region in earlier Paleozoic and in Precambrian time. Time relations of the structures are suggested by various lines of evidence: (1) Superposition of one larger structural feature upon another, such as the warping of the thrust sheets. (2) Superposed minor structures, especially in the crystalline basement rocks, such as cataclastic foliation transecting an earlier plutonic foliation. (3) The record of the Paleozoic sedimentary rocks in or near the region, notably the occurrence of thick masses of clastic sediments, probably of orogenic origin, overlying or intercalated between finer grained nonorogenic sediments. In part, these three lines of evidence supplement each other, but parts of the different records cannot certainly be correlated.

A Precambrian period of deformation is indicated by the profound unconformity separting the basal Chilhowee group from the basement of plutonic and metamorphic rocks. To the southeast, moreover, where the Chilhowee group is not present scattered radiometric determinations in the basement rocks yield ages of 600 to 800 million years (Rodgers, 1952, p. 421–422), indicating plutonism in Precambrian time. The basement rocks change across the strike so as to suggest increasing metamorphic intensity northwestward. In the Spruce Pine district southeast of this region the rocks are schist and gneiss whose layering was probably inherited in considerable part from original sedimentary or volcanic bedding. In the thrust sheets in the southeast part of the map area, the rocks are granitic gneiss and migmatite, whose original bedding has largely been supplanted by plutonic structure. In the Shady Valley thrust sheet and Mountain City window the rocks are in part a plutonic complex, but include considerable bodies of massive granitic rocks, perhaps younger than the remainder of the basement, although still unconformable beneath the Chilhowee group.

A younger deformation of Middle Ordovician age is expressed in the sedimentary rocks of the southeastern edge of the Appalachian Valley. The great carbonate sequence of Middle and Late Cambrian and Early Ordovician time is succeeded abruptly by clastic rocks, thickening and coarsening to the southeast, where they include lenses of conglomerate made up of fragments of the earlier sedimentary rocks (Kellberg and Grant, 1956; Neuman, 1955). However, the Middle Ordovician clastic rocks are deformed equally with the rocks beneath, and no marked unconformity or overlap exists at their base. Evidently the earlier sedimentary rocks were uplifted, folded, and eroded in areas southeast of the present outcrops of clastic rocks, but the precise area of the disturbance is not now known.

A possible product of the Ordovician deformation in the southeastern area is the regional shearing of the basement rocks, which has altered parts of the earlier plutonic fabric to mortar and flaser gneisses and to phyllonite. Unlike the older structures in the basement rocks, those produced during this deformation increase in intensity southeastward, being absent in the basement rocks of the Mountain City window and Shady Valley thrust sheet and becoming increasingly prominent southeastward. They are thus most evident in areas where a cover of Chilhowee group is lacking, so that the deformation which produced them cannot be dated by stratigraphic means. On the basis of relations to radiometrically dated pegmatites of the Spruce Pine district and on other data, partly contradictory, Hamilton suggests that the shearing may be of early or middle Paleozoic age, possibly roughly correlative with the Middle Ordovician clastic rocks of the Appalachian Valley.

The gross structural features of the region possess so much kinship that they evidently formed during a single orogenic period, younger than any of the early Paleozoic rocks now preserved in the region and probably of late Paleozoic age. Nevertheless, successive structures are superimposed in such a manner as to indicate that the orogenic period was prolonged, and it may have extended through one or more geologic periods.

In general, orogenic belts are built by progressive growth of folds and thrust blocks away from the direction of deforming force and toward the stable foreland, with structures becoming progressively younger in this direction. Compression builds up masses of folded and faulted rocks until their weight counterbalances the effect of thrust, after which hitherto undisturbed rocks farther from the deforming force are affected (Campbell and Holden, 1925, p. 92–93). In the complex growth of an orogenic belt it is possible, however, that some exceptional structures arise in the rear of those already formed. The Pulaski fault of southwestern Virginia appears to be younger than structures beneath and northwest of it (Campbell and Holden, 1925, p.

93–94); some of the structures in northeasternmost Tennessee seem to have similar relations. Thus, the rocks on the northwest, in the Appalachian Valley and Mountain City window, were deformed by the time they were overridden by the Shady Valley thrust sheet, whereas the rocks of the thrust sheet, which originally lay farther southeast, were very little deformed prior to thrusting. Moreover, the Shady Valley thrust sheet appears to be older than and truncated by other thrust sheets of the Stone Mountain family on the southeast.

The features mentioned are probably manifestations of a continuous process. The structures overriden by the Shady Valley thrust sheet may have formed in front of or beneath it as it advanced; relations near Sowbed Gap suggest that some of the structures of the overriden block were formed after the first and before the final phases of the thrusting. Possibly also, the warping of the Shady Valley thrust sheet into the arch of the Mountain City window began before thrusting had ended in the region, and may have been accompanied by folding and slicing of the rocks of the Doe ridges in the central segment. On coming against this obstacle, the advancing higher sheets of the Stone Mountain family southeast of the window split from and overrode the Shady Valley thrust sheet, and also moved past the central segment of the window at its ends, forming the northwestward-trending fault segments near Roan Creek and Elk River. The resulting pattern would be that of an "eyelid window" as defined by Oriel (1950, p. 46).

The northwestward advance of the Shady Valley thrust sheet increased toward the northeast, as shown by left-lateral strike-slip displacements along the faults of the Watauga River zone. Later in the cycle, northwestward advance of the structures increased toward the southwest, as illustrated by right-lateral strike-slip displacements on the Cross Mountain and other transcurrent faults that break the Shady Valley thrust sheet and by progressive steepening to the southwest of the thrust sheets on the flanks of the Mountain City window. This increasing advance of thrusts and folds southwestward is toward one of the major salients of the southern Appalachians, whose apex is near the Great Smoky Mountains. A regional tectonic map, such as the one by Rodgers (1953a, fig. 5), shows that the Great Smoky and related faults at the apex of the salient cut off successively the southwestern ends of the Holston Mountain, Pulaski, and other faults of northeastern Tennessee, as though they overrode them. The Great Smoky fault may therefore have developed during growth of the salient, late in the cycle of thrusting and folding.

The possible history of the larger structural features just outlined, as deduced from their mutual relations, is summarized in figure 22:

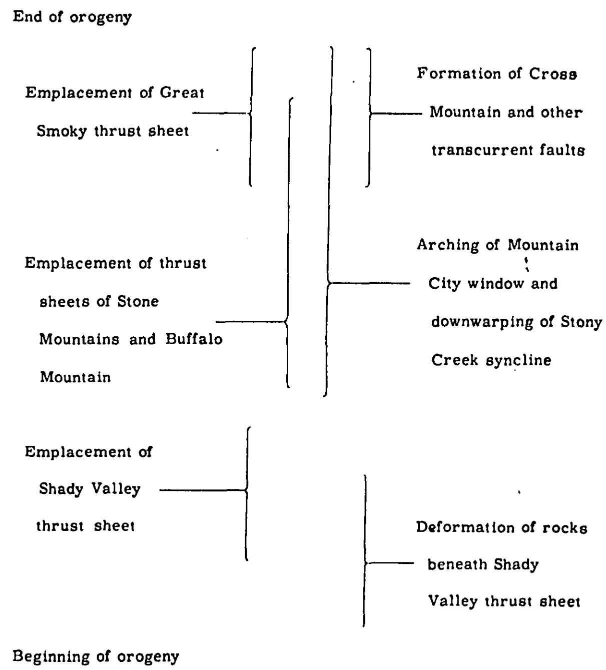

FIGURE 22.—Chronologic relations of structures of northeasternmost Tennessee.

The main orogeny of northeasternmost Tennessee is reflected in the basement rocks by minor structures such as narrow zones of shearing related to the major thrusts, and by deformation of the earlier foliation by broad warps, slip cleavage, and chevron folds.

The main orogeny is not recorded in the sequence of the Paleozoic sedimentary rocks nearby, as it took place much later than the youngest formations preserved, of Ordovician age. The Great Smoky fault southwest of the region, and the Pulaski and Saltville faults northwest of it, all override Mississippian rocks; the Mississippian sediments show little evidence of any contemporaneous orogeny, so that the main orogeny was certainly post-Mississippian. The possible relations of this orogeny to the Pennsylvanian and Permian (Dunkard) sediments now more distantly exposed in the Allegheny and Cumberland Plateaus to the northwest have been treated in another paper (King, 1950, p. 662–663).

MINERAL DEPOSITS OF HYDROTHERMAL ORIGIN

OCCURRENCE AND CHARACTER

Mineral deposits of hydrothermal origin occur in places in the region. Most of the natural showings have been explored by prospect openings, but very little ore has been produced. The deposits have been described in various previous publications (Bayley, 1923; Secrist, 1925; King and others, 1944), where their economic features have been treated; here their geologic features will be treated. Location of the prospects is shown on plate 1 of this report, and in generalized form on figure 23; they are also listed in the table below:

Prospects in hydrothermal mineral deposits

No. (pl. 1)	Name	Mineral	Formation	Reference
Butler district				
72	Dugger prospect	Sphalerite, barite, pyrite	Shady dolomite	King and others, 1944, p. 173.
77	Wagner prospect	Sphalerite	do	King and others, 1944, p. 172-173.
Stony Creek district				
83	Unknown	Barite	Shady dolomite	King and others, 1944, p. 187.
85	Helenmode mine	Pyrite	Helenmode member of Erwin formation.	King and others, 1944, p. 188.
86	Hatcher mine	do	do	King and others, 1944, p. 188-189.
Watauga district				
On Watauga River a little west of area of geologic map.	Watauga Point prospect	Sphalerite, galena, pyrite, chalcopyrite.	Knox group (basal)	Secrist, 1925, p. 140-141.
On Watauga River 1½ miles northeast of Watauga Point prospect.	Unknown	Galena	Honaker dolomite	R. A. Laurence and B. Gildersleeve, written communication, 1954.
Walnut Mountain district				
121	Whitehead or Keystone Ridge prospect.	Hematite, some magnetite	Granitic rocks south of Pond and Little Pond Mountains.	Bayley, 1923, p. 241.
122	Miller or Scrawls Ridge prospect.	Magnetite	Complex of Lunsford Branch area.	Bayley, 1923, p. 244.
123	Black Bear prospect	Magnetite, some hematite	do	Bayley, 1923, p. 242-243.
124	Rabbit Station prospect	Hematitic magnetite	do	Bayley, 1923, p. 242.
125	Mays Ridge prospect	do	do	Bayley, 1923, p. 242.
126	Finney and Teagarden mine	Magnetite and hematite	do	Bayley, 1923, p. 245-251.
127	Lunsford prospect	Magnetite, martite, pyrite	do	Bayley, 1923, p. 244-245.

The known deposits of hydrothermal origin are restricted to a relatively small part of the map area, and are clustered in local districts (fig. 23). Deposits in the Butler district extend about 3 miles along the strike on the southeast flank of the Doe ridges, those in the Stony Creek district lie within 3 miles of one another in the trough of the Stony Creek syncline, the two in the Watauga district lie within a mile and a half of each other. Those of the Walnut Mountain district are more widely scattered but lie within 5 miles of one another, and are limited to the area of basement rocks.

The hydrothermal mineral deposits in the Butler, Stony Creek, and Watauga districts are enough alike to suggest a similar origin and age. The Butler district contains abundant sphalerite, some barite, and minor amounts of pyrite and chalcopyrite. The Stony Creek district contains barite, pyrite, and possibly chalcopyrite. No sphalerite has been seen, although traces of zinc in the residual iron ores (King and others, 1944, p. 190) suggest that it may once have been present. Minerals in the Watauga district include sphalerite, galena, pyrite, and chalcopyrite.

All the deposits of the Butler, Stony Creek, and Watauga districts occur in the Paleozoic sedimentary rocks, chiefly in dolomite and limestone. Although the prospect openings are not extensive enough to permit final conclusions, they suggest that the deposits formed along zones of movement in the deformed bedrock, presumably during or shortly after the main orogeny of later Paleozoic time. The deposit at the Wagner prospect seems to follow particular beds in the steeply dipping Shady dolomite; that at the Dugger prospect is near a thrust fault in the Shady dolomite; that at the Helenmode mine seems to be associated with a bedding plane fault in the nearly flat-lying Helenmode member of the Erwin; that at the Watauga Point prospect occurs in limestone of the Knox group, along bedding showing traces of differential movement. Some of the other openings are in residual clay only and do not show the structure of the underlying bedrock.

The hydrothermal mineral deposits in the Walnut Mountain district are so different as to create doubt as to close relation with those of the other districts. The minerals are mixtures of magnetite and specular hematite in widely varying proportions, with a little associated martite and pyrite. They are entirely in crystalline basement rocks, in which they form lenses and layers along shear planes that, from Bayley's descriptions, appear to correspond to the shears of regional extent described by Hamilton, and interpreted as of

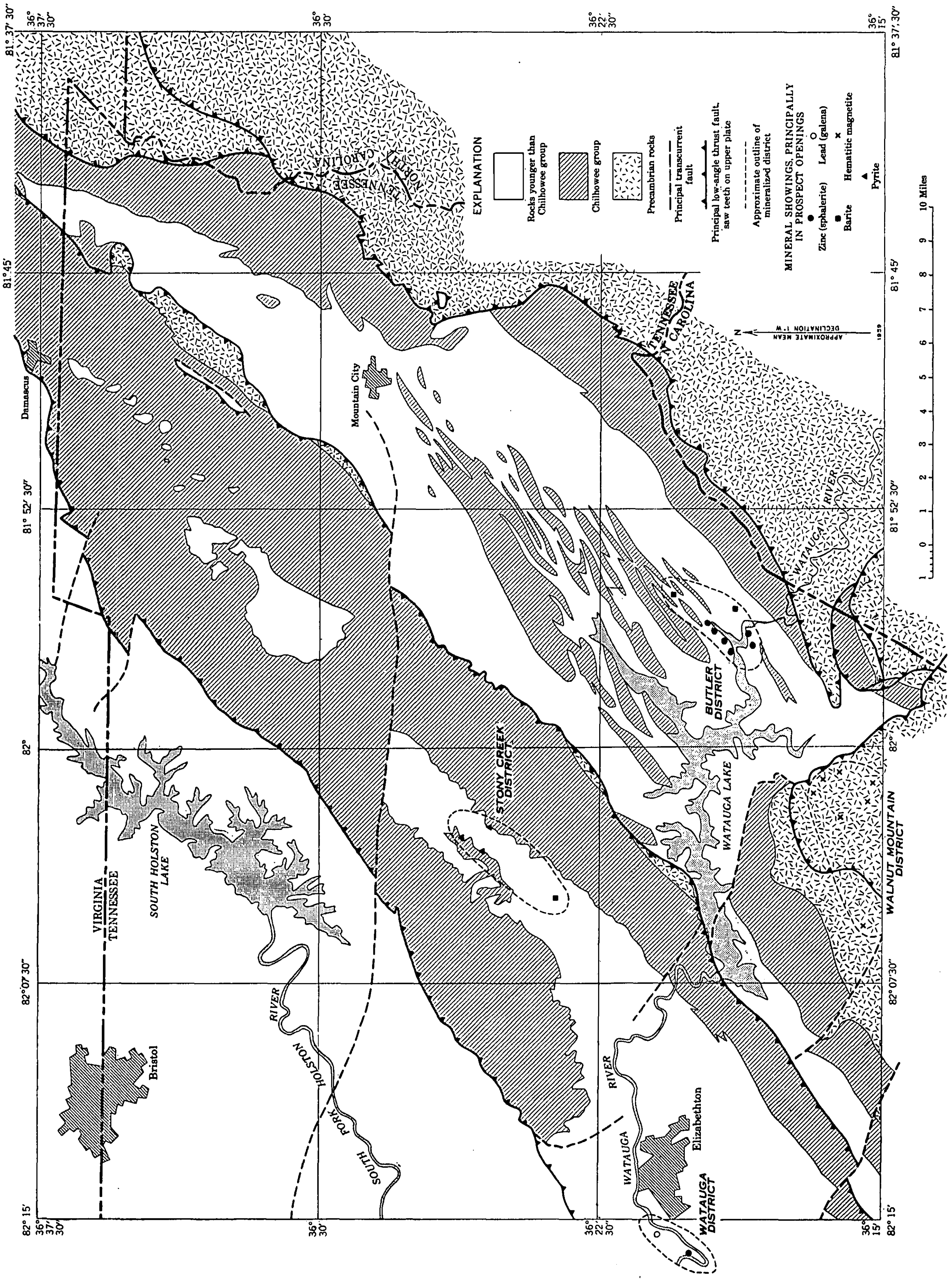

FIGURE 23.—Sketch map of northeasternmost Tennessee, to show location of known mineral deposits of hydrothermal origin.

early Paleozoic age. Bayley (1923, p. 67), in discussing the Tennessee-North Carolina magnetic ores in general, calls attention, however, to crushing and metamorphism of the ore minerals as revealed in thin section. The ores of the Walnut Mountain district may therefore have been introduced before the shearing and were altered by it, or they may have been introduced after the shearing had created a place for them and were metamorphosed later. Accordingly their age is unknown and is either Precambrian or Paleozoic.

In addition to the hydrothermal mineral deposits listed and discussed above, both primary and secondary uranium minerals have recently been found at several localities in the Precambrian basement rocks in the south part of the map area. They are currently being prospected (R. A. Laurence, written communication, 1954). The occurrences appear to be mainly in the granitic rocks of the Mountain City window, south and southwest of Pond Mountain. Johnston (1953, p. 199–200) reports that rocks in this area, mapped by Keith as Cranberry and Beech granites, are rather uniformly radioactive over most of their outcrop (see also p. 13).

Aside from the four districts listed, indications of hydrothermal activity in the region are slight. In many places in Stony Creek valley small pieces of specular hematite have been found in the residual clay of the Shady dolomite but never in place in the parent rock, where they must be sparse and widely dispersed. In Stony Creek valley the ribboned dolomite of the Shady is generally recrystallized, probably by the same processes that introduced the hydrothermal minerals (Rodgers, 1948, p. 13), but this seems to have resulted from reconstitution of the parent rock with little introduction of new material. The more deformed Shady dolomite of the Johnson County cove was also extensively recrystallized, but owing to the character of the dolomite here, it is not as prominent. In Shady Valley, even the ribboned dolomite has been little recrystallized.

Deposits of iron and manganese oxides, which occur in the residuum and other superficial materials overlying the Shady dolomite and Rome formation throughout the region, are attributed by some geologists (for example, Kesler, 1950, p. 48) to an ultimate hydrothermal source, but evidence (p. 48–49) shows that they were concentrated from original constituents of the sedimentary rocks. That these deposits are not related to those of hydrothermal origin may be seen by comparing the distribution of each as plotted on figures 23 and 27. Deposits of hydrothermal origin occur in limited areas; those in the superficial material occur regionally, mainly at stratigraphic levels a little above the top of the Chilhowee group.

Jasperoid has likewise been considered hydrothermal, but the principal occurrences of jasperoid, near Mountain City, are far from definite hydrothermal deposits, and there are no significant concentrations of jasperoid near the latter. These relations suggest that the jasperoid was formed by some other process, perhaps during weathering (p. 50).

REGIONAL RELATIONS

The hydrothermal mineral deposits represent outliers of a well-defined system that occurs widely in the early Paleozoic rocks of the Appalachian Valley of Tennessee and southwestern Virginia, which have been mined chiefly for zinc and barite (Secrist, 1924; Currier, 1935; Edmundson, 1938; Oder and Hook, 1950). These deposits, although hydrothermal, were probably formed at lower temperatures than the sulphide deposits of Ducktown type (Ross, 1935), and the gold deposits of the Piedmont (Pardee and Park, 1948), which occur farther southeast in more highly metamorphosed rocks.

The age and origin of the hydrothermal deposits in the Southeastern States have been much debated. Some authors have suggested that all are of late Paleozoic age, the different systems representing successive zones marginal to the granitic rocks of supposed Carboniferous age in the Piedmont province (Pardee and Park, 1948, pl. 7); however, much of this granite now appears to be of considerably earlier Paleozoic age (W. C. Overstreet, written communication, 1955). A late Paleozoic age for the ores of Ducktown type is suggested by a radiometric determination by the helium method on pyrrhotite from the Ducktown area that yielded an age somewhat greater than 200 million years (Rodgers, 1952, p. 415–416). The zinc and barite deposits in the Appalachian Valley were introduced along faults, breccia zones, and other lines of structural weakness and hence were either formed late in the deformation, or after it. Most geologists have interpreted the zinc and barite deposits as of late Paleozoic age, but Edmundson (1938, p. 16) suggests that the barite deposits of Virginia are of Triassic age.

The small hydrothermal deposits of northeasternmost Tennessee seem to conform to the larger system of deposits of which they are a part, have been introduced into rocks already deformed, and are either of late Paleozoic or Triassic age.

CENOZOIC DEPOSITS AND LAND FORMS

Overlying the Precambrian and Paleozoic rocks of northeasternmost Tennessee are residuum and various unconsolidated deposits that formed during the Cenozoic era. The Cenozoic was primarily a time of erosion, and residuum and deposits formed during only a small part of the time. Thus, to understand the Cenozoic, not only these but also the land forms shaped during the time must be discussed.

During the Cenozoic era, erosion lowered the land surface unequally according to the resistance of the different rocks. In general, limestones and dolomites form the lowlands, shale stands up as hills, and the clastic rocks of the Chilhowee group remain as high mountain ridges. Topography in the plutonic and metamorphic rocks is equally varied, but is less obviously related to lithology; near major streams are narrow valleys and steep-sided ridges, but elsewhere some areas still project as high mountains.

Erosion has been intermittent, with times of stillstand when there was extensive planation of the weaker rocks, alternating with times of accelerated downcutting when the planed-off surfaces were partly destroyed. An especially long time of stillstand, or closely spaced times of stillstand, created extensive valley floors that lie several hundred feet above modern drainage. This time was also one of deep and prolonged weathering, during which the rocks of the floor were thickly blanketed by residuum; it was furthermore a time when extensive deposits of iron and manganese oxides and local deposits of bauxite were formed in the materials of the valley floor. As these are the only minerals that have been mined in large amounts in the region, study of the Cenozoic deposits and land forms to which they are related is of economic interest.

In general, Cenozoic climate was warm and humid, and did not differ markedly from that at present. There has thus been deep chemical decay of the bedrock—greatest in the carbonate rocks, less in the feldspathic rocks, and least in the quartzose rocks. A more rigorous climatic interlude during the Pleistocene period is indicated by talus and block fields, which are derived from more massive and chemically resistant rocks. These accumulated on some of the mountain slopes on land forms and materials that had evolved during the preceding and longer times of warmer climate.

LAND FORMS ABOVE THE VALLEY FLOOR

Rising above the valley floors of the region are the mountains of the Unaka province, composed of clastic rocks of the Chilhowee group, and mountains of the Blue Ridge province, of plutonic and metamorphic basement rocks (fig. 2). Many of the mountains rise to altitudes of more than 4,000 feet, although adjacent ones may be a thousand feet lower. A few in the southeast part of the region, such as Snake Mountain and Rich Mountain, rise to more than 5,000 feet. Ridge forms are varied, but crests are generally narrow, with little flat ground along the tops, and with few spurs that extend any great distances across the strike.

Evidence of the former existence of erosion surfaces at or near the present ridge summits of the region has been cited by various geologists. Wright (1931, p. 160–161) describes an upland level near the headwaters of the Watauga River, in the Blowing Rock area of North Carolina, at an altitude of about 4,000 feet, with Grandfather Mountain and other summits rising above it as monadnocks. Keith (1903, p. 7; 1907, p. 9) postulates surfaces in the Cranberry quadrangle at 3,400 to 4,000 feet, and in the Roan Mountain quadrangle at 3,500 to 3,600 feet, at 3,000 feet, and at 2,600 feet. King and others (1944, p. 43) indicate that the crests of Holston Mountain and the Iron Mountains and their transverse spurs, at altitudes near 4,000 feet, are probable remnants of an erosion surface. This is believed to have sloped longitudinally toward the water gaps of Watauga River and Laurel Creek, and laterally toward Stony and Beaverdam Creeks, so that the mountain areas of the time rose above the valleys as broad, convex arches.

Much doubt exists, however, as to the original character and even the reality of high-level surfaces in the southern Appalachians. It has been pointed out that accordant levels on narrow homoclinal ridges in the northwestern part of the Ridge and Valley province, which have been interpreted as remnants of these surfaces, could have been produced as well or better by normal slope retreat during a single cycle of erosion, the altitude attained depending on the thickness, inclination, and other attributes of the ridge-making beds (Rich, 1933, p. 1231–1233; Cooper, 1944, p. 213–216). Even if a high-level erosion surface once existed in the Appalachians, it has probably been lowered many hundreds of feet since its formation, and may have been broken into sets of accordant remnants standing at more than one altitude, depending on the relative resistance to erosion of different parts of the bedrock (Ashley, 1935, p. 1403–1404).

In nonhomoclinal or massive rocks such as those in the Blue Ridge province it is doubtful that slope retreat alone could produce accordant levels. The multiple erosion surfaces reported by Keith from that area might have been formed by differential lowering of a single initial surface, might be remnants of a single surface of much initial relief, or might be the products of local base-leveling, controlled by belts of hard rock downstream.

Holston Mountain and the Iron Mountains resemble more nearly the homoclinal ridges farther northwest, as their longitudinal crests are formed of resistant quartzite of the upper part of the Unicoi formation that dips toward the intervening Stony Creek syncline. Their crests are somewhat undulatory, with local relief of as much as 500 feet; their general inclination toward the water gaps at the ends suggests control by retreat of slopes away from modern drainage at the sides. However, transverse spurs that extend from the longitudinal ridges toward the axial streams of the Stony Creek syncline seem to indicate the existence of a former high-level surface. Between the main summits formed by the upper division of the Unicoi and the dip slopes on the top quartzite of the Erwin formation that face the valley floor (2 on fig. 25) their crests slope gently toward the axis (1 on fig. 25), and truncate the whole thickness of the Hampton and Erwin formations that dip more steeply in the same direction.

VALLEY FLOORS

The valley floors, or extensive areas of low relief that stand below the mountain ridges, yet well above modern drainage, occupy perhaps half the area, forming much of the surface of the Johnson County and Doe River coves, Shady Valley and Stony Creek valley, and the main Appalachian Valley. The parts within the Unaka province are cut mainly on the Shady dolomite and Rome formation, but in the vicinity of Elizabethton these parts are continuous with the floor of the Appalachian Valley which has been carved from younger carbonate and argillaceous rocks. Equivalent surfaces are also recognizable farther up the Watauga and other large streams, cut on the plutonic and metamorphic rocks of the Blue Ridge province.

The valley floors are generally considered to represent the Valley Floor or Harrisburg peneplain, but although they are generally accordant they are floor-like mainly by contrast with the steeper mountains. They are complex in detail, consisting of hills, ridges, sinks, and terraces, all more or less dissected by recent drainage. Their surfaces expose unweathered bedrock, residuum, and gravel deposits.

The geologic map (pl. 1) chiefly emphasizes bedrock formations and structures; the only surface materials differentiated are the alluvium of the present flood plains and the small areas of clay at the southwest end of Holston Mountain. In the previous publication on the region (King and others, 1944, pls. 2, 3, 4, and 6), the materials of the upland areas were differentiated into parts where bedrock is widely exposed, where it is covered by residuum, and where it is covered by gravel deposits; such a subdivision gives a clearer picture of the diversity of the valley floor surface.

MATERIALS OF THE VALLEY FLOORS

RESIDUUM

All the valley floor surface has long been subject to weathering in a warm humid climate. The bedrock is deeply decayed and the soluble carbonate rocks dissolved, leaving an insoluble residuum, principally clay, but including fragments of chert, jasperoid, sandstone, and nodules of iron and manganese oxides; detailed nature of the residuum of the Shady and Rome formations has been described on pages 50–51, 53. In many parts of the valley floor it has been removed incompletely, and still blankets the unweathered bedrock.

The thickest and most extensive masses of residuum overlie the Shady dolomite, probably because of its position at the edges of the valleys and the bases of the mountains, relatively far from streams that would remove material. The thickest residuum is commonly over dip slopes of the underlying quartzite (fig. 9), perhaps because deeper circulation of ground water was possible there. The most extensive areas of residuum over the Shady are all near the level of the now-dissected valley floor. Residuum is generally sparse or lacking on slopes cut below the floor, where outcrops of dolomite are more numerous. In Stony Creek valley, the size of the upland areas and the extent of the residuum that lies on it become progressively less toward the through-flowing Watauga River at the lower end (King and others, 1944, pl. 5). Conversely, the Shady dolomite of Shady Valley at the head of Beaverdam Creek is very largely represented by residuum, and outcrops of dolomite are small and sparse (King and others, 1944, pl. 2).

Residuum is thinner over the Rome formation than over the Shady, as it contains greater thicknesses of poorly soluble shale beds; residuum like that of the Shady has formed over the interbedded limestone and dolomite layers.

On the higher carbonate formations residuum is apparently thin and discontinuous, even though some of the units contain as much argillaceous impurities as the Shady, or more. In Denton Valley and near Elizabethton, exposures of unweathered carbonate rocks of the Conasauga and Knox groups appear to be much more extensive and continuous than those of unweathered Shady dolomite in comparable areas. Thicker bodies of residuum may be present locally over these formations in swales and sinks, but if so they are less exposed in natural or artificial openings than the residuum of the Shady. The surfaces of the higher carbonate formations generally have been degraded below the level of the valley-floor surface, with which the residuum of the Shady is associated. They also lie farther out in the valleys and nearer the major streams, where residuum can be more readily removed, either during formation, or during subsequent dissection of a residuum-blanketed surface.

These relations suggest that residuum is not now actively accumulating; although the carbonate formations are currently being leached, the insoluble constituents probably are now being removed by erosion almost as rapidly as they are released. Most of the residuum probably accumulated when the valley floor was undissected, and perhaps had been worn down nearly to base level, so that the insoluble weathering products could not be carried away. The present upper surface of the residuum is one of erosion, so that the original thickness and form of surface cannot now be determined. Many mine workings and road cuts show residuum unconformably overlain by gravel deposits that truncate the contortions in the clay, and contain reworked nodules of iron and manganese oxides derived from it. Most of the residuum must have accumulated before the gravel was deposited.

The time of accumulation is uncertain. The valley floor on which the residuum lies has been correlated with the Harrisburg peneplain, which has been assigned variously to an early Tertiary or to a late Tertiary age (Stose *in* Stose and others 1919, p. 34–40; Johnson, 1931, p. 14–21). Many geologists agree that the residuum accumulated, and the closely related iron, manganese, and bauxite deposits formed under unusual conditions of climate, weathering, ground water circulation, and erosion (Hewett, 1916, p. 45–47; Rodgers, 1948, p. 40; King, 1949b, p. 82–83; Bridge, 1950, p. 196–198). The geologic date of these unusual conditions is unknown, although some evidence, cited below, indicates that the bauxite deposits formed in early Tertiary time.

SHALY CLAY, KAOLINITIC CLAY, AND BAUXITE

Near the southwest end of Holston Mountain north of Elizabethton, nine small areas of "shaly clay and kaolinitic clay" are differentiated on the geologic map (pl. 1), and are assigned a doubtful Tertiary age. Two of the areas are at the Watauga bauxite mine, another at the Red Bird Hill bauxite mine; most of the rest are within a mile to the southeast and south. Some are on high-level benches, others on lower ridges; no single deposit is more than an acre or two in extent. All lie in residual clay of the Shady dolomite, those at the Watauga mine being immediately downdip from outcrops of the Erwin formation, and the others farther out in the Shady. Surface and underground openings at the Watauga mine indicate that the shaly and kaolinitic clay forms steep-sided pockets in the residual clay with the residual clay even overhanging it on the south side of the opencut (fig. 24 *B*).

The material in the nine areas consists of lenticular beds of red and yellow clay and silt, with irregular masses of kaolinitic clay, and some conglomerate of angular shale fragments and rare quartz pebbles. At the Watauga and Red Bird Hill mines the kaolinitic clay incloses central cores of pisolitic bauxite of varying purity. Thin streaks of lignite have been found, both in the Watauga mine (fig. 24 *C*) and on the west side of Ellis Branch half a mile to the south-southwest, the latter locality having been first reported by Safford (1869, p. 498).

Lignite was observed by the senior author in a drift on the south side of the Curtis adit 275 feet from the entrance. Here it consists of fragments of disrupted lignitized wood embedded in clay and mascerated carbonaceous material; "fixed organic carbon and combined water comprise about half the material, volatile carbon being low" (J. G. Fairchild, written communication 1942). Specimens were examined by R. W. Brown of the U.S. Geological Survey and Ray Bentall of the Tennessee Division of Geology, and although the latter observed a few fungus spores, neither found any plant material sufficiently well preserved to permit a determination of age.

These deposits of shaly clay and kaolinitic clay are like no others in northeasternmost Tennessee, but remarkably resemble widely scattered small deposits elsewhere in the Appalachian Valley, from Virginia to Alabama (Bridge, 1950, p. 189–195). All consist of kaolinitic and lignitic clay, commonly with included bodies of bauxite, which lie near the valley floor level in pockets in the carbonate rocks or their residuum. Bridge believes that they were deposited in sink holes by streams draining from the Blue Ridge and Piedmont provinces, such as the Watauga River, and that the material was derived from weathering of the crystalline rocks of those provinces. He suggests that "they are only the roots of deposits that were formerly much more extensive, but whose upper parts have long since been removed by erosion."

Bridge further concludes that all these deposits in the Appalachian area were formed at essentially the same time, and also at the same time as bauxite deposits of the Gulf Coastal Plain, which can be dated stratigraphically as late Paleocene or early Eocene. Bridge states (1950, p. 197):

> The assumption that the bauxite deposits of the Appalachian Valley are of the same age is supported and strengthened by the occurrence of lignite associated with the bauxite deposits in both provinces, and also by the local association of bauxite deposits in the Appalachian Valley [of Alabama and Georgia] with fossil plants whose age is not younger than early Tertiary.

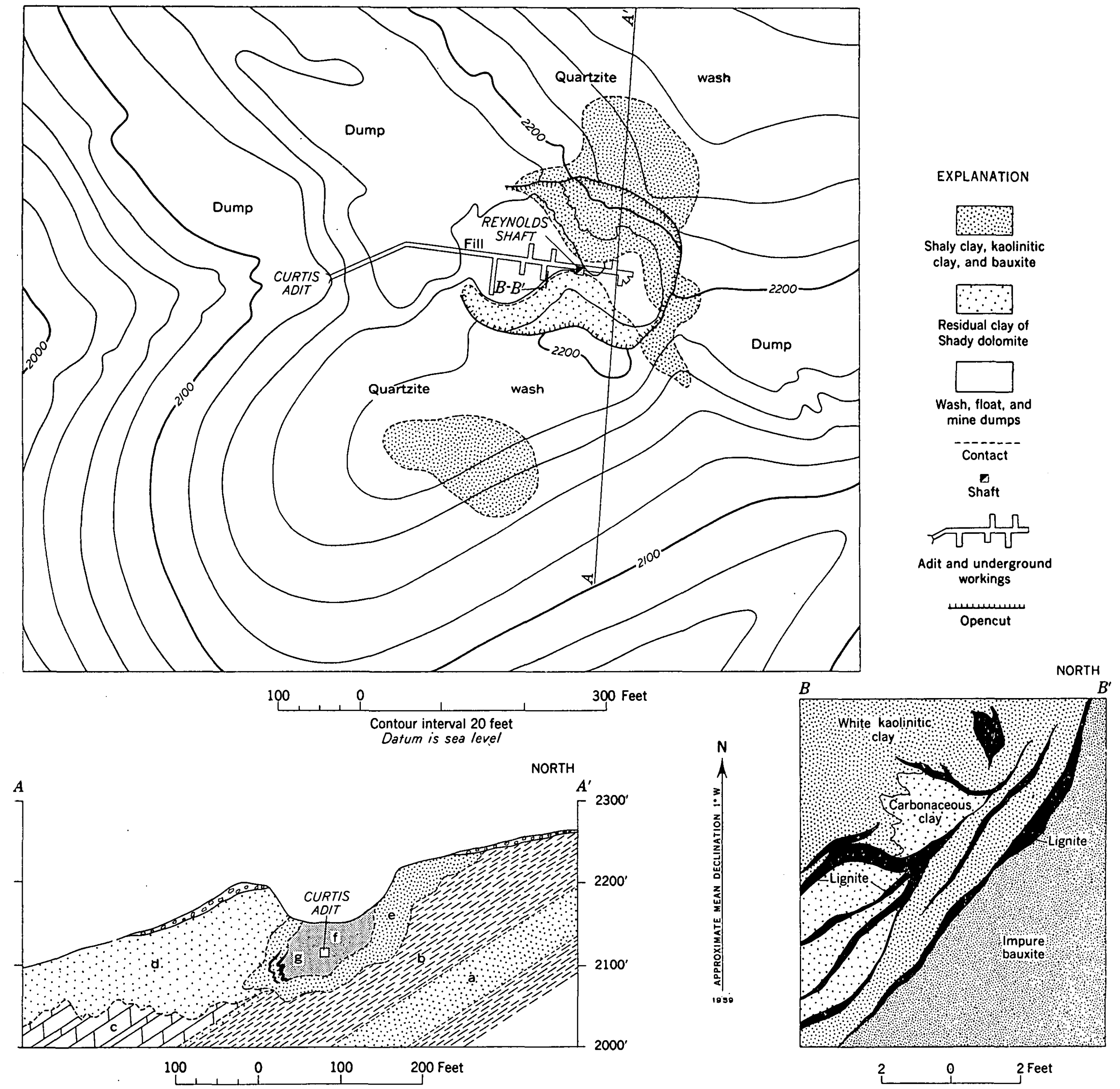

FIGURE 24.—Maps and sections showing relations of shaly clay, kaolinitic clay, and bauxite at Watauga bauxite mine at southwest end of Holston Mountain, north of Elizabethton. Section *A–A'* is based partly on drilling by Republic Mining and Manufacturing Co., in 1942. Sketch *B–B'* shows details of occurrence of lignite; east wall of drift 17 feet south of Curtis adit and 275 feet east of entrance of latter. *a*, Hesse quartzite member and *b*, Helenmode member of Erwin formation; *c*, unweathered dolomite and *d*, residual clay of Shady dolomite; *e*, kaolinitic clay; *f*, central core of bauxite; *g*, lenses of lignite.

GRAVEL DEPOSITS

Wide areas of the bedrock and residuum of the valley floors are covered by rudely stratified deposits of gravel, made up of water-rounded pebbles, cobbles, and boulders of sandstone and quartzite. These deposits were derived from the Chilhowee group in the adjacent mountains, and were brought to their present positions by streams. Where best preserved and least dissected they form steep fans or piedmont alluvial slopes along the mountain bases, and they flatten into gravel plains farther out in the valleys.

Most of the gravel is little weathered, but the deposits generally stand above present drainage and considerably antedate the present erosion cycle. Much of the valley floor consists of depositional surfaces on various levels of gravel deposits, which have been subsequently dissected. During deposition of the gravel, longitudinal gradients of the valleys were evidently less than now, as the principal deposits stand much higher above the main streams than above the head reaches of their tributaries. Depth of dissection decreases gradually up Stony Creek and Roan Creek from the Watauga River; gravel near the mouth of Roan Creek caps ridges 200 to 400 feet above the Watauga, whereas well up Roan Creek near Mountain City it forms benches scarcely 100 feet above the flood plain. Similar gravel benches in Shady Valley stand less than 100 feet above the alluvium at the head of Beaverdam Creek (fig. 25 *B*).

Some valleys contain gravel deposits at more than one level, apparently laid on successively lower surfaces. On the edges of Stony Creek valley, small gravel remnants cap marginal benches, 700 to 1,200 feet above the stream in the axis of the valley (no. 3 of fig. 25 *A*; fig. 26). Most other gravels are lower, the lowest in Stony Creek valley forming terraces only 50 or 100 feet above modern streams (no. 5, fig. 25 *A*); most gravel deposits occupy an intermediate position. During this survey little attempt was made at correlation of the deposits from one district to another; such details as are available are set forth later in the descriptions of the individual areas.

The bases of the gravel deposits, as exposed in artificial openings, lie unconformably on the eroded surfaces of fresh bedrock, weathered bedrock, or residuum; good examples may be seen on Tennessee State Route 67 near Watauga Lake. The erosional contact between gravel and residuum emphasizes that they were formed at widely different times and probably under incompatible conditions.

Small masses of gravelly material beneath the main body are more intimately related to the residuum. In the opencut of the Blevins mine near the head of Stony Creek valley, sand and clay containing deeply weathered boulders form a pocket in the residual clay of the Shady dolomite; like the residual clay they are mineralized by iron and manganese oxides and are overlain unconformably by younger gravel. In a road cut on U.S. Highway 19 E, southeast of Valley Forge (pl. 13 B), residual clay of the Shady dolomite is complexly infolded with red colluvial clay and bouldery gravel, and the whole overlain unconformably by younger gravel deposits and slope wash. Some of the other mine workings of the region show similar relations (King, and others, 1944, p. 244, 248–250). These earliest gravelly and boulderly deposits were evidently intermingled by slump, creep, and slope wash with the residuum on which they were originally deposited.

The different gravel deposits of the valley floors must be closely related in origin, and even those on successive surfaces are probably not far apart in age. Alternation between gravel deposition and downcutting probably resulted from climatic fluctuations. Gravels were laid down when more material was washed onto the valley floors from the adjacent mountains than streams could carry out of the region. Similar conditions obtain today, as the considerable volume of coarse material in the modern alluvium indicates, but conditions were much exaggerated during the times of gravel deposition.

During glacial stages of the preceding Pleistocene epoch, frost action was at a maximum in the mountains and at least the higher summits probably stood above timber line. Exposed rocks were thus broken, and fragments were moved in such quantities down the slopes as to overload the streams below; conditions suitable for deposition of gravel on the valley floors were thereby created. During interglacial stages, when the streams could transport the loads supplied to them, preceding gravel deposits were dissected, and general degradation of the whole region was resumed. Most of the gravel deposits, lying a few hundred feet above modern drainage, were probably thus formed during the Pleistocene epoch. The age of the higher gravel deposits, such as those 700 to 1,200 feet above Stony Creek valley, is less certain, although it would appear more likely that they formed during the early Pleistocene than during the Tertiary.

LOCAL FEATURES

APPALACHIAN VALLEY

The Appalachian Valley within the map area is eroded partly from shale and sandstone (Middle Ordovician) and partly from carbonate rocks (Lower Ordovician and Cambrian).

The shale and sandstone between the foot of Holston Mountain and the South Fork of Holston River to the northwest are intricately dissected into closely spaced, steep-sided knobs and ridges, whose crests slope toward the river where they stand at roughly accordant altitudes of about 2,000 feet. Along the foot of Holston Mountain bedrock is covered by boulderly wash from the Chilhowee group in a piedmont alluvial slope, now dissected, which is probably related to the gravel deposits on the valley floors farther southeast. The younger and lower parts of the deposit extend down into the heads of the modern valleys, but the older parts extend out on the ridge tops. Whether the accordant levels on the ridge crests nearer the river represent an erosion surface at the base of the gravel, or some older surface, has not been determined. The South Fork of the Holston River traverses the shale and sandstone knobs in tightly looped meanders (now largely submerged beneath South Holston Lake), unlike its gently curved course in the carbonate rocks upstream and downstream. These meanders may have been inherited from a surface of low relief near the level of the valley floor.

Carbonate rocks crop out northwest of the shale and sandstone knobs and also form the whole valley farther southwest near Elizabethton. Their surface is lower and more rolling than that of the shale and sandstone deposits, showing little accordance of summits. It is cut into a karst topography, with a maze of sinks and depressions interspersed with isolated residual knobs and ridges of which the largest and highest are Lynn Mountain and Bryant Ridge near Elizabethton. North of Elizabethton along the southwest end of Holston Mountain high rounded ridges project to altitudes of 2,000 feet or more, and near the Watauga and Red Bird Hill bauxite mines the ridges contain the pockets of "shaly clay and kaolinitic clay" (p. 91). The summits in this vicinity may extend nearly as high as the former valley-floor level, although Bridge (1950, p. 193) believes that the clay pockets are probably only the bases of deposits on the valley floor that were originally thicker and more extensive.

Wright (1936, p. 109) suggests that solution and weathering have appreciably lowered the surface of the carbonate rocks since the valley-floor epoch. An alternative possibility is that the valley floor on the carbonate rocks was originally formed on a thick blanket of residuum, now largely removed by erosion, and that the present surface is essentially the stripped surface of the bedrock as it existed beneath the residuum.

STONY CREEK VALLEY

During this survey, the valley floor of Stony Creek valley was studied in greatest detail. Many complexities were found, although a similar complexity might be discovered if other districts were similarly studied. Land forms of Stony Creek valley are illustrated by the projected profiles of figure 25*A*.

Projecting from the dip slopes or "flatirons" of the Hesse quartzite member of the Erwin formation along the edges of Stony Creek valley are marginal benches (no. 3 on fig. 25) formed of deeply weathered shale and sandstone of the Helenmode member and of clay residual from the basal part of the Shady dolomite, both mineralized by iron and manganese oxides and in part capped by quartzite gravel. A detailed map and section of one of the marginal benches appears in figure 26.

The benches form several groups at accordant levels. The highest group, on the northwest flank of the valley, at altitudes of 2,800 to 3,000 feet, is about 1,200 feet above Stony Creek in the center of the valley; another and more extensive group about 500 feet lower on the slope is 700 feet above Stony Creek. On the southeast side of the valley the principal group lies at an intermediate altitude, or between 2,500 and 2,700 feet. The higher benches are relatively small, with areas of 1 to 10 acres on top; commonly there is a gravel-capped knob at the outer end separated from the dip slope behind (section *A–A′*, fig. 26). The lower benches on the northwest side of the valley are larger and include considerable areas of flat or rolling ground.

Gravel deposits on the benches consist of rounded to subangular fragments a few inches to more than 10 feet in diameter, composed of quartzite of the Chilhowee group of the adjacent mountains. They were not merely derived from slumping and creep from adjacent quartzite outcrops, as they show some effects of water transportation and include fragments that can be identified with beds in the lower part of the Erwin formation, whose outcrops in the mountains are more than a mile distant.

The gravel remnants were probably originally the inner edges of piedmont alluvial deposits laid down by streams issuing from the mountains, which sloped toward the center of the valley where the axial stream was several hundred feet lower. Lack of correspondence in altitude between benches on opposite sides of the valley may be due to the fact that only the upper ends of the variably sloping deposits are now preserved. The gravel of the benches lies unconformably on residuum of the Shady dolomite and on deeply weathered underlying Helenmode member of the Erwin formation; if the principal time of accumulation of residuum preceded the deposition of the earliest gravel, the gravel deposits farther out in the valley must have been spread over still greater thicknesses of residuum. Possibly the cutting of the successively lower surfaces now represented by different groups of marginal benches was in the residuum rather than the bedrock, and was thus accomplished with relative rapidity.

Toward the center of Stony Creek valley bedrock ridges (no. 4 of fig. 25) of unweathered dolomite of the Shady stand several hundred feet above the level of Stony Creek, their tops at accordant heights between 2,000 and 2,500 feet. At the lower southwestern end of the valley the ridges of Rome formation rise nearly 400 feet higher.

Close to Stony Creek, most of the surface of the ridges is formed by unweathered dolomite. Many ridges contain sink holes, some of great size and depth, partly filled by residual clay; many are curiously isolated from each other, being separated by lower gravel terraces. Probably the ridges are remnants of prolonged solu-

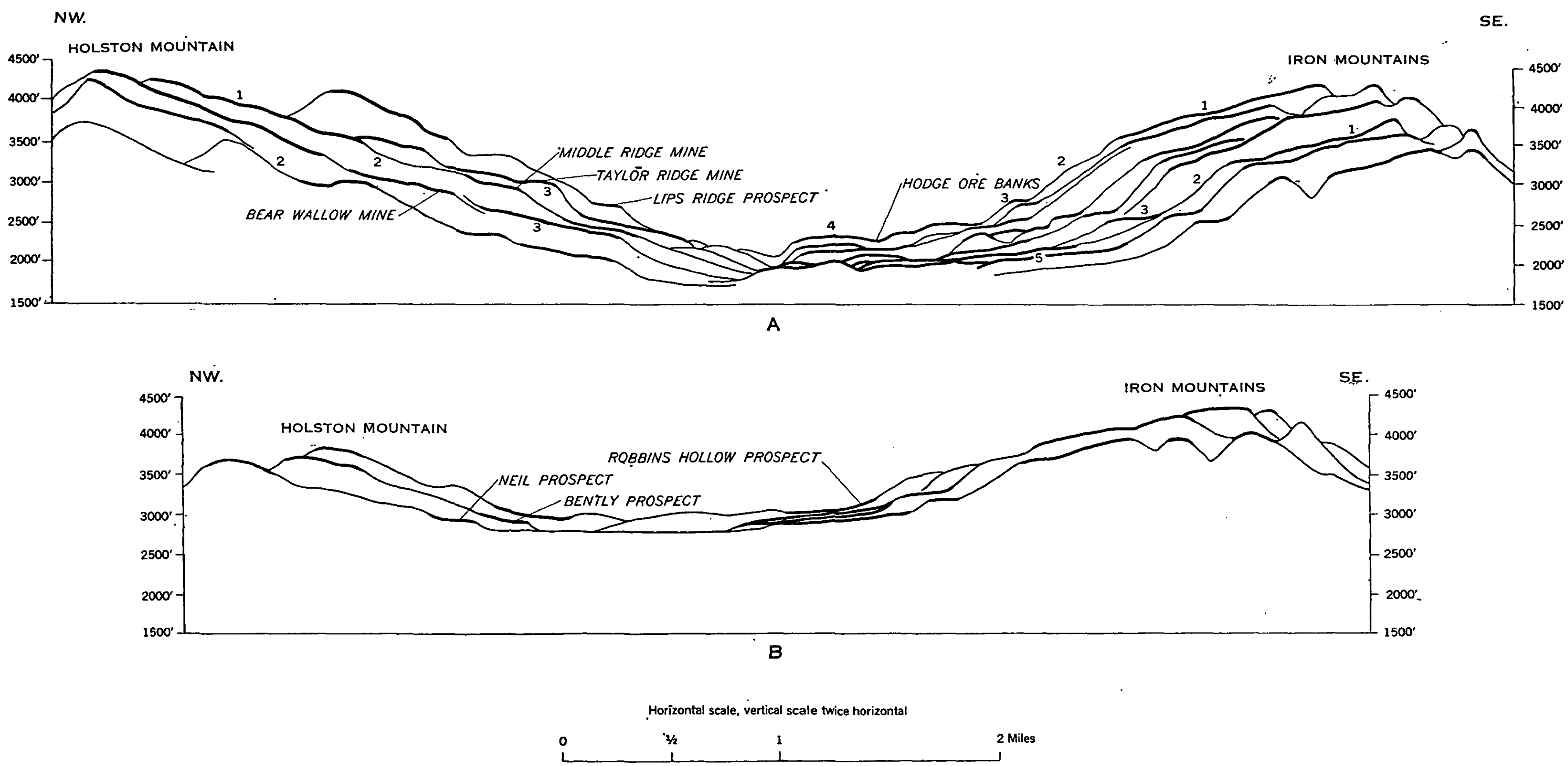

FIGURE 25.—Projected profiles of two intermontane valleys of northeasternmost Tennessee, to show land forms. *A*, Middle part of Stony Creek valley. *B*, Upper basin of Shady Valley. Accordant levels are emphasized by heavier weight of lines. Numbers in figure *A* represent: 1, crests of transverse spurs of the Iron Mountains and Holston Mountain; 2, quartzite dip slopes; 3, marginal benches; 4, bedrock ridges; and 5, gravel terraces.

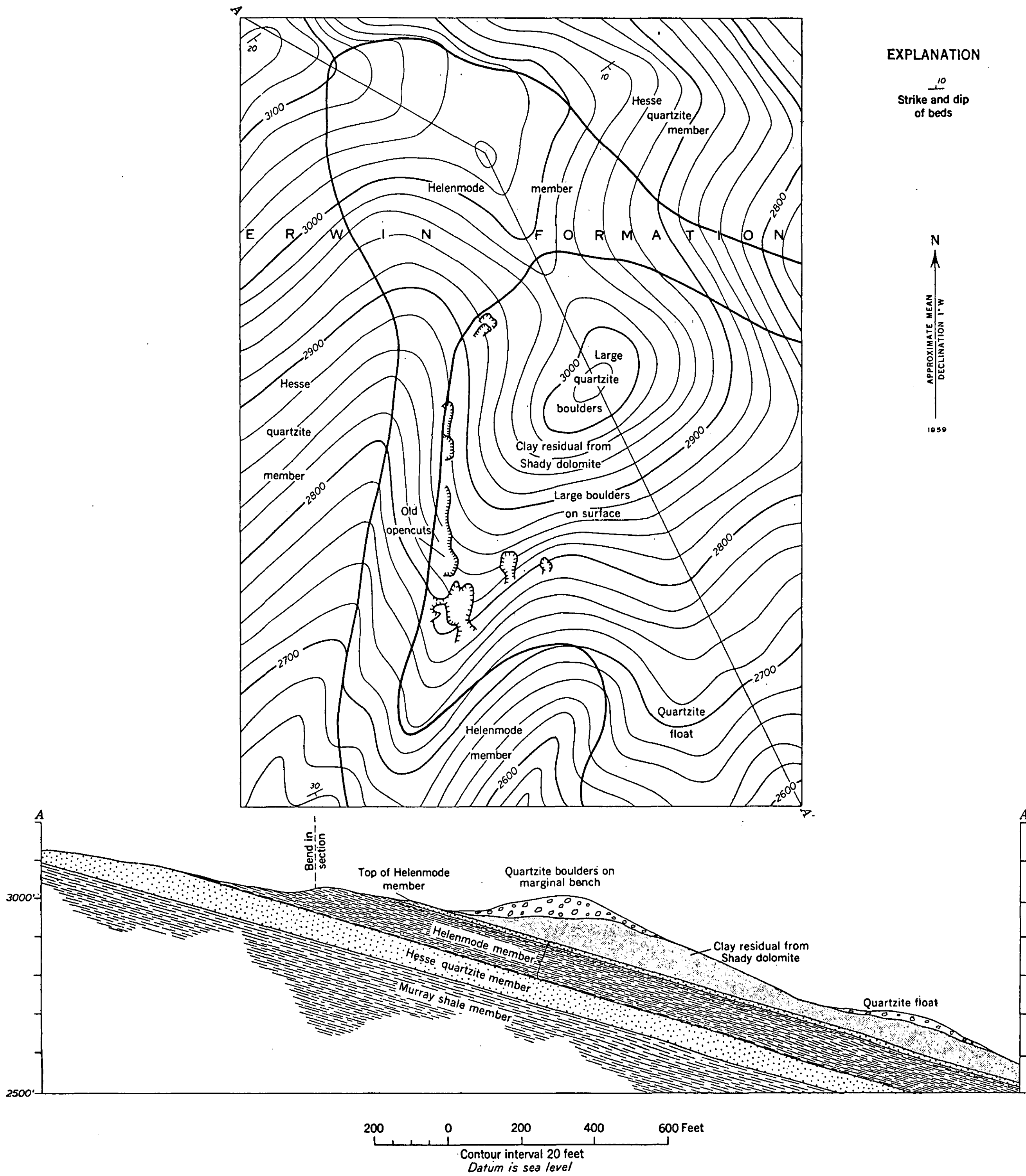

FIGURE 26.—Map and section of a typical marginal bench—Taylor Ridge on northwest edge of Stony Creek valley, showing relation of topographic feature to bedrock units and gravel deposits.

tion and karst erosion, and the intervening larger areas are enlarged sink holes that formed either at the surface or under a blanket of residual clay, now removed. Toward the heads of the ridges, away from Stony Creek, the dolomite is more or less masked by residual clay and by gravel.

The bedrock ridges probably were formed at the same time as the successive gravel-capped surfaces of which the marginal benches are remnants. The high ridge summits on the Rome formation may correspond to the highest marginal benches farther up the valley; the lower summits on the Shady are more or less accordant with the lower gravel-capped marginal benches on the northwest side of the valley (fig. 25*A*). The irregular summits on the unweathered dolomite, however, probably did not result from surface erosion, but formed below ground at the base of the thick body of residuum that may have filled the valley before deposition of the earliest gravel; the dolomite surface has been revealed by the stripping of the residuum.

Gravel terraces lie between and below the bedrock ridges (no. 5 of fig. 25) with surfaces 25 to more than 100 feet above Stony Creek at their lower ends and gradients as steep as 400 feet to the mile toward the bordering mountains. Their surfaces show little else than bouldery gravel, although gullies and road cuts in places expose the residuum or bedrock on which they were deposited. The gravel terraces are the youngest features that stand above and antedate the modern alluvium, but they are comparable to gravel-covered plains that extend back accordantly from the present alluvial flats of Stony Creek.

SHADY VALLEY

Shady Valley lies northeast of Stony Creek valley between Holston Mountain and Iron Mountains in the same synclinal trough, and like it, is drained by an axial stream, Beaverdam Creek. Unlike Stony Creek, which drains southwestward directly into the Watauga River with only low rock sills along its course, Beaverdam Creek drains northeastward by roundabout course into the South Fork of the Holston River, and flows in hard rocks of the Erwin formation at its lower end. The Shady dolomite at the upper end of the valley is thus cut into a wide basin, whose floor is 1,000 feet higher than the floor at the head of Stony Creek valley, only 3 miles distant.

In the upper basin of Shady Valley, broad benches or terraces stand at altitudes of 2,800 to 3,000 feet (fig. 25 *B*), or at about the same altitude as the highest marginal benches in Stony Creek valley, but these project 100 feet or less above the present alluvial flat of Beaverdam Creek. The benches in the two areas may be of about the same age, and formed at a time when Beaverdam Creek, flowing at a higher level than the hard rocks into which its lower course is now cut, was able to grade its valley as completely as Stony Creek. Subsequently, downcutting in Shady Valley was much more retarded than in Stony Creek valley, owing to penetration by the creek of the harder rocks downstream and development of perched base levels above them.

In its course through the Erwin formation between Shady Valley and Damascus, Va., Beaverdam Creek flows in a narrow and sinuous gorge. Some of the sinuosities of the gorge, such as the tight loop at Backbone Rock, may have been inherited from a meandering course in a more open valley at a higher level. Such a higher erosion level is suggested at one locality, at least; on the divide southwest of Fagall Branch at an altitude of 3,200 feet, L. E. Smith observed rounded quartzite boulders, probably remnants of a once more extensive deposit, resting on an outlier of residual clay of the Shady dolomite.

JOHNSON COUNTY COVE

An extensive area of accordant valley-floor levels, above present drainage, is represented by the low ground of Johnson County cove, or that part underlain by the Shady dolomite and Rome formation.

Near the Watauga River, ridge summits at altitudes of 2,400 to 2,600 feet, are remnants of the valley floor and rise gradually upstream; both the Watauga and the Elk now flow 400 feet lower in steep-sided valleys. Outcrops of Shady dolomite and Rome formation are nearly continuous on the valley slopes and extend in places to the ridge summits, but the latter are largely composed of weathered shale and residual clay. In places, especially on the spur ends above the river, the weathered bedrock is capped unconformably by stream-rounded gravel.

Farther north near Mountain City, headwaters of southward-flowing Roan and Doe Creeks and northward-flowing Laurel Creek are not so deeply incised and flow in broad alluvial flats because they are far from master streams, and because they are adjusted to perched base levels sustained by resistant rocks in their lower courses. Outcrops are scattered and widely masked by weathered shale or residuum derived from the dolomite. Deposits of iron and manganese oxides and masses of jasperoid are abundant in the residuum of both the Shady and the Rome. Near the divide between the northward-and southward-flowing drainage, Holy Hill, Red Fox Ridge, and other rounded summits carved from the Rome and Shady project in the middle of the cove as remnants on the valley floor surface.

Near Mountain City, gravel deposits extensively mask the underlying weathered bedrock in benches at 2,600 to 2,800 feet, or scarcely 100 feet above present drainage, thus resembling the benches in the upper basin of Shady Valley. In contrast to Stony Creek valley, only one surface is clearly developed. The deposits are thickest and most extensive along the northwest bases of Doe Mountain and the Stone Mountains, where they form piedmont alluvial slopes that rise steeply from the axial streams to the mountains. The Iron Mountains on the northwest, which stand as high or higher, have no comparable alluvial slope, perhaps because they do not rise as abruptly, but are separated from the cove by foothills a mile or so wide.

Near the north end of the Johnson County cove at Matney are unusual gravel deposits. On the ridge above the Taylor Valley mine, 300 feet above Owens Branch, residuum of the Shady dolomite and Rome formation is capped by fragments of volcanic rock from the Mount Rogers group and of quartzite and sandstone from the Chilhowee group. The fragments of volcanic rock are mostly angular and range from a few inches to several feet across. The quartzite and sandstone fragments are rounded pebbles and cobbles, most abundant toward the east where there is less volcanic material. Volcanic rocks like those on the ridge crop out on Fodderstack Mountain half a mile to the west and 300 feet higher, and on Pond Mountain 1¾ miles to the east and 1,000 feet higher. The volcanic fragments on the ridge were interpreted by Stose and Schrader (1923, p. 45) as remnants of a thrust sheet, but, as shown by Ferguson, they are probably talus fragments derived from an ancient and much larger Fodderstack Mountain and were incorporated in gravel deposits laid down on a surface much higher than present drainage.

BLUE RIDGE PROVINCE

The Watauga River, above its water gap in the Stone Mountains, has cut a steep-sided rocky gorge as much as 400 feet deep in the plutonic and metamorphic basement rocks. Above the rim of the gorge, the ridges flatten into rolling summits at altitudes of 3,000 to 3,400 feet and rise gradually to higher mountains several miles back from the river. These rolling summits seem to define vaguely a former, more open valley in which the river flowed before incision, perhaps equivalent to the valley floor downstream in the Johnson County cove at somewhat lower altitudes.

Elsewhere in the Blue Ridge province immediately southeast of the Stone Mountains, distant views show prominent accordant ridge summits in places, high above modern drainage. These have not been investigated during the present survey, but they might record one or more times of planation of the metamorphic and plutonic rocks.

TALUS AND ROCK STREAMS

Most of the mountain slopes are covered by relatively fine grained weathered fragments and slope wash, derived from shale, siltstone, and feldspathic sandstone; larger blocks of quartzite and other more resistant rocks, if present, are much dispersed. In the Doe ridges, however, where the upper part of the Chilhowee group consists largely of quartzite, many slopes are masked by fields of coarse angular talus that resembles the talus of the Chilhowee farther north in Virginia (King, 1954, p. 62–63). The lavas of the Mount Rogers group on Whitetop and Pond Mountains, and parts of the basement rocks on Snake Mountain and elsewhere likewise break into large blocks that strew the slopes in rock streams.

Modern weathering and erosion are probably breaking free and transporting large blocks of massive rocks, although probably less actively now, when the slopes are heavily forested and the climate is relatively warm, than during the Pleistocene, when the cover of vegetation was lighter, and frost action was at a maximum. As in other parts of the southeastern States, the talus and rock streams are probably mainly of Pleistocene age.

ALLUVIUM

Alluvium, which is separately shown on the geologic map (pl. 1), underlies the present flood plains. Like the earlier gravel deposits it includes pebbles, cobbles, and boulders of quartzite, sandstone, and plutonic and metamorphic rocks, derived from the mountains. It also includes much sand from the same sources, and clay from the carbonate rocks and shale. Alluvial deposits are narrow along smaller streams and in the mountain gorges; such narrow areas have not been mapped. Along the Watauga River near Elizabethton the alluvial plain is a mile or two wide where two large tributaries, Stony Creek and Doe River, join the main stream in the carbonate belt. Wright (1936, p. 119) here noted two alluvial terraces above the flood plain. Several other broad alluvial flats, such as that on Beaverdam Creek in Shady Valley, and that of Roan Creek southeast of Mountain City, lie toward the heads of tributaries, and have evidently formed under the control of perched base levels, controlled by rock sills farther downstream. A succession of smaller perched base levels occurs along Stony Creek, each controlled by projections of the Hesse quartzite member of the Erwin formation into the channel, and forming stretches of alluvial flat immediately upstream. During this survey, the thickness of the alluvial deposits was not determined, but it must be thin in places, as many streams expose rock ledges in their channels well out in the alluvial flats.

Many facts regarding the alluvial deposits of the region and the regimen of its streams have been given by Glenn (1911, p. 34–41), who also reports on the destructive effects of erosion and floods during the first decade of the century, resulting from the clearing of the land for farming, and from deforestation of watershed areas during lumbering operations. Although there have been several large floods later, including one on the Watauga River in 1940, shortly before construction of Watauga Dam, destructive effects of erosion and flooding have generally diminished in recent decades, with incorporation of the forest areas in the national forest, and with construction of dams and reservoirs by the Tennessee Valley Authority.

MINERAL DEPOSITS IN SURFICIAL MATERIALS

The principal mineral deposits of northeasternmost Tennessee occur in surficial materials overlying the bedrock, formed during Cenozoic time. Iron and manganese oxides occur in the residuum of the carbonate rocks, and bauxite in local deposits of shaly clay and kaolinitic clay. The region has produced approximately 350,000 tons of iron concentrate, 27,500 tons of manganese concentrate, and 10,000 tons of bauxite ore. Prospecting and mining of manganese was active at the time of writing this report. (1954).

Descriptions of individual deposits, as known to 1944, were given in a previous report (King and others, 1944, p. 48–273) and are not repeated here. On the geologic map (pl. 1), the mines and prospects are located, as well as all mineral showings seen during the fieldwork. These occurrences are summarized on figure 27. In the text which follows the deposits will be discussed in general terms as geologic features.

MANGANESE DEPOSITS

OCCURRENCE

The manganese deposits are surficial, and have accumulated during the process of weathering. Most are in weathered Cambrian formations, generally in clay residual from dolomite and limestone. By far the greater number are in clay residual from the Shady dolomite, many are in clay overlying the lower part of the Shady. This is illustrated by figure 27, which shows that most of the manganese occurrences lie near or a little above the top of the Chilhowee group.

The bedrock underlying most deposits is homoclinal, with dips ranging from a few degrees to vertical. The deposits show no apparent relation to minor anticlines or synclines. Although some manganiferous areas, such as Shady Valley and Stony Creek valley, are broad synclines of Shady dolomite, there is no assurance that all synclines contain manganese deposits, nor that synclines will prove more productive than homoclines. Some manganese deposits occur near faults, for example, those in brecciated quartzite and jasperoid. Some of the deposits in residual clay are also near faults in the bedrock, but faults are absent or have not been proved near a much greater number of deposits.

By far the greater number of deposits are on ridge crests, especially those near the old valley-floor level. Here the residual clay is thicker than elsewhere, and seems to contain more manganese oxide. Few deposits are known in areas of thick gravel cover; deposits may not have formed there, but more probably they have remained concealed. A few deposits have been discovered in small valleys, but none in broad valley bottoms and alluvial flats.

MANGANESE DEPOSITS ASSOCIATED WITH THE SHADY DOLOMITE

The manganese deposits in residual clay associated with the Shady dolomite are generally discontinuous; the known ore-bearing areas are small in relation both to the area of Shady outcrop and to that of residual clay. The deposits are limited by the extent and thickness of the residual clay, and by the rock structure.

The ore bodies consist of clay that contains nodules and masses of hard manganese oxide or veins and masses of soft manganese oxides such as pyrolusite. The term "ore" is here used for the whole aggregate mined and sent to the mill, although locally the term is used for individual nodules embedded in the clay, or for the mill concentrate, which consists of nodules from which the clay has been washed.

The bodies of ore-bearing clay are generally 50 to 100 feet thick, but reach 250 feet in places. The greater part is brown waxy clay, locally known as "buckfat," but lenses of white kaolinitic clay and yellow silty clay are also present. The manganese oxides are most abundant in the "buckfat." Near the ore bodies the "buckfat" commonly contains much wad, which stains it gray or black. Parts are also stained yellow or red by iron oxides. The clay commonly contains pieces of siliceous material derived from the dolomite, such as quartz dolomolds, chert, and jasperoid, which must be separated from the manganese nodules during milling. Most manganese oxide is free from siliceous material, but some nodules have intergrown with it.

The hard manganese oxides of the ore bodies form nodules and masses a few inches to several feet across. They are variably concentrated, the ratio of nodules to clay ranging from 1 to 2, to 1 to 20 or more by volume. The ore bodies are generally highly irregular lenses. Some apparently follow indistinct laminae in the clay and others are roughly parallel to the ground surface, but there is no systematic arrangement in detail. Each lens pinches out laterally, but may be succeeded by others above, below, or on either side.

Most of the manganese ore bodies associated with the Shady dolomite cover areas of less than 2 acres, although some scattered groups of ore bodies may extend over 10 acres or more. Most have yielded no more than a few hundred tons of concentrate each, and few have yielded more than 1,000 tons.

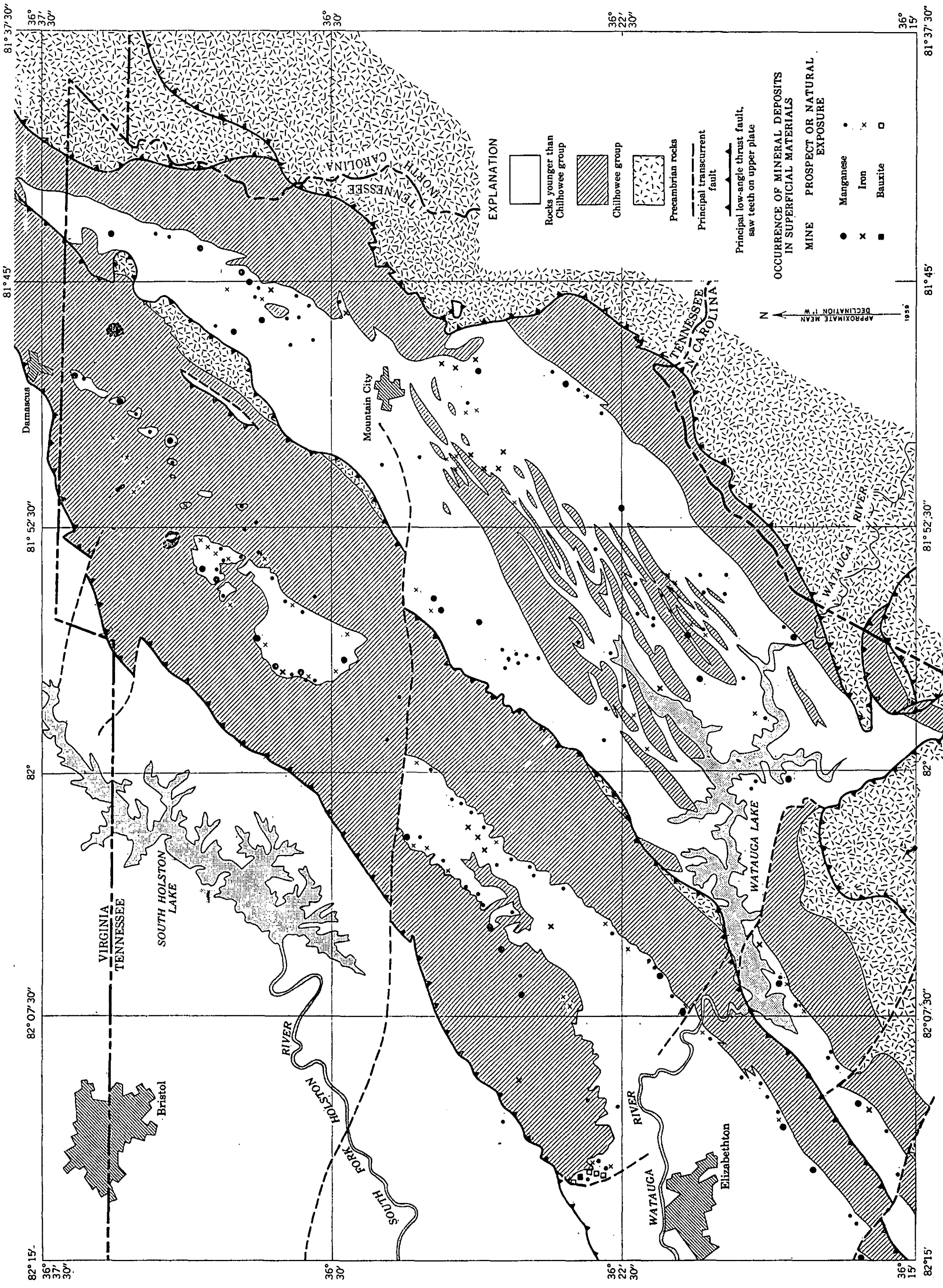

Figure 27.—Sketch map of northeasternmost Tennessee to show location of known mineral deposits in surficial materials (residuum and deposits of Cenozoic age).

MANGANESE DEPOSITS ASSOCIATED WITH THE ROME FORMATION

Manganese deposits associated with the Rome formation occur in weathered shale, and in clay residual from the dolomite beds. The thinner and more shaly dolomite beds yield laminated yellow silty clay, and the thicker layers brown "buckfat" clay not unlike that from the Shady dolomite. The manganese oxides form nodules and thin plates that commonly follow laminae and fractures in the yellow silty clay, but some nodules occur in the buckfat. Manganese oxides also form the matrix of breccia zones in the shale.

As the layers of silty clay and "buckfat" clay are relatively thin and the breccia zones are narrow, the ore bodies in the Rome tend to be much longer than wide. In most areas where the Rome has been prospected, the beds dip steeply and the ore bodies follow the dip. Some underground workings have followed the ore bodies 50 feet or more below the surface, but they probably fade out a greater depth.

Hard manganese oxides are common in the ore bodies of the Rome formation, but much pyrolusite is also present. All the deposits associated with the Rome are much smaller than those associated with the Shady, and the concentration of manganese oxides is rather lean. None has produced more than 500 tons of concentrate.

MANGANESE DEPOSITS IN THE ERWIN FORMATION

Small amounts of manganese oxides are concentrated in the sandstone and quartzite of the upper part of the Erwin formation, but although these have been prospected, no ore is known to have been produced.

Manganese oxides locally cement the beds of coarse sandstone at the top of the Helenmode member. In parts of Shady and Stony Creek Valleys outcrops and float of this sandstone contain 15 percent or more of manganese. Prospecting indicates, however, that this surficial concentration is no more than a few feet thick, and at depth the sandstone contains only a mixture of wad and soft iron oxides.

In some areas, especially near faults, the quartzite beds lower in the Erwin are brecciated, and the breccia is in many places surficially cemented by manganese and iron oxides. Some deposits contain hard manganese oxides of good quality, but in most the manganese oxides are intimately mixed with siliceous fragments. Such deposits may extend hundreds of feet laterally but do not extend far below the surface.

ORIGIN

The manganese deposits have been concentrated in the residuum of rocks so deeply weathered that the initial source of the manganese deposits is no longer evident. Analyses of unweathered Shady dolomite (see p. 49) indicate that manganese was originally disseminated in the sedimentary rocks, probably in carbonate form, the most significant concentrations being in beds 100 to 200 feet above the base of the formation. This disseminated manganese was probably the primary source of the deposits now found in the residual clay.

During weathering, the manganese carbonate, like the calcium and magnesium carbonates of the limestone and dolomite, was dissolved by ground water; it was subsequently precipitated as oxide in the residual clay that was accumulating. The manganese was probably first precipitated as soft hydrous oxides such as wad, and was converted to hard oxides by dehydration (Hewett, 1916, p. 40). Although the concentration of the manganese as oxide took place largely during the formation of the residual clay it was relatively late in this process, as the manganese oxides have replaced the clay (Stose, Miser, Katz and Hewett, 1919, p. 45). Replacement of clay by manganese oxides is demonstrated by the occurrence in the manganese nodules of laminae and slickensides identical with those in the adjacent clay, by ragged areas of clay enclosed in hard nodules of manganese oxides, and by absence of any evidence that the clay adjacent to the nodules was crowded back during growth of the nodules.

Most of the manganese oxides thus probably formed during the same epoch as that in which the residuum accumulated, and hence well back in Tertiary time; Miser (1950, p. 159) notes that "there appear, however, to be valid reasons for the formation of manganese deposits at any time and at any altitude provided local conditions are favorable," and notes that a few manganese deposits of southwestern Virginia can be dated by associated fossil plants as Pleistocene or even younger.

IRON DEPOSITS

The iron deposits are almost identical in character to the manganese deposits and are closely associated with them, as suggested by their distribution as plotted on figure 27. The iron forms oxides and hydrous oxides, or "brown iron ore." This occurs as plates, nodules, and irregular masses in the residuum of the Rome and Shady, and as a surficial cement of sandstone and quartzite breccia in the Erwin. In some deposits, iron oxides dominate to the exclusion of manganese oxides. In others, they form a massive cap above more dominantly manganiferous deposits beneath; in still others, nodules of both iron and manganese oxides are present in the same deposit, or the nodules contain an intimate mixture of the two oxides.

The iron deposits were studied less than the manganese deposits during this survey. No iron mining was being carried on at the time, and most had ceased about 1910. Many of the iron workings are now caved and inaccessible, and where accessible most of the ore has been removed. The iron deposits have been well described by Jarvis (1912), whose observations were made during the period of active production.

Iron deposits greatly exceeded the manganese deposits in volume. Iron mining was carried on almost continuously from the earliest settlement up to about 1910, and although the earlier production was probably small, it was much larger during the last decades. Between 1903 and 1910 a group of mines southeast of Mountain City in residuum of the Shady dolomite and Rome formation yielded more than 220,000 tons of concentrate; similar large tonnages are reported to have been produced during about the same period from mines in Stony Creek valley. The disproportion between the volume of the iron and manganese deposits does not appear on figure 27, which shows more mines and showings of manganese than of iron. This is because only the larger and later iron workings could be located; many of the older and smaller workings have been so long abandoned that they have disappeared. Also, many workings indicated as manganese mines first operated as iron mines.

The iron deposits, like the manganese deposits, were concentrated as oxides in the surficial materials during weathering, and were derived from iron originally disseminated in some other form in the bedrock. Part may have been derived from pyrite disseminated in the upper part of the Chilhowee group (Keith, 1903, p. 8), but most was probably derived from iron carbonate in the original sediments of the Shady dolomite. The reason for the concentration of iron oxides in particular places is no more clear than the reason for the concentration of manganese oxides in other places, nor is it evident why some deposits consist largely of iron oxides, others of manganese oxides, and still others of mixtures of both.

BAUXITE DEPOSITS

The bauxite deposits, although in surficial materials like the iron and manganese deposits, are less widespread; they are limited to the small areas of shaly clay and kaolinitic clay near the southwest end of Holston Mountain (fig. 27). The bauxite deposits of the region are, however, nearly identical with others in the Appalachian Valley between Virginia and Alabama, reported on by Bridge (1950, p. 189–222).

The shaly clay and kaolinitic clay, derived originally from weathered crystalline rocks of the Blue Ridge province and laid down in pockets on the valley floor surface, were, after deposition, partly converted to bauxite by desilication of the kaolin. The bauxite and incompletely altered bauxitic clay form central cores or kernals in the larger pockety deposits, such as those at the Watauga mine (fig. 24 *B*), but the cores are small or lacking in the smaller pockets.

STRATIGRAPHIC SECTIONS

The stratigraphic sections measured, or otherwise described and calculated during this survey, are given below. Sections of the Chilhowee group are also shown graphically on plate 9; those of the Shady and Rome formations are shown graphically on plate 14. Two sections of the later Cambrian and the Ordovician formations are included which are not shown in graphic form. On plate 9 some sections of the Chilhowee group are plotted graphically for which insufficient data were obtained to present a written description. These are noted in the text below at their appropriate places.

SECTIONS OF CHILHOWEE GROUP

SECTION 1—*Miller Branch*

[Section on Miller Branch, draining southeastward into Stony Creek in western part of Carter quadrangle. Thicknesses calculated from field sheets by John Rodgers in November 1941]

Data on sequence in this area are included in Mill Creek section, below.

SECTION 2—*Mill Creek*

[Upper beds crop out near Mill Creek, a stream draining southeastward into Stony Creek in central Carter quadrangle; also contains generalizations from adjacent areas to northeast and southwest; by John Rodgers, November, 1941. Unicoi formation based on outcrops on Morrill Trail on northwest slope of Holston Mountain; by P. B. King and L. C. Craig, November, 1942. This section was not measured, but described in field and thicknesses calculated from field sheets]

	Feet
Shady dolomite: Residual clay of this formation overlies section.	
Erwin formation:	
Helenmode member:	
29. Shale and sandy shale, with sandstone beds near top composed of coarse rounded quartz grains, cemented on weathered surfaces by manganese oxides; thickness not observed, but probably about	100
Hesse quartzite member:	
28. Quartzite, white, massive, without *Scolithus*. Forms a strong ledge nearly everywhere, and in only a few places fails to crop out. Top of ledge is commonly pebbly and in many places is marked by giant ripples. Thickness nowhere less than	20

Feet

Erwin formation—Continued

Murray shale member:

27. Siltstone, green, and thin-bedded sandstone; contains thin beds of bluish or resinous quartzite. To the northeast, on Little Flint Mill Branch, a ledge of pure white quartzite lies a little more than 100 ft below top. To the southwest, on Furnace Branch and vicinity, a thin-bedded quartzite lies 75 ft below top — 520
26. Quartzite, ferruginous, speckled; made up of well-rounded quartz grains whose interstices are filled by green mineral, probably glauconite, that weathers to brown limonitic specks; weathered surface is bluish or violet — 5
25. Siltstone, green; and sandstone with a little interbedded argillaceous shale. On Mill Creek contains two beds of ferruginous quartz conglomerate with a rather dirty cement. To southwest, in Miller and Hinkle Branches, contains two beds of *Scolithus*-bearing quartzite; their exact relation to the conglomerate beds is not clear — 250

Nebo quartzite member:

24. Quartzite, white; contains *Scolithus;* in successive ledges, separated by beds of green siltstone. From Mill Creek southwestward are four ledges, the tops of each being 50–100 ft apart; on Mill Creek the second ledge from the top is the most prominent. To the northeast, only three ledges are present, possibly due to dropping out of third bed from top — 350

Total Erwin formation — 1,245

Hampton formation:

23. Argillite, greenish-banded, siltstone, and thin-bedded sandstone. On the crest of Holston Mountain just east of Low Gap is a *Scolithus*-bearing quartzite near middle of unit. To northeast, arkose lies well above middle of unit — 250
22. Quartzite, arkosic, and sandstone; from Mill Creek southwestward the top of this unit is well marked, but to northeast it is indefinite — 250
21. Shale, green, micaceous, with beds of arkosic sandstone — 250
20. Sandstone, arkosic and quartzite, with interbeds not well exposed. On Mill Creek, thickness is difficult to determine because of small-scale faulting, but appears to be between 400 and 600 ft, a fair average being — 500

Cardens Bluff shale member:

19. Shale, mostly deeply weathered; float consists of orange-rusty chips — 100

Total Hampton formation — 1,350

Feet

Unicoi formation:

18. Quartzite, white, sugary, vitreous; contains small pebbles, the quartzite being made up mostly of quartz, but with a little feldspar. Forms a strong ledge on crest of Holston Mountain at head of Morrill Trail — 50
17. Covered; fine-grained sandstone float, but some shale may also be present — 400
16. Quartzite, arkosic, vitreous; forms ledge, with talus below — 25
15. Arkose, thin-bedded — 300
14. Quartzite, arkosic, vitreous; forms ledge — 25
13. Arkose, thin-bedded — 75
12. Quartzite, arkosic, vitreous; forms a large prominent cliff that makes the rim of an escarpment — 100
11. Poorly resistant beds, mostly concealed by talus — 25
10. Quartzite, arkosic, vitreous, forms prominent cliffs — 75
9. Arkose, thin-bedded — 115
8. Quartzite, arkosic; contains seams of pebbles, forming a small ledge — 10
7. Shale, red, arkosic — 90
6. Quartzite, arkosic, vitreous; forms a prominent ledge — 50
5. Arkose, thin-bedded, part of which projects in small ledges — 200
4. Quartzite, arkosic, vitreous, forming a small ledge — 25
3. Arkose, thin-bedded — 275
2. Quartzite, arkosic; forms a prominent ledge — 50
1. Arkose, probably soft but mostly covered by talus — 200

Part of Unicoi formation exposed — 2,090

Holston Mountain fault at base of section, with shale of Middle Ordovician series beneath.

SECTION 3.—*Johns Branch*

[Section on Johns Branch, a stream draining southeastward into Stony Creek in north-central part of Carter quadrangle. Thicknesses calculated from field sheets by John Rodgers in November 1941]

These data are included in Mill Creek section, above.

SECTION 4.—*Bristol road*

[Section on U.S. Highway 421 (Shady Valley-Bristol road) over Holston and Delaney Mountains, Shady Valley quadrangle. Extends from southeast foot of Holston Mountain in Shady Valley, west-northwestward to Holston Mountain fault on northwest side of Delaney Mountain. By P. B. King, March, April, and August 1942. This section was not measured, but was described in fair detail in field and thicknesses calculated from outcrops plotted on field sheets]

Feet

Shady dolomite: Residual clay of this formation exposed in road cuts in Shady Valley, at lower end of grade off Holston Mountain.

Erwin formation:

Helenmode member:

23. Sandstone, thin-bedded, soft, pale-greenish, silty; weathers to pale buff chips. Contains thin layers of quartzite, and toward the top thicker beds of coarse gritty sandstone, made up of rounded quartz grains, in part with iron and manganese cement — 100

	Feet
Erwin formation—Continued	
Hesse quartzite member:	
22. Quartzite, hard, vitreous, parts are full of large, rounded quartz grains; some giant ripple marks on bedding surfaces; more deeply weathered parts are friable	60
21. Sandstone and shaly sandstone, thin-bedded; weathers soft and brown	100
20. Quartzite, white to buff, in 3- to 5-ft beds, crossbedded in places; some bedding surfaces are hummocky	110
Murray shale member:	
19. Shale, not well exposed	100
18. Quartzite, greenish-gray; in 3- to 4-foot beds, with laminae in the beds; interbedded sandstones and quartzites, at top, the latter in 2- to 3-ft beds, in part whiter and more vitreous than main ledges. Forms top of Holston Mountain at Low Gap. It is difficult to calculate the thickness of beds 18 to 22 as they lie on dip slope and dips are low and undulatory. Calculations near the highway gave about 400 ft, the figure used here; calculations to the northeast and southwest gave 725–800 ft. but these seem excessive	30
17. Sandstone, pale-greenish-gray, thin-bedded, argillaceous	325
16. Quartzite, ferruginous, fine-grained, gray, semivitreous; in 2- to 5-ft beds; not prominent on highway, but forms strong ferruginous ledges on crest of Holston Mountain to northeast and southwest	25
15. Sandstone, fine-grained, dull-greenish, with argillaceous bands, in beds a few inches to a foot thick; some papery, silty layers	170
14. Quartzite, ferruginous, fine-grained, vitreous, gray to greenish; forms several ledges 3–15 ft thick, separated by shale. Quartzite beds are lenticular and differ in prominence from place to place	80
13b. Shale, like unit 13A, but probably equivalent to lower beds of Erwin formation elsewhere. At the base, within 2 miles to northeast and southwest, *Scolithus*-bearing quartzite of Nebo wedges in, although no quartzite beds occur in area of section	200
Total Erwin formation	1,300
Hampton formation:	
13a. Shale, blue-black, fine-grained, thin-bedded, argillaceous; mica sheen on well-marked bedding; no cleavage; spheroidal weathering on a large scale; crops out for nearly a mile along highway where it descends northwest face of Holston Mountain. Toward top some interbedded thin-bedded sandstones, and at wide intervals a few thin quartzite layers	600
Hampton formation—Continued	
12. Shale, with four or five beds of sandstone or quartzite as much as a foot thick	120
11. Shale	115
10. Quartzite, medium-grained, gray; gives rise to float blocks on adjacent hill slopes	3
9. Sandstone and sandy shale, thin-bedded	440
8. Shale, with many interbedded layers as much as a foot thick of fine to medium-grained arkose, weathers brown. Many of the shale layers show a mica sheen on bedding	220
Total Hampton formation	1,498
Unicoi formation:	
7. Quartzite, buff or gray, brown-weathering, medium-grained, arkosic; in 3-in. to 2-ft beds, varying in coarseness from bed to bed; some layers crossbedded; interbedded with shale toward top	100
6. Quartzite, very massive, coarse, vitreous, finely pebbly; in 3- to 5-ft beds, standing out in ledges	30
5. Quartzite, fine- to coarse-grained, arkosic; in 6-in to 3-ft beds, with sporadic shaly partings as much as a foot thick; some quartzite is green when fresh; some contains grains of red feldspar	380
4. Quartzite, medium-grained, more vitreous than beds above and below, forms a great ledge that extends up the mountain side	60
3. Arkose, red-purple, in 1- to 3-ft beds, with thin-bedded red-purple shale layers between. Arkose contains grains of well-rounded quartz, feldspar, and some mica; matrix darker than grains. Red color particularly prominent in lower part	570
2. Quartzite, vitreous, conglomeratic; forms ledges on mountain side	10
1. Arkose, medium- to coarse-grained, earthy; in 1- to 2-ft beds, with some interbedded shale, becoming pebbly below; at least two 15-ft beds of vitreous ledge-making quartzite. Structure irregular, thickness difficult to calculate	$\ngtr$ 300
1A. Shale, in new cuts on highway, made since 1942; dull-olive, indurated; contains fine-grained silty blocky sandstone, the whole much folded, sliced, and slickensided. May be same as lower division of Unicoi formation of Iron Mountain area	150
Part of Unicoi formation exposed	1,600

Holston Mountain fault at base of section (fig. 11); shale of Middle Ordovician series beneath.

SECTION 5—*Denton Valley road*

[Section on Crandull-Denton Valley road over Holston Mountain in east-central part of Shady Valley quadrangle. Extends from valley of Beaverdam Creek near Crandull northwest across Holston Mountain into headwaters of Dry Run. By P. B. King, assisted by C. A. Nelson and L. E. Smith, April and July, 1942. This section was not measured, but was described in fair detail in field; thicknesses calculated from field sheets; thicknesses of upper beds averaged from observations in several nearby valleys]

	Feet
Shady dolomite: Residual clay of this formation, partly concealed by gravel outwash, exposed along lower end of road in Crandull basin.	
Erwin formation:	
Helenmode member:	
30. Sandstone, soft, and shale, weathered yellow and purple, with some beds of coarse sandstone containing well-rounded quartz grains, cemented by iron oxides on weathered surfaces	100
Hesse quartzite member:	
29. Quartzite, white, in 2- to 3-ft beds. Thickness indeterminable because of irregular dips; may be about	100
28. Sandstone, soft, thin-bedded, dark-gray, silty, with some 1-ft beds of sandstone	150
27. Sandstone in 2- to 5-ft beds; not vitreous, yet strong and massive	30
Murray shale member:	
26. Sandstone, mostly thin bedded, dark-gray, shaly; contains two units of fine-grained sandstone in 3-ft beds, one at base and one in middle; these weather dark gray or gray-brown, but on fresh surfaces are dull greenish and earthy	120
25. Sandstone, thin bedded, and shaly sandstone	80
24. Sandstone, thick bedded; weathers to greenish, exfoliated surfaces; freshly broken surface is medium-grained, gray, and much more quartzitic than adjacent beds	10
23. Sandstone and shale, thin bedded, dark-gray; some sandstone beds as much as a foot thick, others paper-thin and argillaceous	200
22. Quartzite, ferruginous, medium-grained; with pepper-and-salt texture on broken surfaces; upper part vitreous, lower part weathers friable	25
21. Sandstone and shale, thin bedded, contorted in part	300
20. Quartzite, ferruginous, fine- to medium-grained, bluish-gray, vitreous, with some earthy sandstone beds above and below	10
19. Sandstone and shale, thin bedded, in part contorted	350
Nebo quartzite member:	
18. Quartzite, gray; thickens to northeast along the outcrop, where it contains *Scolithus*	10
Total Erwin formation	1,485
Hampton formation:	
17. Sandstone and shale, thin bedded	250
16. Quartzite, gray, vitreous, slightly ferruginous, in two beds each about 10 ft thick, separated by thin-bedded sandstone and shale; the upper bed contains small rounded quartz pebbles	100
15. Sandstone and shale, thin bedded, poorly exposed	200
14. Quartzite, white, medium-grained, vitreous, most of whose grains are quartz, but with some traces of feldspar. Forms beds several feet thick, and crops out in prominent ledges along crest of Holston Mountain. To northeast near Abingdon Gap, and also near head of Dark Hollow, the unit contains traces of *Scolithus* in upper part	100
13. Sandstone, thin-bedded, and sandy shale, with quartzite layers interbedded in places that are 1–2 ft thick	200
12. Quartzite, vitreous in 1- to 3-ft beds, forming prominent ledge, overlain by earthy, buff, arkosic sandstone in 1- to 2-ft beds	100
11. Sandstone, thin-bedded, silty, mostly finely arkosic, with some beds of silty shale, passing down into micaceous argillaceous shale; spheroidal weathering well developed in latter	800
Total Hampton formation	1,750
Unicoi formation:	
10. Arkose, soft, in beds 1–3 ft thick, much stained by iron on weathered surfaces	90
9. Shale and interbedded arkose	50
8. Arkose, medium-grained, in 1- to 2-ft beds	145
7. Quartzite, vitreous, conglomeratic; in beds as much as 3 ft thick	25
6. Shale, arkosic	100
5. Quartzite, coarsely conglomeratic; contains quartz and feldspar fragments	10
4. Shale, thin-bedded, arkosic; with thick streaks of arkosic sandstone. The shales of units 4 and 6 appear to be duplicated lower on the mountain by thrusts so that they reappear at Sowbed Gap	230
3. Arkose in 1- to 2-ft beds	75
2. Shale, arkosic	75
1. Arkose in 1- to 2-ft beds, with some 3- to 5-ft beds near top; mostly medium-grained, buff-weathering, crumbly	>100
1A. Lowest beds of section not measured because of erratic dips. Consist of medium-bedded arkose like unit above, with some beds of coarse conglomeratic arkose	900
Part of Unicoi formation exposed	1,800
Holston Mountain fault at base of section, concealed by wash from the mountain; Rome formation beneath.	

SECTION 6.—*Valley Forge*

[Section in gorge of Doe River between the Iron Mountains and Gap Creek Mountain, between Valley Forge and Hampton, central part of Elizabethton quadrangle (pl. 12). By P. B. King, John Rodgers, and L. C. Craig, March and July 1942; additional data on lower part of section by H. W. Ferguson, October 1942. This section was measured and described in detail in field. Principal observations were made along U.S. Highway 19E, supplemented by observations lower on the slope, on the now-abandoned line of the E. T. & W. N. C. Railroad, the old highway, and in the bed of the river. Thicknesses given for many of the large shaly intervals represent averages of measurements on these different traverses.]

	Feet
Shady dolomite: At top of section; mostly weathered to residual clay (pl. 13), but with some dolomite pinnacles low on the slope.	
Erwin formation:	
Helenmode member:	
45. Sandstone and shale, mostly soft and crumbly from weathering but well exposed in highway and railroad cuts; contains following subdivisions:	
d. Sand, made up of coarse, rounded quartz grains, cemented by ocherous and manganiferous clay	5
c. Shale, sandy; purple-stained with white clay stringers	5
b. Shale, thin-bedded silty or sandy, weathers ashen or white	30
a. Sandstone, argillaceous or silty; weathers ashen or pale greenish, in part iron-stained. Traces of *Scolithus* tubes in railroad cut; fucoidal markings on bedding planes	32
Hesse quartzite member:	
44. Quartzite, light-gray, massive, medium-grained, much stained by iron on joint surfaces, forms single ledge	30
43. Sandstone, earthy, in 1- to 3-ft beds, with thinner-bedded sandstone partings and some shale beds near middle	70
42. Quartzite ledge with following subdivisions:	
b. Quartzite in a single massive bed; medium-grained, light-gray to white, with brown flecks, perhaps from weathered pyrite	15
a. Quartzite in 1- to 2-ft beds	25
41. Sandstone, fine-grained, in 1-in to 3-in beds, with some quartzitic beds 1–2 ft thick. One bed near base contains small quartz pebbles. The top 15 ft is thicker bedded and grades into overlying member	130
40. Quartzite, ledge-making, with following subdivisions:	
c. Quartzite, thin-bedded, with a more massive bed at top	10
b. Quartzite, light-gray, massive; in a prominent bed, with dark laminae containing glauconite, in part crossbedded	15
a. Sandstone, fine-grained, compact, greenish-gray, in 1- to 2-ft beds, with some shale partings	30
Erwin formation—Continued	
Murray shale member:	
39. Shale and shaly sandstone, in part not well exposed:	
c. Outcrops of upper part along highway: Sandstone, fine grained, gray; in 1- to 3-in beds, with argillaceous laminae; some partings of argillaceous shale and some thicker sandstone beds	90
b. Covered at all places	70
a. Outcrops of lower part along old Valley Forge-Hampton road below highway: Sandstone, earthy, greenish; in beds as much as 2 ft thick, with interbedded sandy shale	70
38. Quartzite, ferruginous. On old Valley Forge-Hampton road below highway consists of following subdivisions:	
e. Quartzite, ferruginous	5
d. Shale and shaly sandstone	20
c. Quartzite, massive, ferruginous, bluish or purplish, vitreous; almost without bedding, with some glauconite	20
b. Shale and shaly sandstone, with some beds of gray crossbedded sandstone a foot thick	20
a. Sandstone, greenish-gray and thin-bedded, but becoming thicker-bedded and more ferruginous toward top	15
37. Shale, dark gray, thin-bedded; in part strongly argillaceous but with some sandy beds	100
36. Quartzite, gray, vitreous; in 6-in to 1-ft beds; strongest at base and top	18
35. Covered at all places; probably mostly shale and shaly sandstone. Boundary between Murray and Nebo members may lie in this interval	390
Nebo quartzite member:	
34. Shale, dark-gray, and thin-bedded sandstone	45
33. Quartzite in 3- to 6-in beds, containing *Scolithus* on west side of river. On slope above highway on east side of river, a ledge of white vitreous quartzite, in part crossbedded, with no *Scolithus*	15
Total Erwin formation	1,275
Hampton formation (type section):	
32. Shale and sandstone, dark-gray, in beds a few inches thick, exposed only on west side of river	60
31. Quartzite, fine- to medium-grained in 1- to 2-ft beds, containing *Scolithus* tubes in upper 35 ft. Some beds in lower and middle part are crossbedded; many beds show brown flecks, perhaps weathered from glauconite or pyrite. Well exposed on west side of river; not exposed on highway on east side	90
30. Sandstone, thin-bedded, quartzitic, and interbedded shale	70

	Feet
Hampton formation—Continued	
29. Shale, mostly sandy or silty, in thin beds, containing light and dark laminae; greenish where fresh, but weathers to tan plates. Some sandstone beds 15–25 ft from base	95
28. Shale, silty sandstone, and quartzite, interbedded in beds a few inches to a foot thick; some quartzite is arkosic; a few beds contain *Scolithus* tubes; some bedding surfaces have fucoid markings	40
27. Quartzite, arkosic; forms a prominent ledge on river bank, less prominent on highway	45
26. Arkose, thin-bedded, soft, buff	40
25. Quartzite, dark-greenish-gray, arkosic, medium-grained; contains abundant small, irregular *Scolithus* tubes. Exposed on highway at north end of northern bridge over river	5
24. Not exposed, except for one bed of arkosic quartzite	160
23. Quartzite, arkosic, light-gray to pale-greenish, medium-grained; in part crossbedded, with ripple marks on some bedding surfaces; beds a few inches to 2 ft thick, with some massive beds 6 ft thick; two or three beds near middle weather brown and may originally have been glauconitic. Grades up from underlying unit, with some interbedded dark shale in lower part. Forms crest of ridge enclosed by meander of river, and well exposed in deep highway cut through the ridge	180
22. Siltstone and argillaceous sandstone, in beds a few inches thick, dark-blue-gray where fresh. Exposed in railroad tunnel and in deep highway cut. Mapped by Keith as "Hiwassee slate" in Roan Mountain folio	85
21. Quartzite, medium-grained, light-gray, slightly arkosic; with even beds 2–3 ft thick, forms very prominent ledge. Grades up from underlying unit, but is sharply separated from beds above	70
20. Sandstone, dark-greenish-gray, earthy, thin-bedded; with argillaceous laminae; weathers rusty; lower part more shaly than beds above	70
Cardens Bluff shale member:	
19. Not exposed either on highway or railroad; probably shale like underlying unit	105
18. Shale, dark-greenish-gray, argillaceous; in beds a few inches or less thick, but with strongly developed cleavage that dips at a lower angle than bedding (pl. 11*B*); this shale is much more argillaceous than any above or below, although there are some thin interbedded sandy layers. Exposed at south end of southern highway bridge	135
Total Hampton formation	1,250

	Feet
Unicoi formation:	
Upper division:	
17. Sandstone, gray, arkosic, medium-grained and thinly laminated; in beds 6 in. to 2 ft thick	65
16. Quartzite, medium-grained, white; in 2- to 5-ft beds; contains fewer pebbles and less feldspar than ledge-making units beneath; upper beds darker and well laminated. Forms moderately strong ledges	55
15. Sandstone, medium-grained, arkosic in 6-in. to 1-ft beds, with some shale streaks a few feet thick	40
14. Quartzite in 1- to 3-ft beds, fairly coarse grained and with some pebbles; forms poor ledges	45
13. Sandstone, soft, thin-bedded, shaly with some thicker-bedded, dark-greenish-gray sandstone beds toward top	45
12. Sandstone, arkosic, greenish in 1- to 2-ft beds	55
11. Quartzite, making an exceedingly prominent ledge on mountain sides, divided into following parts:	
c. Quartzite, fine-grained, white with less feldspar than beds below	10
b. Quartzite, single massive ledge of medium-grained arkosic pale-greenish when fresh, but weathering light buff	35
a. Quartzite, thin-bedded, conglomeratic	15
10. Unit which forms slopes on mountain side, but which is well exposed on highway, where following divisions are recognizable:	
b. Sedimentary greenstone, blue-green and fine-grained, with strong conchoidal fracture; upper part thin-bedded and arkosic	100
a. Sandstone or siltstone, thin-bedded, shaly	25
9. Sandstone, arkosic, in 6-in to 1-ft beds, in part laminated, in places crossbedded on a small scale; forms thin ledges and intervening slopes on mountain sides	65
8. Quartzite, medium- to coarse-grained, in 3- to 5-ft beds, containing many small quartz and feldspar pebbles; bedding is fairly straight, but there is some pinching and swelling of layers; forms ledges on mountain sides	60
7. Unit which forms slopes on mountain side, but which is well exposed on highway, where following divisions are recognizable:	
b. Sedimentary greenstone; dark-blue green on fresh surfaces; fine-grained, with marked conchoidal fracture, in even beds, 2–3 ft thick. The rock has the appearance of a basalt, but its sedimentary nature is indicated by the occurrence of seams of small pebbles	35
a. Sandstone, very thin bedded, shaly, fine-grained	5

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	Feet
Unicoi formation—Continued	
Upper division—	
6. Quartzite in 6-in to 3-ft beds; light-buff or creamy, vitreous, coarse-grained in thicker beds, containing well rounded quartz and feldspar pebbles as much as one-eighth inch in diameter in an arkosic matrix. Thinner beds are greenish-gray, finer grained, more arkosic sandstone. Bedding planes are mostly even, but with faint ripple marks on some bedding surfaces; top of unit is a sharp, even surface. Forms a strong massive ledge on mountain sides	80
5. Arkose, scattered outcrops along stream below highway; there appear to be two groups of ledges, one near middle and one near base	325
Lower division:	
4. Covered	300
3. Small outcrop of arkose	25
2. Covered	50
1. Basalt, amygdaloidal, greenish; exposed on abandoned railroad line a thousand feet north of old railroad station at Hampton	50
Part of Unicoi formation exposed	1,485

Iron Mountain fault at base of section, covered by alluvium of Doe River cove. Beneath the fault are Rome formation and Shady dolomite.

SECTION 7.—*Cardens Bluff*

[Section in gorge of Watauga River through Iron Mountains, Elizabethton and Fish Springs quadrangles (pl. 18). Top of section to north begins at Wilbur Dam, the Erwin formation being measured along west bank of river south of dam, or on ridge to west. Hampton and Unicoi formations measured principally on west bank of river, past Cardens Bluff, and ending on the south at Iron Mountain fault, a little above present site of Watauga Dam. Outcrops of beds 1 to 8 as described in 1942 are now covered by Watauga Dam and Watauga Lake, but similar outcrops are still accessible higher on the slope. By P. B. King, assisted by W. J. Souder and H. W. Ferguson, August 1942; additional notes on lower part of section have been taken from a report by L. F. Grant and P. M. McMinn (TVA Geol. Branch, 1949, table 10, p. 376). This section was measured and described in detail in field.]

	Feet
Shady dolomite: At top of section; road cuts show residual clay and unweathered dolomite.	
Erwin formation:	
Helenmode member:	
50. Consists of following subdivisions:	
c. Siltstone, thin-bedded, probably near top of member	5
b. Sandstone, massive, coarse, iron-cemented	4
a. Siltstone, thin-bedded, blue-gray, laminated; with some interbedded fine-grained sandstone	69
Hesse quartzite member:	
49. Massive ledge that forms abutments of Wilbur Dam; divided into:	
c. Quartzite, massive	4
b. Sandstone, thin-bedded	4
a. Quartzite, gray to white, vitreous, medium-grained; forms a very massive layer, overlain and underlain by some 1- to 3-ft beds	48
Erwin formation—Continued	
Hesse quartzite member—Continued	
48. Shale and siltstone, thin-bedded, fine-grained, blue-gray and laminated, with a few quartzite beds as much as 1 ft thick	95
47. Quartzite, very massive, light-gray or buff, vitreous, and medium-grained; the main body in beds as much as 10 ft thick	27
46. Quartzite, thin-bedded	10
45. Quartzite, thick-bedded, light-gray, medium-grained	40
44. Quartzite, light-gray, in 6-in to 1-ft beds, with some shale partings	29
43. Quartzite, dark-gray, fine-grained, in 6-in to 1-ft beds, with interbedded dark-blue-gray shale and siltstone	15
42. Quartzite, gray to buff, medium-grained, vitreous; in 1- to 3-ft beds, with a few thicker layers and some shale partings. These and succeeding beds are well exposed on road near and south of Wilbur Dam	60
Murray shale member:	
41. Shale, forming a thick, monotonous sequence; in lower part, interbedded with thin-bedded, dark greenish-gray sandstone beds and occasional quartzite beds as much as a foot thick. Higher up, unit is dominantly argillaceous, with only narrow sandy seams or laminae; much of it is cut by closely spaced strong cleavage planes that dip at low angles. Difficult to determine thickness of unit because of variations in dip; some estimates are as much as 1,100 feet; approximate thickness may be	400
40. Quartzite, ferruginous; mainly gray to brown, vitreous to resinous, some dark gray, 3- to 5-ft beds. At point measured is 35 feet thick, but is both thicker and thinner elsewhere. Forms a very prominent ledge or cliff on northwest side of river above Horseshoe Lake, where its lenticular nature is well displayed	35
39. Quartzite, gray, vitreous, fine-grained; in 1- to 3-ft beds; weathers to rounded surfaces, with interbedded shale layers	70
38. Shale	13
37. Sandstone and quartzite, gray, in 6-in to 1-ft beds, in part laminated, with shale partings	35
36. Shale and thin-bedded sandstone, the lower part being the most argillaceous	123
Nebo quartzite member:	
35. Quartzite, gray, fine- to medium-grained; in 2- to 5-ft beds; upper beds ferruginous and gritty; shale partings throughout. Forms ledges	75
34. Sandstone, greenish-gray, fine-grained; with argillaceous laminae, covered by talus in places	85

	Feet
Erwin formation—Continued	
Nebo quartzite member—Continued	
33. Quartzite ledges, somewhat variable. On northwest side of river a basal 10-ft layer of thick-bedded quartzite, full of *Scolithus* tubes that show as nodes on bedding, with flattened shale pebbles as much as 3 in across the upper part, followed by quartzite in 1-ft beds and interbedded with shale. On southeast side of river, consists of white or light-gray vitreous quartzite with only faint traces of *Scolithus*, in massive beds as much as 6 ft thick	40
Total Erwin formation	1,286
Hampton formation:	
32. Shale, well exposed only in part. Upper 90 ft crops out on road on east side of river, and consists of dark-greenish-gray sandy shale and thin-bedded sandstone, with argillaceous laminae, weathers rusty, with occasional thicker sandstone beds; some beds contain flattened shale pebbles. Lower down in the unit along the road are some outcrops of dense, dark-green rock that breaks with conchoidal fracture, which resembles the sedimentary greenstones of the Unicoi formation beneath	150
31. Quartzite, thin-bedded, with a massive 5-ft bed at base	45
30. Mostly covered; a few outcrops of shale and thin-bedded sandstone	30
29. Quartzite, medium-grained, vitreous; in 1- to 3-ft beds, with some shale partings	15
28. Poorly exposed; outcrops of lower beds occur on west side of river and of upper beds on east side. The latter consist of fine-grained, greenish, thin-bedded sandstone, with argillaceous laminae, and some shale partings	225
27. Quartzite, thin-bedded, with 5 ft of shale at base	15
26. Quartzite, light-blue gray, vitreous, thick-bedded; forms a ledge in upper part; lower part is light gray or white, subvitreous, fine grained, with dark laminae, and forms 1- to 2-ft beds	25
25. Mostly covered; much shale in float	100
24. Quartzite, vitreous, light-greenish-gray; in 6-in to 2-ft beds, weathers buff, with some shale partings in upper part	25
23. Covered, probably shale	110
22. Shale, thin-bedded, argillaceous, with light and dark-gray laminae. Mapped as "Hampton shale" by Keith in Roan Mountain folio	85
21. Sandstone, fine-grained, gray to buff, arkosic, in 3- to 6-in beds, with shaly laminae and shale beds that increase in number toward top	100
Hampton formation—Continued	
20. Quartzite, fine- to medium-grained, vitreous, arkosic; contains dispersed feldspar grains; bluish or greenish when fresh, but weathers buff or brown. In lower part, beds 3–5 ft thick, in upper part 6 in to 2 ft thick. Middle part is strongly crossbedded; upper 50 ft is crowded with well-marked, closely spaced *Scolithus* tubes	300
Cardens Bluff shale member (type locality):	
19. Shale, thin-bedded to fissile, argillaceous, hard and black; weathers rusty and in places to ellipsoidal forms. Well exposed on northeast side of river bend below Cardens Bluff. Mapped as "Hiwassee slate" by Keith in Roan Mountain folio	75
18. Shale, dark-blue-gray to black, silty; in 6-in to 1-ft beds, with seams of fine-grained sandstone; gradational with bed above, but rests with abrupt contact on unit beneath	45
Total, Hampton formation	1,345
Unicoi formation:	
Upper division:	
17. Quartzite, medium-grained, vitreous, gray with sparse feldspar grains, and in upper part black slate pebbles one-fourth inch across. Forms a prominent ledge, the lower 15 feet being a single massive bed, and the upper part being thinner bedded	60
16. Quartzite, greenish-gray, fine- to medium-grained, vitreous, with some feldspar, forming 6-in to 1-ft beds, but marked by many closely spaced dark laminae. Contains interbedded shale seams and some shale beds as much as 1 ft thick	55
15. Quartzite, gray; in 6-in to 1-ft beds, containing flecks of pyrite; weathers dark brown to black in part, and in others is coated by yellowish efflorescence. Along river, the dark-weathered surface of this bed contrasts strongly with surfaces of adjacent beds	50
14. Quartzite, buff, vitreous; contains scattered feldspar, passing up into finer grained greenish-gray quartzite; forms 2- to 3-ft beds, but with a thin-bedded member 20 ft thick near middle. Stands out in ledges which form the north part of the ridge in the Cardens Bluff meander	155
13. Quartzite, thin-bedded, mostly poorly exposed	90
12. Quartzite, lower part is vitreous, gray to greenish-gray, in 6-in to 2-ft beds, with scattered feldspar grains, well laminated and crossbedded, with slaty partings a few inches thick; upper part is quartzose, vitreous, in 3- to 5-ft beds, with seams of rounded quartz pebbles. Forms ledges on south side of ridge in Cardens Bluff meander	90

Feet

Unicoi formation—Continued

Upper division—Continued

11. Slope-making beds: Sedimentary greenstone, or greenish dense rock with conchoidal fracture, on west side of river in rounded ledges, passing up into shale. Apparently largely greenish thin-bedded quartzite on east side of river ---- 35

10. Quartzite; lower two-thirds is gray, vitreous, medium grained, with scattered feldspar, in 2- to 5-ft beds; upper third is thinner bedded, more arkosic, with slate partings and pebble bands; top contains flat black slate pebbles as much as 2 in across. Stands in a prominent ledge and forms a great dip slope on northwest side of Chimney Top ---- 130

9. Slope-making beds: Sedimentary greenstone, very dense, dark-greenish-gray or black, with strong conchoidal fracture, appearing very much like a basalt, but here and there with some traces of clastic texture; forms thick beds and weathers to rusty surfaces; some shale at base and top ---- 130

8. Quartzite, fine- to medium-grained, bluish to greenish-gray, laminated, cross-bedded, and slightly arkosic; in 6-in to 2-ft beds; top bed gray and vitreous. Forms small ledges ---- 80

7. Quartzite, medium-grained, vitreous, gray or white; weathers pink, in beds 5 ft or more thick, with a very massive bed at top; forms the strongest and most prominent ledge in this part of section; beds 5 to 7 make the abutments of Watauga Dam (pl. 10). TVA report gives a thickness of 60 ft ---- 30

6. Slope-making beds: Main body is fine-grained, thin-bedded greenish arkose, weathering brown. Upper 10 ft are medium-grained green feldspathic quartzite in 2- to 3-ft beds. Some dense purple sandy shale at base. Covered by talus on west side of river ---- 60

5. Quartzite; lower 10 ft thin-bedded and greenish, followed by two or three very massive ledges of medium-grained, pale-greenish, quartzose quartzite, without feldspar, weathering pink. According to TVA report this bed lies unconformably on and truncates beds beneath, thinning by overlap in places to 35 ft. Forms very prominent ledge ---- 55

4. Covered by talus; according to TVA report, consists of medium to fine-grained, medium-bedded dark-gray quartzite ---- 30

Feet

Unicoi formation—Continued

Upper division—Continued

3. Quartzite, medium-grained, gray to dark-gray; mostly rounded quartz grains, but with some pink feldspar grains and rare rounded quartz pebbles as much as one-fourth inch in diameter; some limonite flecks; forms beds 2 to 5 ft thick, but with thinner beds at top; laminae and cross-beds within the layer. Covered by talus on east side of river, but forms fairly strong ledges on west side ---- 40

Lower division:

2. Not exposed. According to TVA report consists of fine-grained, medium-bedded, dark-greenish-gray quartzite, with arkose at top containing pink feldspar pebbles, and a 12-ft bed at base consisting of dense, hard, dark-greenish-gray sandy shale, with many chlorite-coated slickensided surfaces. King suggests that this basal bed may be an altered tuff ---- 150

1. Quartzite, medium-grained, pale-greenish-gray, vitreous; with a few grains of feldspar, in part laminated and crossbedded, in 1- to 2-ft beds, with some thinner beds between; top forms a sharp contact with beds above. About 90 feet below top is a shale parting, immediately above which are some conglomeratic layers with pebbles as much as one-fourth inch in diameter. Lower hundred feet of unit, close to Iron Mountain fault, is highly broken and disturbed. Forms ledges in part. Our measurement for unit was 100 ft, but TVA report gives a thickness of ---- 235

Part of Unicoi formation exposed ---- 1,475

Iron Mountain fault at base of section, with Shady dolomite beneath (fig. 16 and pl. 19).

SECTION 8.—*Peters Branch*

[Upper beds of section based on outcrops between Peters and Grindstaff Branches, which are streams draining northwestward into Stony Creek in southeast part of Carter quadrangle. Lower beds of section based on outcrops on opposite or southeastern side of Iron Mountains near oKpley Branch. By John Rodgers, October and November 1941. This section was not measured, but was generalized from beds as mapped for several miles along the strike; thicknesses were calculated from field sheets]

Feet

Shady dolomite: At top of section; represented by residual clay on lower northwest slope of Iron Mountain.

Erwin formation:

Helenmode member:

20. Shale and shaly sandstone, with beds of coarser sandstone in upper part, contains large rounded quartz grains ---- 100

Hesse quartzite member:

19. Quartzite, white, massive; conglomeratic in upper part, forming a strong ledge and dip slope; contains no *Scolithus* ---- 25

18. Poorly exposed; probably mostly green siltstone and sandstone ---- 100

	Feet
Erwin formation—Continued	
Hesse quartzite member—Continued	
17. Quartzite, white, thins out and disappears northeast of Grindstaff Branch. From Grindstaff Branch southwestward it is fairly massive, and in places makes a dip slope or flatiron higher on spur than that of bed 19	10
16. Siltstone and sandstone, green	150
15. Quartzite, white, thin-bedded but commonly forms ledges; in places more bluish than higher quartzite beds; *Scolithus* noted, apparently from this bed, on slope northeast of Stover Branch	15
Murray shale member:	
14. Siltstone and sandstone, green with shale near base. Contains ferruginous quartzite layers, especially one about 100 feet above base; also some thin interbedded layers of white quartzite	400
Nebo quartzite member:	
13. Quartzite, white, massive; contains *Scolithus*, forming one or more ledges	≧25
12. Siltstone and sandstone poorly exposed, mostly green	315
11. Quartzite, yellow, vitreous; weathering white, containing *Scolithus* in places	10
Total Erwin formation	1,150
Hampton formation:	
10. Siltstone and sandstone, poorly exposed, but perhaps including some shale	250
9. Sandstone and quartzite, arkosic; grading down from the siltstones. On Peters Branch, forms a weak ledge at top; on Grindstaff Branch there is no prominent ledge for a hundred feet below the top	250
8. Quartzite; forming a fairly strong group of arkosic ledges, the most prominent ones being at base; interbedded with arkosic siltstone higher up	250
7. Siltstone, arkosic; interbedded with sandstone and quartzite, and in lower part with shale	350
Cardens Bluff shale member:	
6. Shale, gray to dark-gray weathering to orange-rusty chips	300
Total Hampton formation	1,400
Unicoi formation:	
Upper division:	
5. Quartzite, white or bluish, conglomeratic and quartzose, but with a few grains of feldspar; weathers sugary. Forms prominent ledge along crest of Iron Mountains	50
4. Sandstone, arkosic, as well as quartzite and conglomerate, with a prominent ledge near middle	300
3. Quartzite, arkosic, conglomeratic, forms a line of cliffs on rim of Iron Mountain	50
Unicoi formation—Continued	
Upper division—Continued	
2. Sandstone and conglomerate, arkosic; includes two quartzite ledges, and several interbedded layers of sedimentary greenstone	350
Lower division:	
1. Basalt, amygdaloidal; not well exposed, presence of layer indicated mostly by float	50
Part of Unicoi formation exposed	800

Long interval to base of mountain, mostly poorly exposed and apparently with complex bedrock structure. A strong ledge of conglomeratic quartzite near top, and conglomeratic layers near middle and base. Nature of remainder of sequence indicated only by float, which is of crumbly arkose, greenish shale, fine conglomerate, and some purple siltstone. Thickness undetermined, may be as much as 7,000 ft, but probably less.

Unconformity; basement rocks beneath, lying on Iron Mountain fault.

SECTION 9.—*Cross Mountain*

[Section on road over Cross Mountain from Stony Creek Valley to Shady Valley, in northwest part of Doe quadrangle. Starts below road crossing over Lindy Camp Branch of Stony Creek; top beds generalized from outcrops on northeast slope of Cross Mountain into Shady Valley. By P. B. King, L. E. Smith, and R. L. Miller, May 1942. Main part of section measured and described in detail along road; top beds calculated from outcrops as plotted on field sheets]

	Feet
Shady dolomite: At top of section; residual clay in south part of Shady Valley, mostly covered by wash.	
Erwin formation:	
Helenmode member:	
21. Sandstone, thin-bedded; exposed on road near base of slope into Shady Valley	100
Hesse quartzite member:	
20. Quartzite, white; deeply weathered near road	50
19. Sandstone and sandy shale, thin-bedded	40
18. Quartzite, massive, vitreous white or pale-brown; forms a ledge	30
Murray shale member:	
17. Sandstone and quartzite, not well exposed near road	27
16. Sandstone, in layers as much as several feet thick, interbedded with quartzite; some shale layers as much as 4 or 5 ft thick	36
15. Sandstone and quartzite in 1- to 3-ft beds, with many partings of thin-bedded sandstone and sandy shale. Some beds are light buff, very hard and vitreous; others greenish-gray and dull-lustered. Top of ledge is thick, hard, and persistent	49
14. Quartzite, bright-green, fine-grained, vitreous, has marked conchoidal fracture; resembles sedimentary greenstones of Unicoi formation of other sections. Exposed in road bend at bench mark LHT 338	13

	Feet
Erwin formation—Continued	
Murray shale member—Continued	
13. Quartzite, fine- to medium-grained, greenish-gray to dark gray, somewhat ferruginous; forms beds 2 to 4 ft thick, but beds are lenticular in places; contains interbedded layers of sandstone and shale	18
12. Sandstone, thin-bedded, shaly	15
11. Sandstone, thin-bedded, and very argillaceous shale; some 1-ft beds of sandstone and quartzite	26
10. Quartzite, vitreous, greenish-gray; beds as much as 3-ft thick, with shaly and sandy partings	55
9. Sandstone, fine-grained, dark-greenish, in 6-in to 2-ft beds; weathers rusty and to knobby lenticular boulders; a few vitreous layers and some shale partings	32
8. Sandstone, thin-bedded, shaly, and some fissile argillaceous shale; poorly exposed	28
7. Sandstone, greenish, in 3- to 6-in beds, interbedded with shaly sandstone	11
6. Covered	6
5. Sandstone, fine-grained, greenish-gray, shaly; in part thinly fissile, in part in beds as much as 8 in. thick	46
4. Sandstone, thin-bedded, shaly, weathers to dark rusty surfaces; some shaly partings as much as 3 in. thick, and a 2 ft bed of medium-grained quartzite near top. Unit contains a steeply dipping fault of unknown throw which may modify thickness given	59
3. Sandstone, fine-grained, dark-greenish; in 1- to 2-ft beds, with thin shale partings	24
2. Shale and sandstone, alternating layers 5 to 10 ft thick. The shale is thin bedded, fissile, blue green, and argillaceous; the sandstone is thin bedded, fine grained, and weathers rusty	27
1. Quartzite, dark, fine-grained; in 1-ft beds	10
Part of Erwin formation exposed	702

Base of section at crossing over Lindy Camp Branch, at sharp bend in road and at bench mark LHT 337. Exposures continue down road below, but, because of low dips, they do not appear to extend any lower in section than those described.

Section 10.—*Mountain City road*

[Section on U. S. Highway 421, or Shady Valley-Mountain City road over Iron Mountains, in Shady Valley, Doe, and Mountain City quadrangles. Extends from east edge of Shady Valley up Green Mountain Branch to crest of Iron Mountain at Sandy Gap, and thence down southeast side of Iron Mountain as far as a reliable sequence could be followed. By P. B. King, assisted by L. C. Craig and H. W. Ferguson, April and July 1942. Upper part of section was measured and described in field; lower part based on fairly detailed descriptions and calculations of thicknesses from field sheets.]

	Feet
Shady dolomite: At top of section, represented by residual clay in road cuts above highest beds of section.	
Erwin formation:	
Helenmode member:	
30. Sandstone, fine-grained, thin-bedded, and sandy clay, well laminated, weathers pink or purple. At top and 10 ft below top are several beds as much as 2 ft thick of coarse-grained quartz sandstone with a ferruginous matrix	100
Hesse quartzite member:	
29. Quartzite beds, showing following subdivisions:	
c. Quartzite, similar to basal bed	15
b. Sandstone, soft, weathers white or buff	15
a. Quartzite, medium-grained, white, in 1- to 2-ft. beds, made up largely of quartz, but with some dark minerals and sparse glauconite; weathers soft and friable. Some bedding surfaces show faint, shallow ripple marks	30
Murray shale member:	
28. Sandstone, thin-bedded, shaly; covered near highway, crops out to north and south. Thickness undetermined because of changes in dip at top and base; in Jim Wright Branch to south appears to be 400 ft.; on Marriage Ground Ridge to north is probably 240 to 260 ft.; average thickness about	300
27. Quartzite, ferruginous. Composed of following subdivisions:	
c. Quartzite in 1- to 3-ft beds, thicker-bedded below	10
b. Sandstone, thin-bedded, fine-grained; with some thicker and more quartzitic beds	35
a. Quartzite, medium-grained, quartzose; with many dark grains and some glauconite, giving a pepper-and-salt texture to rock; traces of giant ripples on bedding. Forms a massive ledge with few bedding planes	10
26. Shale, greenish, fine-grained, sandy, platy; with mica flakes on some bedding planes, weathers buff or brown; in upper half contains many interbedded layers of quartzite 3 in. to 1 ft. thick	100
25. Quartzite, medium- to fine-grained, dark-greenish or bluish, ferruginous; in beds several feet thick. At top is a gritty or pebbly quartzite, with grains as much as one-eighth inch in diameter, in a glauconitic and blue-gray ferruginous matrix	17
24. Shale, soft, thin-bedded, very argillaceous; interbedded with thin quartzite layers in upper quarter	100
Nebo quartzite member:	
23. Quartzite, white, gray, or pinkish, medium-grained and vitreous; in 1- to 3-ft. beds, many of which are full of *Scolithus* tubes	110
22. Shale, dark-greenish-gray and thin-bedded argillaceous sandstone; weathers rusty, probably with some interbedded thicker sandstone layers in lower part	250

	Feet
Erwin formation—Continued	
Nebo quartzite member—Continued	
21. Quartzite, white; in beds several feet thick, with abundant *Scolithus* tubes. Not well exposed near highway, but forms strong ledges on Grindstone Knob to northeast	100
Total Erwin formation	1192
Hampton formation:	
20. Sandstone, thin-bedded, fine-grained, and sandy shale, with some thin quartzite layers	300
19. Quartzite, fine- to medium-grained, gray or white in 1- to 2-ft beds; no definite *Scolithus*, although some faint vertical structures suggest their presence	50
18. Shale, divided into:	
b. Quartzite, interbedded with fine-grained sandstone, and sandy shale	30
a. Shale, dark-gray, very fine-grained, very argillaceous; without grit, but with a few thin sandy seams; weathers to chips and plates or to spheroidal forms; detrital mica on bedding surfaces. Cleavage poorly developed	285
17. Arkose, bedded; lower part, exposed northeast of Sandy Gap, is very coarse-grained, in places with quartz and feldspar pebbles one-eighth inch in diameter, but with interbedded layers of finer-grained, thinner bedded, more micaceous arkose. Upper part, west of Sandy Gap, is finer grained and grades upward into fine-grained rusty-weathering earthy sandstone; a thin bed of sandy shale 100 ft below top	750
Cardens Bluff shale member:	
16. Not exposed, but expressed topographically by a narrow, creaselike valley	25
Total Hampton formation	1,440
Unicoi formation:	
Upper division:	
15. Arkose in beds several feet thick, some full of grains as much as one-eighth inch in diameter, with faint ripples on some bedding surfaces	175
14. Quartzite, massive; composed of rounded quartz grains as much as one-eighth inch in diameter, buff on fresh surfaces, but weathers reddish; forms prominent ledge	20
13. Arkose, fine-grained, thin-bedded	100
12. Quartzite, white vitreous medium-grained; weathers reddish	10
11. Arkose, thin-bedded, shaly, with some thicker-bedded layers	185
10. Quartzite, grading into arkose above and below	10
9. Arkose, thin-bedded, shaly, with some thicker layers	175
8. Quartzite, thick-bedded, light-gray arkosic; contains much feldspar; not as massive as quartzite beds higher up	30
Unicoi formation—Continued	
Upper division—Continued	
7. Arkose, soft, crumbly, with partings of shaly arkose, and some interbedded, harder and more vitreous, medium- to coarse-grained arkose; weathers reddish. At base are pebbly beds containing quartz and feldspar grains one-fourth inch in diameter	430
Lower division:	
6. Basalt, amygdaloidal; composed of following subdivisions:	
b. Igneous rock, massive, blue, aphanitic, contains amygdules	20
a. Sedimentary rocks, probably tuffaceous, as suggested by abundant dark minerals, fine-grained texture, and bright reddish-brown weathered surfaces	80
5. Covered across saddle	250
4. Arkose, medium-grained, soft; contains much dark mineral and weathers reddish; interbedded with thin layers of hard green and purple slate	125
3. Gritstone and conglomerate in beds as much as 3 ft. thick, containing rounded pebbles of quartz and feldspar as much as half an inch in diameter; interbedded with finer grained arkose and slate	35
2. Shale, light-buff, micaceous and interbedded fine-grained arkose, with some beds of medium-grained arkose near middle	425
1. Sandstone, arkosic, in two beds; contains quartz pebbles, the largest pebbles being half an inch in diameter; between is thin-bedded arkose	25
Part of Unicoi formation exposed	2,095

Underlain by arkose, slate, and conglomerate similar to those immediately above, but dipping and striking in such an erratic manner that thickness cannot be determined (fig. 15 *B*).

Unconformity; basement rocks at base of section, resting on Iron Mountain fault (fig. 15 *A*).

SECTION 11.—*Parks Branch*

[Section on Parks Branch, a stream that drains northwestward from Iron Mountains into Beaverdam Creek, Shady Valley and Laurel Bloomery quadrangles. By L. E. Smith, July 1942. Thicknesses calculated from field sheets]

Shown graphically on plate 9.

SECTION 12.—*Fagall Branch*

[Section in Fagall Branch, a stream that drains northwest from Iron Mountain into Beaverdam Creek, west-central Laurel Bloomery quadrangle. By L. E. Smith, July 1942. Thicknesses calculated from field sheets]

Shown graphically on plate 9.

SECTION 13.—*Tank Hollow*

[Section on Tank Hollow, a valley that drains northwest from Iron Mountains into Beaverdam Creek, central Laurel Bloomery quadrangle (fig. 12). By L. E. Smith, July 1942. Thicknesses calculated from field sheets]

Shown graphically on plate 9.

SECTION 14.—*Reservoir Branch*

[Section on Reservoir Branch, a stream that drains northwest from the Iron Mountains and enters Beaverdam Creek at Sutherland, north-central Laurel Bloomery quadrangle (fig. 12). By L. E. Smith, August 1942. Section described in fair detail in field; thicknesses calculated from field sheets]

	Feet
Shady dolomite: At top of section in Sutherland basin; mostly represented by residual clay.	
Erwin formation:	
Helenmode member:	
12. Shale and sandy shale	110
Hesse quartzite member:	
11. Quartzite, white or light-gray, vitreous	90
10. Quartzite, thin-bedded; similar to that at Backbone Rock, with some earthy layers	50
9. Quartzite, massive, vitreous	90
Murray shale member:	
8. Siltstone, thin-bedded, earthy	170
7. Quartzite, thick-bedded, light-gray, vitreous	20
6. Siltstone, thin-bedded, earthy; with thin to medium-bedded layers of white quartzite in lower 50 ft	280
5. Quartzite, ferruginous; contains following subdivisions:	
b. Quartzite, thin to medium-bedded, fine-grained, ferruginous; weathers dirty yellow	48
a. Quartzite, coarse-grained, massive, purplish, ferruginous	24
4. Sandstone, greenish, thin-bedded	55
3. Quartzite, dense, earthy, ferruginous	1
2. Sandstone and siltstone, dark-greenish-gray, medium-bedded	34
Nebo quartzite member:	
1. Quartzite, fine- to medium-grained, white, vitreous, medium- to thick-bedded; contains *Scolithus* tubes. Lower part exposed discontinuously	160
Total Erwin formation	1132
Hampton formation at base of section.	

SECTION 15.—*Davis Hollow and Butt Mountain*

[Section near across the Iron Mountains, a little south of Tennessee-Virginia State line, northeastern part of Laurel Bloomery quadrangle. Erwin formation from Davis Hollow, a valley which drains northwest from Iron Mountains into Beaverdam Creek and Sutherland basin; Hampton formation from south fork of London Bridge Branch, the next valley to the northeast; by L. E. Smith, September 1942. Unicoi formation from summit of Butt Mountain southeastward to Laurel Creek, and thence southward on Tennessee State Route 91 (Damascus-Mountain City road); by P. B. King, August 1942. Part of Erwin formation was measured in field, but most of section was calculated from field sheets.]

	Feet
Shady dolomite: At top of section; represented mainly by residual clay.	
Erwin formation:	
Helenmode member:	
44. Shale and sandy shale. From here northward the member contains a thin but fairly prominent bed of quartzite in lower part. Thickness in different places is 90 to 130 ft; average about	110
Erwin formation—Continued	
Hesse quartzite member:	
43. Quartzite, massive, white, vitreous. From here northward units 41 and 43 merge and unit 42 becomes indistinct	40
42. Quartzite, thin-bedded	40
41. Quartzite, massive	60
Murray shale member:	
40. Shale and siltstone; poorly exposed in Davis Hollow; northward, many quartzite beds appear and make up a large part of the section in the hills south of Damascus. Four traceable quartzite ledges are recognized, of which the second from the top is the thickest and most prominent; the lowest is dark colored and somewhat ferruginous	560
39. Quartzite, ferruginous	40
38. Siltstone, thin-bedded greenish	200
Nebo quartzite member:	
37. Quartzite, white, vitreous; contains *Scolithus*	60
Total Erwin formation	1,110
Hampton formation:	
36. Covered, probably shale	240
35. Quartzite, light-gray, thick-bedded; speckled with brown spots; contorted in places	20
34. Siltstone, thin-bedded, greenish; some thin to medium-bedded quartzite layers toward top	470
33. Sandstone, medium to thick-bedded, dark-greenish-gray, quartzitic	30
32. Siltstone, thin-bedded, greenish	210
31. Quartzite, dark-gray, medium-grained and medium-bedded, vitreous, apparently without feldspar	40
30. Covered, probably shale	190
29. Quartzite, light-gray, fine-grained, quartzose; in north fork of London Bridge Branch coarser and somewhat feldspathic	40
28. Siltstone, thin-bedded, greenish, with two beds of feldspathic sandstone; exposed in north fork, covered in south fork	420
27. Quartzite, massive, coarse-grained, arkosic	60
26. Mostly covered; on adjacent hills are much float, and some outcrops of quartzite	350
Total Hampton formation	2,070
Unicoi formation:	
Upper division:	
25. Quartzite, white, thick-bedded, coarse-grained; contains a little feldspar; forms cap and northwest slope of Butt Mountain	145
24. Covered by talus	150
23. Quartzite, vitreous, somewhat arkosic and conglomeratic; forms great masses of coarse blocky talus, and a ledge	25
22. Covered by talus	125
21. Quartzite; forms a ledge	25

	Feet
Unicoi formation—Continued	
Upper division—Continued	
20. Covered by talus	125
19. Quartzite; forms a ledge	40
18. Covered by talus	50
17. Quartzite; forms a ledge	40
16. Slope, mostly covered, possibly soft arkose	525
15. Quartzite, vitreous	25
Lower division:	
14. Mostly covered in upper part. Lower down are float and some outcrops of micaceous shale; some quartz pebbles in float	300
13. Basalt, amygdaloidal; float only along line of section; well exposed on Laurel Creek just south of State line, where it is divisible into following units:	
c. Basalt, dark-blue-gray, aphanitic; full of amygdales; strongly jointed	50
b. Sandstone, medium-grained, arkosic; with conglomerate seams; dark-greenish on fresh surfaces; possibly tuffaceous	50
a. Basalt, dark, aphanitic; with irregular amygdales filled by pink mineral	50
12. Arkose, gritty	450
11. Arkose, soft, fine-grained, and thinly fissile, dark-reddish shale; some interbedded gritty arkose	175
10. Arkose, gritty	25
9. Shale, arkosic below and argillaceous above, with interbedded pebbly arkose	530
8. Conglomerate, coarse; in massive ledges, with well-rounded pebbles as much as 3 in in diameter, mostly quartz, but including some of volcanic rocks of Mount Rogers group	250
7. Conglomerate, with quartz and feldspar pebbles as much as one-fourth inch across; outcrops scattered, mostly covered across valley of Laurel Creek	500
6. Arkose, conglomeratic, vitreous, forming a very massive ledge on ridge southwest of Laurel Creek and a narrows on creek; beds 3 to 5 ft thick, with thin shale partings; contains pebbles of quartz and feldspar as much as one-fourth inch across	160
5. Covered	60
4. Arkose and slate, each forming about half the unit	65
3. Quartzite, coarse, arkosic; in 1- to 5-ft beds, massive, and well cemented, of light greenish gray color. Some beds contain quartz pebbles as much as one-fourth inch across, and some slate pebbles; there are some interbedded layers of dark argillaceous slate, one of which is as much as 10 ft thick	205
2. Slate, argillaceous, thin-bedded, micaceous; passing up into more massive argillite that contains interbedded arkosic quartzite	70
Unicoi formation—Continued	
Lower division—Continued	
1. Underlying beds that are not exposed in a continuous section: In lower part are coarse conglomerate beds with rounded quartz pebbles more than half an inch in diameter; higher up, the conglomerate is interbedded with finer-grained, thinner-bedded arkose. In upper part of unit on Lyons Branch, a mile northwest of Laurel Bloomery, is a bed of greenstone, possibly a basalt. Thickness uncertain, probably about	700
Total Unicoi formation	4,915
Unconformity.	
Mount Rogers volcanic group at base of section, resting on Iron Mountain fault, with Rome formation beneath.	

SECTION 16.—*London Bridge Branch*

[Section on London Bridge Branch, a stream which drains northwestward from Iron Mountains into Beaverdam Creek, which it enters just south of Damascus, Va.; northeast part of Laurel Bloomery quadrangle. By L. E. Smith, September 1942. Thicknesses mainly calculated from field sheets.]

Shown graphically on plate 9.

SECTION 17.—*Unaka Springs*

[Section along Nolichucky River southeast of Unaka Springs, Chestoa quadrangle. Section begins ¼ mile east of Unaka Springs, extends up the river 1½ miles, to a point ⅓ mile north of the Tennessee-North Carolina State line, where an unnamed stream enters the river from the southwest. Most of observations were made in cuts along the line of the Clinchfield Railroad, but these were supplemented by outcrops in the bed of the river. By P. B. King, John Rodgers, and L. E. Smith, November 1942. The section was measured and described in detail in the field.

This section lies about 15 miles southwest of the southwest corner of the region covered in the present report, but it is included because it contains the type sections of the Erwin and Unicoi formations]

	Feet
Shady dolomite: At top of section; blue dolomite exposed along river several hundred feet above base; basal beds in railroad cut are represented by residual clay containing masses of jasperoid.	
Erwin formation (type section):	
Helenmode member:	
46. Quartzite in 1- to 2-ft. beds, containing partings of shale and sandy shale	44
Hesse quartzite member:	
45. Quartzite, very massive, pinkish, vitreous; forms wall above the railroad tracks (Keith, 1907, fig. 14)	25
44. Sandstone or quartzite, earthy, greenish; with shaly partings	22
43. Quartzite, bluish, vitreous; in 2- to 5-ft beds; forms a ledge	12
Murray shale member:	
42. Sandstone, earthy, greenish with shaly partings; cleavage in shale dips northwest	22
41. Shale or slate, thin-bedded, argillaceous; in part laminated; forms massive outcrops	72
40. Shale exposed at intervals, but partly covered	168

	Feet
Erwin formation—Continued	
Murray shale member—Continued	
39. Sandstone in 1-ft. beds, in part earthy, in part white and almost vitreous; contains some interbedded shale with well-marked northwestward-dipping cleavage	66
38. Shale, thin-bedded; with some cleavage	61
37. Sandstone in 3- to 6-in. beds	18
36. Shale	36
35. Sandstone, shaly; passes into argillaceous shale below	63
34. Quartzite, slightly ferruginous, massive and vitreous below; parts are crossbedded. Crops out just north of Mine Branch	21
33. Covered across Mine Branch; some shale outcrops farther up the valley of this branch	85
32. Shale, thin-bedded, dark-greenish, argillaceous; faint northwestward-dipping cleavage	56
Nebo quartzite member:	
31. Quartzite bluish-gray, vitreous, medium-grained; contains traces of *Scolithus*. This bed, and bed 29, make prominent outcrops in river channel and on mountain slope to east	24
30. Shale and thin-bedded sandstone	12
29. Quartzite, gray to buff, vitreous; some greenish, earthy sandstone at base	28
28. Sandstone, greenish, shaly	28
27. Covered	200
26. Quartzite ledges, prominent, forms ridge across river to east. Middle 10 ft is white massive quartzite; above and below are thinner darker beds	90
25. Quartzite, thin-bedded, poorly exposed	21
24. Quartzite, massive, medium-grained, vitreous, with some crossbedding. Forms prominent ledge	46
Total Erwin formation	1,220
Hampton formation:	
23. Shale, mostly covered along railroad, although forming rapids here and there in river. A fault may occur in this interval, as one is proved along the strike to the northeast	390
22. Quartzite, white, in 1- to 3-ft beds, contains some feldspar grains and a little pyrite; interbedded with softer sandstone	50
21. Shale and siltstone, not well exposed	135
20. Quartzite, arkosic, feldspathic; in 3-in. to 3-ft beds, in part crossbedded, bluish or greenish where fresh, weathering brown. Thicker beds are full of *Scolithus* tubes. Crossbedded layers alternate with the *Scolithus*-bearing layers, and themselves contain some tubes	45
19. Quartzite, massive, vitreous, no *Scolithus* tubes except at top	35

	Feet
Hampton formation—Continued	
18. No outcrops on railroad or west bank of river. On east bank, a prominent sandstone bluff in middle, apparently with softer and shaly beds above and below	325
17. Quartzite, contains much feldspar, forms a fairly prominent ledge	25
16. Covered, probably shale; base of unit lies at mouth of Long Branch	120
Total Hampton formation	1,125
Unicoi fromation (type section):	
15. Quartzite, coarse, vitreous; in 1- to 3-ft beds, contains much feldspar, with some crossbedding and pebbly layers. Makes a prominent ledge	100
14. Sandstone, thin-bedded, arkosic; some shale partings	300
13. Quartzite ledge, massive	80
12. Quartzite, thin-bedded, arkosic	170
11. Quartzite, massive; forms a prominent ledge on each side of river	40
10. Quartzite, thin-bedded, arkosic; with sedimentary greenstone below	170
9. Quartzite, very arkosic; forms a ledge that is not as prominent as those above	60
8. Quartzite, arkosic	290
7. Quartzite, thick-bedded to massive; mostly coarse-grained, with pebbles as much as an inch in diameter at base	75
6. Basalt, amygdaloidal; thin bed of green, schistose igneous rock, with traces of amygdules	24
5. Quartzite, vitreous, arkosic; in 3- to 5-ft beds; contains pyrite in some layers. Upper part is coarse-grained and contains pebbles as much as an inch across of quartz and slate, but no feldspar; becomes finer-grained below	110
4. Quartzite, thick-bedded arkosic; large scale crossbedding in places; coarse and fine beds alternate; the coarser are vitreous and pebbly, with some fragments as much as half an inch in diameter; the finer are earthy and shaly. Makes scattered ledges on mountain sides	600
3. Similar to bed above, but becomes very conglomeratic in lower part	102
2. Basalt, amygdaloidal; schistose igneous rock, with some amygdules	20
1. Arkose, conglomeratic. Lower half includes some very coarse beds, containing rounded pebbles of quartz and slate as much as 2 in across, but none of feldspar. Pebbles are sliced and shattered by deformation	320
Part of Unicoi formation exposed	2,461

Fault or unconformity at base. When section was measured in 1942, it was believed that base of the Unicoi was cut off by a fault, below which formation was repeated. During field work in 1948, Jean Lowry concluded that basal contact is an unconformity, beneath which is a pre-Unicoi sedimentary series. No preference can be expressed for either interpretation without further field review. Nature of lowest Unicoi beds indicates that they are very near actual base of the formation.

SECTION 18.—*Hampton*

[Section in gorge of Doe River through Fork Mountain and Cedar Mountain, south of Hampton, southeast part of Elizabethton quadrangle. Most of observations were made in cuts along the now-abandoned line of the East Tennessee & Western North Carolina Railroad, but these have been supplemented by outcrops in bed of river and on Cedar Mountain to northeast. By P. B. King, L. E. Smith, and C. A. Nelson, October 1942. The section was measured and described in the field]

	Feet
Shady dolomite: At top of section. White silty dolomite exposed on northeast bank of Doe River below the gorge.	
Erwin formation:	
Helenmode member:	
43. Mostly covered; shaly float	60
42. Sandstone, iron-bearing; worked for iron in large opencut on northwest spur of Cedar Mountain	70
41. Sandstone, white, feldspathic, nonvitreous; considerably disturbed; about	100
Hesse quartzite member:	
40. Quartzite, in tunnel on railroad	42
39. Shale	3
38. Quartzite, white, vitreous; in 1- to 3-ft beds; some bedding surfaces have large ripple marks; units 38 to 40 form a very prominent ledge	47
Murray shale member:	
37. Shale outcrops, poorly exposed near middle on railroad; just above them in river is a quartzite ledge; in lower part on Cedar Mountain, float of ferruginous quartzite was observed	620
36. Quartzite, gray and buff, vitreous	10
35. Shale and siltstone, with thin sandstone beds toward the base	135
Nebo quartzite member:	
34. Quartzite, vitreous, laminated; in 1- to 3-ft beds, forms ledges	75
33. Covered	50
32. Quartzite, containing *Scolithus* in lower part	100
31. Quartzite, buff to gray, vitreous to resinous; in 1- to 3-ft beds, containing a little fine-grained feldspar; a few shale partings at wide intervals. *Scolithus* noted in outcrops along river	234
Total Erwin formation	1,546

	Feet
Hampton formation:	
30. Covered	300
29. Sandstone in 6-in. to 1-ft beds, with interbedded shale; quartzite outcrops on river; to southwest on Fork Mountain arkosic quartzite contains *Scolithus;* this is the same as the mid-Hampton arkose of the Unaka Springs section (bed 20)	20
28. Shale, slaty; mainly banded and argillaceous, but becoming silty and sandy upward	85
27. Sandstone, earthy; in beds as much as 3 ft thick	20
26. Shale, silty and argillaceous; thin interbedded sandstone layers; prominent cleavage	45
Total Hampton formation	470
Unicoi formation:	
25. Quartzite, gray; in 1-ft beds, partly vitreous, partly earthy; contains some pyrite	23
24. Quartzite in beds as much as 4 ft thick, mostly vitreous, all arkosic; lower part is light gray or buff, upper part darker colored; part very pyritic and covered by weathered crust. Unit does not form a prominent ledge along the railroad, but on Cedar Mountain to the northeast projects in a tremendous ledge, indicated by the contouring on the topographic map	104
23. Covered along railroad; on Cedar Mountain, a cliff-making bed of arkosic quartzite in middle	268
22. Quartzite, light-buff, vitreous, thick-bedded to massive; exposed at second railroad tunnel	300
21. Covered along railroad, probably mostly shaly; in river bed and on east bank is a ledge of coarse-grained arkose near middle	310
20. Quartzite, slightly arkosic, light gray, cross-bedded, and laminated; forms prominent massive ledges above and thinner-bedded layers below	76
19. Sandstone, arkosic, in 1- to 3-ft beds, earthy below, becoming more vitreous above; less resistant than beds above and below	70
18. Quartzite, dark-gray or bluish, moderately vitreous, cross-bedded, and ripple-marked, in 1- to 3-ft beds, interbedded with earthy sandstone and shale	79
17. Quartzite, arkosic; sharply folded and with well-developed cleavage; estimated	30
16. Sandstone, earthy, arkosic; shale partings at intervals; less resistant than beds above and below	33
15. Quartzite, vitreous, dark-gray; contains scattered feldspar grains, in 3- to 5-ft beds below, very massive above	42
14. Covered	35
13. Quartzite, vitreous, in part very coarse-grained	15
12. Not well exposed along railroad; similar to beds below in nearby outcrops	13

	Feet
Unicoi formation—Continued	
11. Sandstone, earthy, arkosic, in 1- to 2-ft beds, contains layers of quartz and feldspar pebbles as much as ¼ in in diameter	37
10. Sandstone and quartzite, arkosic, blue-gray, medium-grained, with pebbly bands; contains some feldspar throughout; much more vitreous than units below or above. Forms beds as much as 5 ft thick at base, but becoming thinner-bedded higher up; forms a great cliff that is undercut by railroad, and part of a succession of cliffs northeast of river	74
9. Sandstone, arkosic, with some shale partings; less resistant than adjacent beds	104
8. Sandstone, arkosic, in 1- to 4-ft beds; composed of quartz and pink feldspar grains in a dark-greenish earthy matrix, with some pebbly seams. Exposed in a narrow cut on the railroad	100
7. Covered, probably mostly thin-bedded sandstone	20
6. Sandstone, arkosic; dark-colored, medium-grained; in 1- to 3-ft beds, somewhat thicker-bedded toward top, in part cross-bedded; some pebbly seams contain grains as much as one-eighth inch in diameter, and some shale partings	79
5. Covered by talus	155
4. Quartzite, dark-colored, very feldspathic; in 1-ft beds, containing pebbly seams	13
3. Quartzite, vitreous, medium-grained; in 2- to 4-ft beds, with very little feldspar	12
2. Sandstone, fine-grained, thin-bedded, greenish arkosic; contains pebbly seams	5
1. Conglomerate, made up of quartz and feldspar pebbles as much as half an inch in diameter, mostly well-rounded, lying in a greenish-gray arkosic matrix. Some shaly streaks in places. Exposed at Pardee Point on railroad	29
Total Unicoi formation	2,026

Unconformity

Basement rocks beneath, with gneissic structure, containing granitic and pegmatitic layers, and interbedded schistose layers. The contact with the Unicoi formation is well exposed in a railroad cut (fig. 7), where the two rocks are welded together, without a strong parting between. The unconformable relations are indicated by truncation of schistose layering of the basement rocks by the overlying conglomerate of bed 1.

Section 19.—*Laurel Fork*

[Section on northeast side of gorge of Laurel Fork through Black Mountain and Pond Mountain, southeast part of Elizabethton quadrangle. The section is based principally on outcrops on trail (now the Appalachian Trail) that follows old railroad grade, but is supplemented by adjacent outcrops in stream bed and elsewhere. By L. E. Smith and John Rodgers, December 1942. Most of this section was measured and described in detail in field, except for inaccessible cliff-making quartzite beds of unit 3]

	Feet
Shady dolomite: At top of section.	
Erwin formation:	
Helenmode member:	
16. Covered, probably siltstone and shale	150
Hesse quartzite member:	
15. Quartzite, thin-bedded, dense, white to gray; some interbedded shale	75
14. Quartzite, massive; pebbly in part	15
13. Quartzite, thick-bedded, vitreous, white; some interbedded shale	20
12. Quartzite, massive, white; pebbly in part	30
11. Quartzite, medium- to thin-bedded, white; some interbedded shale	30
10. Quartzite, massive and thick-bedded; top white and vitreous, lower part yellow and impure	34
Murray shale member:	
9. Sandstone, thick-bedded, silty, greenish	30
8. Shale	30
7. Sandstone, thick-bedded, silty; somewhat vitreous	12
6. Shale, some greenish siltstone	125
5. Quartzite, thick-bedded to massive, light-brown, fine- to medium-grained, vitreous to subvitreous; in part silty and feldspathic; forms prominent ledge on Pond Mountain	35
4. Siltstone, shaly, dark-green	300
Nebo quartzite member:	
3. Quartzite, mostly massive, white to light-gray, fine-grained; contains some feldspar, as well as abundant *Scolithus* tubes throughout. Top beds on Cedar Mountain are ferruginous. Forms a sheer cliff on south side of Laurel Fork gorge. Thickness not measured because of cliffy outcrops; estimated	475
Total Erwin foundation	1,361
Hampton formation:	
2. Arkose, thin- to medium-bedded; interbedded with shale and thin layers of quartzite. *Scolithus* abundant in some beds	187
1. Divided into:	
b. Quartzite, thin- to medium-bedded, light-gray, fine-grained; feldspathic and contains some *Scolithus*	21
a. Shale and siltstone	206
Total Hampton formation	414
Unicoi formation: Massive quartzite ledges at top of formation; lower beds not measured.	

Section 20.—*Sink Mountain*

[Section across the southern of the two Sink Mountains shown in the northwest part of the Butler quadrangle. Lower beds exposed on steep scarp on southeast side; higher beds on dip slope to northwest, toward valley of Sink Branch. By H. W. Ferguson, 1944. This section was not measured, and detailed description of beds was not made, but the total thickness of each formation was calculated]

	Feet
Erwin formation:	
Helenmode member: Shale with some interbedded layers of coarse sandstone. Several well-exposed sections in Butler quadrangle, about	50

	Feet
Erwin formation—Continued	
Main body of formation: Quartzite, massive, white; *Scolithus* in many beds, especially in upper half, where there is possibly also a little interbedded shale. Lower beds are light-gray quartzite with closely spaced ferruginous bands or layers	990
Total Erwin formation	1,040
Hampton formation: Shale, silty; with many interbedded layers of feldspathic sandstone, in part crossbedded; coarser grained arkosic beds below; a thin ledge of dark-buff arkose containing small *Scolithus* tubes near the base	405
Unicoi formation: Arkose, crossbedded; unusually coarse-grained and in part pebbly or finely conglomeratic. Exposed	280
Base of section cut off by normal fault on southeast side of Sink Mountain; no lower beds exposed.	

SECTION 21.—*Nowhere Ridge*

[Section on south side of Nowhere Ridge, on Elk Mills-Poga road, in northwest part of Elk Park quadrangle (Linville 15-minute quadrangle). Top of section is on road half a mile south of crossing over Elk River and about 250 feet higher than river; continues half a mile eastward beyond road that branches to southeast, to basement rocks. Preliminary observations on section were made by H. W. Ferguson in 1944; it was measured and described in detail in the field by P. B. King and R. A. Laurence in February 1954. Because of structural complications, especially in the Erwin formation, thicknesses given are approximations]

	Feet
Shady dolomite: At top of section. At base, lying on Erwin formation, are rounded and knobby, dark-weathered ledges, which on broken surfaces are seen to be composed of white, saccharoidal dolomite, with vugs and gash veins of white crystalline dolomite. About 50 ft above base are two 10-ft beds of dark-gray shale, weathered tan and platy, separated by 25 ft of light-blue-gray dolomite with crystalline vugs. Dolomite is sharply pinnacled and overlain by dark red residual clay.	
Erwin formation:	
16. Shale; dominantly blue-gray with interbedded layers of sandstone or quartzite 6 in to 1 ft thick; rocks do not resemble Helenmode member, but if its equivalent is present it lies in this interval	100
15. Quartzite, gray; in ledges 2–3 ft thick, extending up slope above road. *Scolithus* reported in this and other quartzite beds by Ferguson; not seen on revisit	140
14. Shale, blue-gray, poor outcrops	75
13. Covered by wash	75
12. Shale, blue-gray, silty; interbedded with quartzite, shows much disturbance; thickness uncertain. At one point crossed by cleavage which dips more steeply than bedding, suggesting beds are not inverted	20
11. Quartzite, pink or buff; in ledges several feet thick, with many dark bedding laminae, crossbedded in some layers, with an attitude proving that strata are not inverted	150
Disturbed zone, 10–20 ft wide, in which rocks are much contorted and faulted.	
Erwin formation—Continued	
10. Sandstone, fine-grained; more earthy than vitreous, in 1- to 2-ft beds, with softer, more deeply weathered interbeds	45
Total Erwin formation	605
Hampton formation:	
9. Shale, dominantly blue-gray, slaty; quite different in appearance from shale next beneath; interbedded with 3-in to 1-ft layers of gray earthy sandstone, containing fine grains of feldspar	90
8. Shale, gray-green, fissile; faint mica sheen on bedding surfaces, breaking out in platy layers; no evidence of cleavage. Most of the shale body is very uniform; some 3-in to 1-ft beds of fine-grained sandstone or siltstone at intervals	270
Total Hampton formation	360
Unicoi formation:	
7. Quartzite, very quartzose; forms strong, massive ledges, of typical upper Unicoi aspect, with a few feldspathic layers, the whole relatively fine-grained; no partings of shale or fine-grained sandstone	200
6. Sandstone, thick-bedded, feldspathic, very coarse to medium-grained; some partings of finer grained, more readily weathered sandstone, but none of slate; some ledges show graded bedding that indicates overturn of strata	350
5. Sandstone or quartzite, very quartzose, with almost no feldspar, in beds several feet thick	85
4. Sandstone, fairly coarse, with strong crossbedding	80
Disturbed zone, about 10 ft wide, full of irregular shear planes.	
3. Sandstone in 1- to 3-ft beds, with some seams containing quartz and feldspar grains an eighth to a quarter of an inch in diameter, interbedded with layers of blue-gray shale as much as 6 in thick	210
2. Sandstone, fine-grained, feldspathic; with seams of glassy and rose quartz grains a quarter of an inch in diameter; feldspar grains slightly smaller; some beds contain purple aphanitic rock fragments as much as half an inch in diameter that may be of volcanic origin. Lower part of unit partly concealed across a small creek	80
1. Siltstone, fine-grained, brown-weathering, thin-bedded at base, in contact with granitic rocks; no evidence of structural disturbance at contact, yet this rock type is not that which occurs as the basal deposit above an unconformity	5
Part of Unicoi formation exposed	1,010
Probable fault, presumably a member of Stone Mountain fault family.	
Basement rocks, exposed east of base of section.	

SECTION 22.—*Stone Mountain*

[Section on the Stone Mountains, in segment northeast from east-central part of Butler quadrangle, through Sherwood quadrangle, into southeast part of Mountain City quadrangle. By H. W. Ferguson, 1949. No section was measured or calculated in this area, on account of complex structure and scattered exposures. Descriptions given below are generalized from many traverses, especially in northeast half of segment; thicknesses given are very rough estimates.]

	Feet
Shady dolomite: At top of section.	
Erwin formation:	
Helenmode member: Not certainly recognized, probably largely concealed.	
Main body of formation: Quartzite, with *Scolithus* from top to base, generally with three prominent groups of ledges, the highest thin and weak, the middle massive and white, and the lowest in part ferruginous. Interbedded with silty shale, and in lower part with silty earthy sandstone	950?
Hampton formation: Shale, argillaceous, and silty shale; interbedded thin quartzite layers in upper part, and arkosic layers in lower part, some rather coarse grained	1,000?
Unicoi formation:	
Upper division and main part of unit exposed: Arkose, coarse-grained, conglomeratic; in part crossbedded.	
Lower division: Arkose, soft, with interbedded conglomerate and green, drab, or purple shale; amygdaloidal basalt at a few localities; exposed only in places in northeast part of range, on southeast slope next to Stone Mountain fault	2,400?
Base of section generally cut off by Stone Mountain fault, which carries basement rocks over Unicoi formation; basement rocks in a few small areas apparently lie unconformably beneath lowest beds of Unicoi.	

SECTION 23.—*Forge Mountain*

[Section on Forge Mountain, in northeast part of Mountain City quadrangle and northwest part of Baldwin Gap quadrangle. By H. W. Ferguson, 1948. No section was measured or calculated in this area, on account of complex structure and scattered exposures. Descriptions given below are generalized from many traverses; thicknesses given are very rough estimates]

	Feet
Shady dolomite: At top of section.	
Erwin formation:	
Helenmode member: Not certainly recognized, probably largely concealed.	
Main body of formation: Quartzite, white, commonly containing *Scolithus*, with some ferruginous quartzite in lower part; some interbedded shale	700?
Hampton formation: Shale, quite argillaceous at base; some interbedded layers of feldspathic quartzite	900?
Unicoi formation:	
Upper division, and main part of unit exposed: Arkose, coarse-grained, pebbly; some ledge-making layers of vitreous quartzite.	
Lower division: Slate, red and purple and interbedded coarse conglomerate, in part red colored; amygdaloidal basalt observed at several localities; exposed at only a few places on southeast slope, next to Stone Mountain fault	2,000?
Base of section cut off by Stone Mountain fault.	

SECTION 24.—*Matney area*

[Section exposed on the western spurs of Pond Mountain and Catface Ridge, east of community of Matney, Grayson quadrangle. From manuscript report by H. W. Ferguson, 1942. No section was measured, nor were the beds described in detail because of structural complexities and discontinuity of outcrop, but thickness of the Erwin and Hampton formations were calculated from position of outcrops as plotted on field sheets]

	Feet
Shady dolomite: At top of section; mostly represented by residual clay near outcrops of underlying formations, but with unweathered dolomite exposed in lower ground near Matney.	
Erwin formation:	
Helenmode member: 75 feet of light-colored sandy shale, overlain by 15 feet of coarse-grained sandstone, of well-rounded loosely cemented quartz grains. Crops out in a series of knobs west of Rogers Ridge. Between Atchison and Gentry Branches, and in anticline on Dyestone Branch, the lower shale is interbedded with medium-grained white quartzite with abundant *Scolithus* tubes	90
Main body of formation: Quartzite, light-colored, medium-grained, vitreous and thin-bedded ferruginous quartzite, and interbedded dark-greenish sandy shale. Along Gentry Branch there are only minor amounts of shale, but along Atchison Branch shale makes up a large part of lower half of formation	>1,000
Total Erwin formation	1,090
Hampton formation: Shale and siltstone, dark-gray; with interbedded layers of thin-bedded arkose, and at some localities a 50-ft ledge near middle of arkosic, *Scolithus*-bearing quartzite. Best exposures are in upper part of Gentry Branch	1,000
Unicoi formation:	
Quartzite, arkosic	50
Arkose, thin-bedded, and interbedded siltstone	750
Arkose, thicker bedded, coarser; some sedimentary greenstone. Total exposed thickness not determined.	
Base of section cut off by Catface fault.	

SECTIONS OF SHADY DOLOMITE AND ROME FORMATION

SECTION 25.—*Jenkins Hollow*

[Section on west side of Doe River, west of village of Valley Forge near mouth of Jenkins Hollow, central Elizabethton quadrangle (pl. 12). The section begins at top of section 6 of Chilhowee group, at lower end of gorge through Iron Mountain, continues northwest past mouth of Jenkins Hollow on slopes west of river, and ends at base of Honaker dolomite north of Long Hollow. By P. B. King, John Rodgers, and H. W. Ferguson, November 1941, August and October 1942. This section was not measured in detail in field, and thicknesses were calculated from field sheets]

	Feet
Honaker dolomite: At top of section.	
Rome formation:	
I. Shale and siltstone, red, in thin to thick beds; some bedding surfaces ripple-marked	700
H. Dolomite, white, thin-bedded	15
G. Shale and siltstone, red	35
F. Dolomite, cherty, thick-bedded	125

	Feet
Rome formation—Continued	
E. Shale, red, and interbedded thin layers of dolomite	375
Total Rome formation	1,250
Shady dolomite (represented mostly by red and brown residual clay, more or less covered by quartzite wash. Outcrops of unweathered dolomite occur only at intervals):	
Upper blue member:	
D. Dolomite, thick-bedded, blue-gray; exposed north of mouth of Jenkins Hollow	400
Upper white member:	
C. Dolomite, white, exposed half a mile southwest of the river in Bremer Hollow, above its junction with Long Hollow. Belt occupied by this unit probably passes near mouth of Jenkins Hollow, but is not exposed there	100
Middle blue member, ribboned member, and lower blue member:	
B. Limestone, blue-gray, ribboned; extends relatively high in section; crops out extensively on ridges immediately south of Jenkins Hollow. Lower down and farther southeast, relatively close to dip slope of Erwin formation, are outcrops of blue-gray ribboned dolomite	400
Lower white member:	
1. Not well exposed on either east or west sides of river. In railroad cut on east, within 30 ft of base, are pinnacles of gray dolomite and blue ribboned dolomite. In cuts on U. S. Highway 19 E, above, is a thick body of well laminated, buff or brown, waxy buckfat clay, with platy seams of manganese oxide (pl. 13). Twenty feet above base in a 5-ft bed of purple sandy clay with streaks of white kaolinitic clay, which was probably originally a sandy dolomite	50
Total Shady dolomite	950

Erwin formation: At base of section, with Helenmode member at top (see section 6).

Section 26.—*Wilbur Dam*

[Section on northeast side of Watauga River below Wilbur Dam, northeast part of Elizabethton quadrangle (pl. 18). The section begins at the top of the Chilhowee group of section 7, and continues northward along the slopes northeast of the river to a point where the sequence is broken and duplicated by faulting (fig. 13). Preliminary work on section by John Rodgers, August 1942; detailed observations by P. B. King, L. C. Craig, L. E. Smith, and C. A. Nelson, October 1942. This section was measured and described in detail in field]

	Feet
Top of section cut off by fault.	
Shady dolomite:	
Upper blue member:	
O. Dolomite, blue, thick-bedded	10
N. Shale bed. Argillaceous dolomite, brown and silty, in massive outcrops; weathers to shaly chips	6
Shady dolomite—Continued	
Upper blue member—Continued	
M. Dolomite, blue-gray, drab-weathering; large irregular masses of white chert near base and middle	31
L. Covered	8
Upper white member:	
K. Dolomite, white, massive, saccharoidal; mostly finely crystalline, of white, creamy, or flesh color, weathers to smooth white or ashen surfaces	102
Middle blue member:	
J. Dolomite, blue-gray, in prominent, well-bedded ledges; has a sharp contact with beds above	57
I. Dolomite, blue, more thinly bedded than units above or below; mostly covered in upper part	64
H. Dolomite, blue, blebby; very massive ledge	35
G. Dolomite, blue; in 6-inch to 1-ft beds, some containing laminae within beds, some massive; a few contain recrystallized stringers and ribbons. Upper half poorly exposed	41
F. Dolomite, blue, well-bedded; in part with recrystallized blebs and ribbons, in part with wavy laminae. Forms massive cliffs along river	47
Ribboned member:	
E. Dolomite, laminated somewhat ribboned, with some ribboned limestone	21
D. Limestone, dark-blue-gray to black, ribboned; contains argillaceous seams	39
C. Dolomite, ribboned, with the lighter ribbons unaltered except for scattered recrystallized blebs	28
B. Dolomite, ribboned, in scattered outcrops	50
Ribboned member (lower part), lower blue member, and lower white member:	
A. Not exposed	200
Part of Shady dolomite exposed	739

Erwin formation: At base of section, with Helenmode member at top (see section 7).

Section 27.—*Blue Spring*

[Section measured northwestward up the slope from floor of sink hole a quarter of a mile northeast of Blue Spring, northwest part of Fish Springs quadrangle. Preliminary work on section by John Rodgers, August 1942; detailed work by P. B. King, L. C. Craig, L. E. Smith, and C. A. Nelson, October 1942. This section was measured and described in field]

	Feet
Top of section: higher beds not measured.	
Rome formation:	
Q. Shale and siltstone, red in float and outcrops	
P. Limestone, earthy; laminated, drab-weathering; in loose blocks with much intermingled shale float	35
O. Covered; elsewhere in vicinity this interval consists of silty and shaly dolomite and dolomitic shale, with little or no red shale, forming a transitional unit with Shady dolomite	133
Part of Rome formation exposed	168

	Feet
Shady dolomite:	
Upper blue member:	
N. Dolomite, laminated, blue-gray; thin bed of shale in lower part	41
M. Shale, platy, dark-gray, calcareous	2
L. Dolomite, blue-gray; in 6-in beds, some thicker beds toward top; in part compact, in part finely crystalline; beds contain laminae a few millimeters thick of alternating light and dark blue-gray color; thin lenses of black chert near top; forms a massive ledge	21
K. Dolomite, blue-gray, thin-bedded and laminated; in part weathering white, with thin layers of blue chert; forms scattered outcrops	238
J. Covered; dolomite outcrops to north and south	37
I. Dolomite, thin-bedded, blue-gray; well laminated, with two thin shaly beds in lower part	26
H. Shale bed. Argillaceous dolomite, weathering to brown silty surfaces. Forms a projecting bench, marked by thickets and hillside seeps along its course	21
G. Dolomite, blue-gray, laminated; mostly in thin beds, some massive layers; contains large irregular chert concretions in lower part	15
F. Covered	15
Upper white member:	
E. Dolomite, compact, white, well-bedded, laminated	18
D. Dolomite, silty; weathers to shaly chips	2
C. Dolomite, light-gray to buff, crystalline; in thick beds. Weathers to knobby and cavernous surfaces, and in places crumbles to dolomite sand	120
Middle blue member:	
B. Dolomite, blue-gray; without blebs or ribbons; upper part well laminated and light blue gray	57
A. Dolomite, blue-gray; in 1- to 2-ft beds, laminated within the beds; contains some recrystallized ribbons 3 to 6 in. apart and one-fourth inch thick, and some recrystallized blebs; weathered surface covered by small knots. The ribboned dolomite appears to extend to an abnormally high level in section; presumably it is not part of true ribboned member, which must be lower in sequence and not exposed	21
Part of Shady dolomite exposed	634

Base of section; no lower beds exposed.

Section 28.—*Sadie*

[Sections near Sadie, in upper part of Stony Creek Valley, in central part of Carter quadrangle. By P. B. King, November 1941. Section A is generalized from observations on outcrops between the communities of Sadie and Carter. Sections B and C were measured in detail by hand level]

Section A: Generalized section in area between Sadie, and Carter 2 miles to southwest.

Top of section; no higher beds exposed.

	Feet
Shady dolomite:	
Ribboned member:	
C. Dolomite, ribboned and thin-bedded, blue-gray, finely crystalline; contains closely set white crystalline layers or ribbons less than one-fourth inch thick and somewhat wavy. On weathered surfaces, rock is slabby or laminated, in part with argillaceous ribs	>100
Lower blue member:	
B. Dolomite, blue-gray, massive or thick-bedded, blue-gray and finely crystalline; with blebs and irregular masses of white crystalline dolomite. On weathered surfaces bedding shows as ridges, creases, and widely spaced partings, in places with crinkled argillaceous ribs of very irregular structure	90
Lower white member:	
A. White or cream-colored crystalline dolomite, possibly sandy in part	10
Part of Shady dolomite exposed	200
Erwin formation:	
Helenmode member (type section):	
4. Sandstone, quartzitic; with large, remarkably rounded quartz grains; matrix slightly calcareous and glauconitic; apparently gradational with dolomite above	5
3. Siltstone, thin-bedded, greenish, argillaceous appearing on fresh surfaces much like the shaly and silty interbeds lower in Erwin formation, but weathering to soft blue chips	90
2. Sandstone, shaly, interbedded with buff quartzite	5
Hesse quartzite member:	
1. Quartzite, white or buff; massive ledge whose top is pebbly and shows giant ripple marks on bedding surfaces; exposed in bed of Stony Creek	50
Part of Erwin formation exposed	150

Section B: Section on west end of Roundabout Ridge, southwest of Sadie, beginning at Stony Creek and ending at top of ridge.

Top of section; no higher beds exposed.

	Feet
Shady dolomite:	
Ribboned member:	
G. Dolomite, ribboned, very thin-bedded, blue-gray and finely crystalline, with thin and inconstant recrystallized layers. Wavy beds a few inches thick are visible on weathered surfaces, with some projecting argillaceous ribs or ribbons	32
F. Dolomite, thin-bedded, gray or blue-gray, finely crystalline or dense, occasional white crystalline blebs; bedding planes a few inches apart are visible on weathered surfaces, with some irregular inclined bedding planes	41

	Feet
Shady dolomite—Continued	
Lower blue member:	
E. Dolomite, blue-gray, finely crystalline, with widely spaced white crystalline blebs. Many thin, wavy, reticulated argillaceous ridges project on weathered surfaces in a complicated pattern; bedding forms ridges and recesses. Crops out in thick ledges, the top making a shelf, but merging with beds above and below into a cliff to northeast	29
D. Poorly exposed; represented by dolomite ledges nearby	8
C. Dolomite, finely and evenly crystalline, with widely spaced bedding planes, gray below, becoming blue-gray upward; lower part weathers buff, upper part gray. Contains widely spaced blebs of white crystalline dolomite, and associated quartz dolomolds	58
Lower white member:	
B. Dolomite, thick-bedded, medium-crystalline; buff or creamy when fresh, weathering buff and hackly; becomes grayer and finer-grained upward, grading into overlying unit	37
A. Not exposed; top of Erwin formation crops out several hundred feet to southeast; interval probably small	?
Part of Shady dolomite exposed	205

Erwin formation: At base of section, with Helenmode member at top.

Section C: Section on west end of ridge between Hurley and Estep Branches, half a mile northeast of Sadie, beginning at Stony Creek and proceeding to top of ridge.

Top of section; no higher beds exposed.

	Feet
Shady dolomite:	
Ribboned member:	
G. Dolomite, ribboned, poorly exposed	35
F. Dolomite, ribboned, dark-blue-gray; contains still darker, wavy, argillaceous seams, and narrow seams or stringers of white crystalline dolomite; forms layers several inches thick, but crops out in ledges a few feet thick	26
E. Dolomite, thin-bedded, with wavy laminae within the beds; sharp contact at top	18
Lower blue member:	
D. Dolomite, light-blue-gray, with wavy laminae and white crystalline stringers containing quartz dolomolds; forms massive ledge	10
C. Dolomite, light-blue-gray, in 1- to 2-ft beds, containing white blebs of crystalline dolomite, with associated quartz dolomolds; forms discontinuous outcrops on slope, partly masked by red soil	43
B. Dolomite, blue-gray; in 1- to 3-ft beds, with lumpy and nodular structure; contains irregular blebs of white crystalline dolomite with abundant quartz dolomolds that project as knobs on surface; crops out on slopes above cliff-making bed beneath	45

	Feet
Shady dolomite—Continued	
Lower blue member—Continued	
A. Dolomite, cream-colored, medium-crystalline; in 3- to 5-ft beds, with few laminae within the beds; becomes bluer and finer grained upward, where there are some thin argillaceous seams. Weathers to smooth or hackly surfaces and forms prominent cliff. Base generally concealed by soil and talus	37
Part of Shady dolomite exposed	214
Erwin formation:	
Helenmode member: Sandstone, quartzitic; contains rounded quartz grains as much as one-sixteenth inch in diameter, lying in a fine-grained buff matrix, probably siliceous, calcareous, and glauconitic. Weathers to pockets and ridges parallel to bedding, in the manner of a calcareous rock	8

Bed of Stony Creek; no lower beds exposed.

SECTION 29.—*Damascus, Va.*

[Sections on southeastern margin of Appalachian Valley north of town of Damascus, Va., in Damascus quadrangle at north edge of region covered by this report. By C. A. Nelson, John Rodgers, and P. B. King, September 1942. Sections were described and measured in detail in field, thicknesses being obtained by pacing across the strike of nearly vertical beds; differences in thickness of units from section to section may be due to slight variations in dip of beds.]

Section A: Section along slopes on north side of valley of Laurel Creek, beginning below within town limits of Damascus, and proceeding westward.

Elbrook dolomite: Dolomite, thin-bedded, blue-gray, and shaly gray dolomite, having an abrupt contact with the underlying formation.

	Feet
Rome formation:	
V. Shale, red	50
U. Limestone	15
T. Shale, fine-grained, red; with some slightly limy and slightly sandy layers	1,125
S. Limestone, blue-gray	130
R. Shale, red	160
Q. Limestone, thin-bedded, blue-gray	60
P. Shale, red	65
O. Dolomite, silty, shaly; with a shale bed near middle	40
N. Covered	155
Total Rome formation	1,800
Shady dolomite:	
Upper blue member:	
M. Dolomite, blue; with a thin layer of buff shale 70 ft below top, and with oolitic dolomite at base; base lies at mill dam	197
L. Covered	55
K. Dolomite, medium- to thick-bedded, blue	90
J. Dolomite, light-gray, compact	2
I. Dolomite, medium- to thick-bedded, blue	25
H. Dolomite, light-gray, compact; fairly well bedded	16
G. Dolomite, blue, well-laminated and well-bedded; gray colored in lower part	35
F. Shale, buff, dolomitic; a thin layer of straight-bedded dolomite in middle	18

	Feet
Shady dolomite—Continued	
Upper white member:	
E. Dolomite, white, compact; contains pink streaks	90
D. Dolomite, blue; thick bedded, with faint laminae and some blebby streaks	70
C. Dolomite, white or light-gray; massive beds, grading up into slightly darker gray dolomite	88
Middle blue member:	
B. Dolomite, blue, laminated with vague thin ribbons and recrystallized stringers in some beds	155
A. Covered, except for a single pinnacle of ribboned dolomite at base; this may lie near top of ribboned member	215
Part of Shady dolomite exposed	1,056

Lower beds poorly exposed and not measured; top of Erwin formation some distance beneath to east.

Section B: In hills north of Damascus, near an abandoned quarry a quarter of a mile northeast of Laurel Creek.

Rome formation: Red shale outcrops and float.

	Feet
Shady dolomite:	
Upper blue member:	
H. Dolomite, light-blue-gray; much chert on surface	190
G. Shale, dolomitic, buff	5
Upper white member:	
F. Dolomite, white, massive; exposed above top of quarry	80
E. Dolomite, gray or white, massive; compact below, saccharoidal above; pink colored near joints; contains large veins of crystalline calcite or dolomite. Exposed in quarry	160
Middle blue member:	
D. Dolomite, blue, thick-bedded	50
C. Dolomite, light-gray, massive	50
B. Dolomite, blue, somewhat laminated	50
A. Dolomite, blue-gray; in part well laminated, in part very thin-bedded and shaly; some blocks of dolomite contain thin recrystallized ribbons; one outcrop of blue limestone with thin dolomite ribbons. Unit is exposed in a series of pinnacles that project from dark red residual soil; much jasperoid float on surface	50
Part of Shady dolomite exposed	635

Base of section; no lower beds exposed.

SECTION 30.—*Honeycomb Creek*

[Section on Honeycomb Creek, 4/10 mile southwest of Carter-Unicoi County line in northeast part of Unicoi quadrangle. Section lies about 1½ miles southwest of the southwest corner of the region covered in the present report. By L. E. Smith, November 1942. Section measured by pacing across nearly vertical beds]

	Feet
Rome formation: Red shale.	
Shady dolomite:	
D. Dolomite, silty, white, and calcareous white shale	120
C. Dolomite, white or light-gray, massive	115
B. Dolomite, dark- and light-blue-gray; as much as 20 percent of rock recrystallized into blebs and short ribbons of white coarsely crystalline dolomite, containing quartz dolomolds	300
A. Shale, limy, yellow, and silty dolomite, interbedded with white, saccharoidal, coarse-grained dolomite	110
Part of Shady dolomite exposed	645

Base of section; no lower beds exposed.

SECTION 31—*Cedar Mountain*

[Section along Doe River and the steep slope of Cedar Mountain to northeast, a mile south of Hampton in south-central part of the Elizabethton quadrangle. Base of section begins at top of section 18. By L. E. Smith, November 1942. Thicknesses calculated from field sheets]

Top of section; top of formation not exposed.

	Feet
Shady dolomite:	
E. Dolomite, yellow, shaly.	
D. Dolomite, dense, white to light buff, massive or thick-bedded, with slightly recrystallized areas	390
C. Dolomite, light-gray, in beds of medium thickness, slightly silty and containing quartz dolomolds	27
B. Dolomite, thin-bedded, drab-gray, silty; standing in a cliff	83
A. Covered, possibly shaly dolomite	35
Part of Shady dolomite exposed	535

Erwin formation: At base of section, with Helenmode member at top (see section 18).

SECTION 32—*Grindstaff Cave*

[Section on slopes northeast of Laurel Fork in vicinity of Grindstaff Cave, half a mile east of Hampton in southeast part of Elizabethton quadrangle. Base of section begins at top of section 19. By L. E. Smith, November 1942. Section was measured and described in detail in field]

Rome formation: Mostly covered, but indicated in places by red shale float. Top of Shady dolomite may lie in covered area, as much as 50 ft above top of unit X.

	Feet
Shady dolomite:	
X. Dolomite, dark-blue, silty; in 1- to 4-in. beds	19
W. Covered	18
V. Dolomite, light-blue; in 2- to 6-in. beds, some recrystallized areas	7
U. Dolomite, massive, dark-blue	5
T. Dolomite, thin-bedded, light- to dark-blue-gray; in part shaly, with occasional lighter colored beds 6 to 8 in. thick	21
S. Dolomite, thin- to thick-bedded, dark-blue, silty; poorly exposed in lower part	12
R. Dolomite, thick-bedded, blue-gray; in part silty; quite coarsely crystalline in middle	23
Q. Dolomite, dark-blue, thick-bedded; thinner beds at base	20
P. Dolomite, thin-bedded, shaly or silty, soft, yellow; some thin red shale partings, and a layer of chert 8 ft below top	30

	Feet
Shady dolomite—Continued	
O. Shale, yellow, silty	10
N. Dolomite, massive, light-gray; weathers yellow	19
M. Shale, yellowish to light-gray; interbedded with silty dolomite	15
L. Dolomite, white to flesh-colored, saccharoidal, massive; with a 3-ft bed of dense sky-blue dolomite 27 ft below top	75
K. Covered, probably soft silty dolomite	62
J. Dolomite, very light blue, massive; much is moderately recrystallized	57
I. Covered	29
H. Dolomite, with quartz dolomolds	4
G. Covered	52
F. Dolomite, dense, blue; in medium-thick to massive beds; contains scattered masses of light-gray chert as much as 8 in. in diameter, and a 4-in. bed of dark-gray chert	233
E. Dolomite, blue, finely crystalline, thick-bedded	20
D. Dolomite, dark-blue, coarsely crystalline; contains lenses of dark chert in lower part; much silicified and fractured, and in part recrystallized to coarse white dolomite	50
C. Dolomite, thin-bedded, blue; in part shaly and silty	4
B. Dolomite, dark-blue, thick-bedded; in part recrystallized, containing some chert	80
A. Covered across highway to base of formation;	300
Total Shady dolomite	1,165

Erwin formation: At base of section, with Helenmode member at top.

SECTIONS OF MIDDLE AND UPPER CAMBRIAN SERIES AND OF LOWER ORDOVICIAN SERIES

SECTION 33.—*Big Spring*

[Section on Gap Creek below Big Spring, west-central Elizabethton quadrangle. Section follows a lane on northeast side of Gap Creek, beginning above to south at Big Spring, and ending below at bridge over creek near west line of quadrangle; outcrops on county road on southwest side of creek are more scattered. Measured and described in detail in field by P. B. King and R. A. Laurence, February 1954]

	Feet
Conococheague limestone:	
13. Limestone, thick-bedded, gray; full of winding tubes made up of more silty or dolomitic limestone that project on weathered surfaces. Tubular structures in places merge into a spongy mass, in which gray limestone forms the interstices. Unit lies with fairly abrupt contact on beds beneath. Thickness not determined	
Nolichucky shale (including Maynardville limestone member equivalent above):	
12. Limestone, in large part containing silty laminae or ribbons a few inches apart, with wavy structure, that project on weathered surfaces; some interbedded more massive limestone layers, without ribbons, 3 in. to 2 ft thick; some thin granular layers full of fossil fragments	67
Nolichucky shale—Continued	
11. Limestone, blue, ribboned by thin silty layers, forming a "layer cake" structure. Silty laminae one half to 2 in. apart, formed of dolomitic silt that weathers brown, in part silicified on weathered surfaces. Intervening limestone in part forms continuous beds, and is in part lumpy or cobbly	29
10. Limestone, dominantly, but with very thin, closely spaced silty seams, forming a "candy stripe" structure	30
9. Limestone, very shaly at base, passing up into blue, fine-grained limestone with thin wavy silty layers, forming a "layer cake" structure; about three times as much limestone as silt	30
8. Limestone, very shaly at base, but not a clay shale as in bed 6, passing up into a solid bed of blue limestone at top	30
7. Shale grading upward into an alternation of limestone layers an inch or so thick, and thinner, slightly shaly layers that protrude on weathered surfaces, forming a "layer cake" structure; ends at top in a rather solid bed of blue limestone 5 ft thick	32
6. Clay shale, dull-greenish, fissile; contains many oboloid brachiopods on bedding surfaces, and less definite fragments of other fossils	23
5. Limestone, laminated, gray	4
4. Clay shale, dull-greenish, fissile; an abrupt contact on bed beneath	3
Total Nolichucky shale	248
Honaker dolomite:	
3. Limestone or dolomitic limestone, dark-gray contains small fossil fragments, interbedded with blue mottled limestone containing reticulated or wavy silty ribbons or laminae, the laminae increasing in number upward	160
2. Dolomite, crystalline, dark-gray, or black, fetid, in beds 2 and 3 ft thick; weathers to rounded knobby surfaces, interbedded with crystalline gray dolomite and with slabby, fine-grained, light gray dolomite and limestone, in part weathering buff or tan	90
1. Dolomite, fine-grained, gray; in beds 1 to 2 ft thick, with thin wavy laminae within the beds, in part weathered gray, in part brown. Outcrops are intermittent, but a fairly continuous section may be pieced together by combining exposures in creek, on road, and adjacent hillsides	110
Part of Honaker dolomite exposed	360

Base of section; lower beds not measured.

SECTION 34.—*Denton Valley*

[Section in Denton Valley area, north-central Shady Valley quadrangle. Generalized from outcrops on Mill Creek from Denton Valley School, in Virginia, southeastward to foot of Little Mountain near Virginia-Tennessee State line, supplemented by outcrops half a mile on either side, especially on county road to west that follows Cox Creek and its eastern branch. By P. B. King and R. A. Laurence, September 1953. Thickness estimated from field sheets. Assignment of units in section to various formations is tentative and not based on paleontological evidence]

	Feet
Clastic rocks of Middle Ordovician series:	
15. Sandstone, medium- to coarse-grained, greenish, feldspathic; beds several feet thick, containing seams of angular rock fragments as much as one-eighth inch in diameter, and in places beds of conglomerate 3 to 5 ft thick, composed of closely packed rounded fragments of limestone, chert, and quartzitic sandstone an inch or so in diameter, lying in a sandstone matrix. Some partings of thinly fissile greenish shale. Thickness not determined	
14. Shale, thinly fissile, pale-olive-green; weathers tan, with small grains of detrital mica on bedding surfaces that give a luster or sheen to broken pieces; shows weak cleavage, and breaks in places into pencillike fragments. Contact with underlying beds is abrupt, and apparently not gradational	2,300
Lenoir limestone (well exposed in road cut a few hundred feet northeast of Denton Valley School):	
13. Limestone, dark-gray, cobbly; many fossil fragments	11
12. Limestone, blue-gray, compact; in 1- to 5-ft beds; contains many fragments of trilobites and brachiopods	28
11. Limestone, very granular, crystalline, clastic; has an irregular and probably unconformable contact with rock beneath	1
Total Lenoir limestone	40
Jonesboro limestone:	
10. Dolomite: in 1- to 5-ft beds; part is light gray, glistening, thoroughly crystalline ("recrystalline" type), weathers light gray or buff; part is gray or blue-gray and compact, with some darker laminated beds; rare small chert lenses; occasional interbedded layers of limestone, which increase in number below, grading into underlying unit. This unit resembles Mascot dolomite of sections farther northwest	600
9. Limestone, mainly gray to blue-gray; occasional dolomite beds in upper part; limestone includes massive, structureless beds, beds that are smoothly and evenly laminated, beds composed of gray limestone lumps or knots separated by crinkled yellowish laminae of more dolomitic or argillaceous composition, and occasional granular clastic beds full of small carbonate pellets and siliceous shreds; a few rare stringers of chert half an inch thick	700
Jonesboro limestone—Continued	
8. Limestone, similar to beds above, but with more prominent argillaceous laminae, spaced an inch to a fraction of an inch apart; laminae slightly crinkled, but extend with great regularity across outcrops	400
Total Jonesboro limestone	1,700
Conococheague limestone:	
7. Sandstone, of fine rounded quartz grains in a calcareous matrix, weathered brown and crumbly, in four or more beds 1 to 2 ft thick, traceable entirely across Denton Valley. Sandstone is interbedded with thick limestone layers, containing prominent crinkled argillaceous laminae, and thinner beds of tan laminated dolomite. Some limestone layers contain *Cryptozoon* reefs as much as 3 ft thick and 10 ft long, with knobby upper surfaces. Unit has aspect of typical Conococheague limestone farther northeast in Virginia	300
6. Limestone, laminated, and interbedded dolomite; laminae generally not made up of contrasting lithologic types and fainter than those in unit above; some laminated beds broken into an intraformational conglomerate; occasional layers of platy tan chert	1,400
5. Limestone and dolomite similar to those above; as many as five interbedded layers as much as 6 ft thick of coarsely crystalline, black, fetid dolomite, with lumpy structure, in massive dark ledges; latter are like beds in lower part of Copper Ridge dolomite in sections farther northwest; some masses of porous slaggy chert	500
Total Conococheague limestone	2,200
Elbrook dolomite:	
4. Limestone and dolomite, rather nondescript, laminated; gradational with beds above; interbedded with many other rock types: limestone and dolomite with argillaceous ribbons, and a few beds of crystalline black fetid dolomite, both of Conococheague type; thin-bedded, platy or papery light-gray dolomite of Elbrook type; finely crystalline ("recrystalline") gray or tan dolomite; and partings of thinly fissile calcareous shale. Chert includes small biscuit-like nodules, silicified oolite, and large black masses with *Cryptozoon* structure. This unit shares lithologic characters of both Conococheague and Elbrook, but is placed in the latter largely because of its position in the sequence	1,400

	Feet
Elbrook dolomite—Continued	
3. Dolomite, thinly laminated, light-gray; splits into chips or plates a few inches thick, with occasional stronger beds a foot or so thick, the whole having aspect of the typical Elbrook farther northeast in Virginia; contains some small strongly laminated *Cryptozoon* heads, and long narrow stringers of black chert; contact with underlying formation concealed by wash in all sections studied	600
Total Elbrook dolomite	2,000
Rome formation:	
2. Shale, red; generally broken down into red soil, but with occasional more silty ledges projecting in places. Maximum thickness exposed below Holston Mountain fault on Mill Creek	1,500
Shady dolomite:	
1. Dolomite, fine-grained, gray forming float blocks in pasture southwest of Mill Creek, probably representing Shady in a fault sliver immediately beneath the Holston Mountain fault. At intervals along fault, especially at its western terminus a quarter of a mile southeast of Denton School, are loose blocks of white quartzose quartzite, probably representing other fault slivers of Erwin formation	

Holston Mountain fault at base of section, along northwest foot of Little Mountain and Wheeler Spur; no lower beds exposed beneath fault; Unicoi formation in overriding block.

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