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DEPARTMENT OF CONSERVATION AND DEVELOPMENT
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DIVISION OF MINERAL RESOURCES
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Geology and Mineral Resources
OF THE
Hot Springs Window,
Madison County, North Carolina

By
STEVEN S. ORIEL

●

PREPARED IN COOPERATION WITH THE TENNESSEE VALLEY AUTHORITY

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LETTER OF TRANSMITTAL

Raleigh, North Carolina
March 20, 1950

To His Excellency, HONORABLE W. KERR SCOTT
Governor of North Carolina

SIR:

I have the honor to submit herewith manuscript for publication as Bulletin 60, "Geology and Mineral Resources of the Hot Springs Window, Madison County, North Carolina." This bulletin is another in a series being made possible by the cooperation of the Tennessee Valley Authority.

The Hot Springs window is an interesting area from the standpoint of both the geology and mineral resources. It is believed that this report will be of value to those interested in the area.

Respectfully submitted,

GEORGE R. ROSS,
Director.

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ABSTRACT

By STEPHEN S. ORIEL

The area covered by this report includes about 55 square miles in the western part of Madison County, North Carolina, and easternmost Coker County, Tennessee. It is roughly coextensive with the Hot Springs window which is framed by four different thrust faults. The area lies in the Bald Mountains of the Unaka Range in the Blue Ridge physiographic province and is drained by the French Broad River.

The rocks within the window include, in ascending order, a pre-Cambrian crystalline complex and a thick sequence of sedimentary rocks composed of about 5200 feet of elastic rocks of unknown age (Snowbird and Sandsuck formations), at least 4300 feet of elastic rocks of Early Cambrian age (Unicoi, Hampton, and Erwin formations), and an unknown thickness of carbonate and fine-grained elastic rocks of Early and Middle Cambrian age (Shady, Rome, and Honaker formations). The rocks framing the window belong to the same formations, up to and including the Unicoi formation.

The rocks at and near the thrust faults in the area are considerably fractured and mylonitized in most exposures. Where granitoid rocks of two thrust sheets are adjacent to each other, mylonite belts are useful in mapping the trace of the intervening fault. Mylonitized pre-Cambrian crystalline rocks, however, are difficult to distinguish from mylonitized Snowbird arkose in many places. The fractured and mylonitized nature of the rocks along the contact between the Snowbird formation and the pre-Cambrian crystalline complex within the window suggest that this contact may also be a thrust fault, rather than an unconformity. If the contact is a fault, then the pre-Cambrian crystalline rocks adjacent to it occur in a small window within the Hot Springs window.

The Hot Springs window is analogous in certain respects to the Engadine window of the central Alps. Both are framed by more than one thrust fault and are therefore eyelid windows. (*Eyelid window* is here proposed to replace the term *shear-window* which Sander defined as a window whose rocks are directly overlain by more than one thrust sheet.) The tectonic events which led to the formation of the Hot Springs window may have been similar to those of the Engadine window and are interpreted as follows: 1) Thrusting of the sedimentary rocks over the crystalline rocks now exposed within the window, if the contact between them is a fault; 2) Folding of the rocks now exposed within the window with development of NE-SW structures which may have been continuous with those of the Mountain City window to the northeast; 3) Relative northwestward movement of the lowest and first-formed of the thrust sheets framing the window, truncating the underlying anticlinal structure; 4) Thrust of an upper mass with clockwise rotation of earlier structures, producing east-west trends within the window; 5) Rupturing of this mass into three thrust sheets during continued or renewed application of forces.

The most important mineral resources in the area are barite, dolomite, shale, and the hot springs. Barite occurs along or near the thrust faults. The unfortunate choice of drilling sites in the Stackhouse area during a recent prospecting program may account for the failure to discover barite; results might have been more favorable if holes had been drilled through the nearby thrust fault.

Recent chemical analyses of portions of the Shady dolomite show that the rock is a high magnesian dolomite which has many uses. Quarry sites, no longer in operation, are the most favorable locations for possible future work.

Laboratory tests of red maroon shale from the Rome formation in the Hot Springs area show that the material is suitable for lightweight aggregate. Reserves, and transportation and power facilities are favorable, but careful sampling and more tests are suggested before large-scale operations are undertaken.

The hot springs for which the town is named have attracted visitors from many states since they were discovered in 1778. Although available data strongly suggest that the waters are of meteoric origin and derive their heat from the geothermal gradient, the nature of the artesian system involved is not known. However, a hypothesis is offered in this report.

INTRODUCTION

PURPOSE OF INVESTIGATION

The present investigation was undertaken to obtain a comprehensive picture of the Hot Springs window, a geologic structure of particular interest. Although much has been written about the geology of the Hot Springs area, almost all previous workers have been hampered by the lack of adequate topographic base maps and by the necessity of restricting their efforts to reconnaissance studies. The present writer was free from both limitations and was further aided by the recently available results of detailed studies of similar rocks in eastern Tennessee.

In addition to being of great scientific interest, the Hot Springs area has been the site of considerable prospecting and mining; the chief products have been barite, limestone, and iron ore. The area is one of the three in North Carolina where barite is known to occur. During the present study, efforts were made to determine the relation of the barite occurrences to the general geology and to provide a sufficiently detailed geologic base for future economic investigations in this area.

PREVIOUS WORK

The geologic section exposed along the French Broad River near Hot Springs has long been a noted one. As early as 1809, Maclure (1809, p. 417)¹ observed the contact between the granitic rocks and the overlying sedimentary rocks near the mouth of Big Laurel Creek. It was through this point on the French Broad that he drew the southwest trending contact between the Wernerian "Primitive" and "Transition" units on his, the first geological map of the United States. In the text accompanying the second edition of his map, Maclure (1818, pp. 26, 37-38, 77) described the rocks a little more fully and included a plate of five structure sections, one of which passes through the town of Warm Springs (as it was then known). Maclure was probably the first to note the occurrence of "the sulphate of barytes" (1818, p. 37).

A brief description of the hot springs and the nearby rocks appeared the same year in the first volume of the American Journal of Science (Kain, 1818, pp. 66-67). Three years later, the first comparatively detailed account of the hot springs, with chemical analyses of the mineral constituents, appeared in the same journal (Smith, 1821).

The dual Wernerian classification of the rocks in the Hot Springs area persisted (Olmsted, 1827; Mitchell, 1842, map, pp. 36, 137-139) until Troost, then state geologist of Tennessee, became acquainted with the work of Murchison and Sedgwick (Troost, 1841, p. 3; Merrill, 1924, pp. 216-217). In his Sixth Annual Report (1841, pp. 3-5) Troost announced that rocks previously classified as "Transition" under the names of graywacke, etc., belong to the Cambrian System, and further stated, "Geologists will rejoice that henceforth the name of grauwacke (sic) will be doomed to oblivion."

In 1856, Emmons (pp. 43-44, 57) correlated the sedimentary rocks in the Hot Springs area with his Taconic System, but retained the granitic rocks in the "Primary System".

Kerr referred to the French Broad River section in his report of 1867 (pp. 32, 36, 49), but did not publish a detailed description of this geologic section until 1869 (pp. 28-30).

It remained for Safford (1856, map, pp. 151-153; 1869, map, section, pp. 173-174, 176, 193-194, 202) to make the first notable attempt to present an areal geologic map and a structural interpretation of the Hot Springs area. He divided the clastic rocks here into the Ocoee and Chilhowee formations, which he had defined and named for rocks in eastern Tennessee, and placed the dolomitic rocks in his Knox formation. Safford was the first to point out the fault between the dolomitic rocks and the quartzites to the north and northwest. Safford's report, more than any other, elicits the admiration of the modern reader.

In his comprehensive report on the geology of North Carolina, Kerr (1875, map, pp. 138-140) clung to the dual classification of the rocks in the Hot Springs area, calling the granitic rocks "Laurentian" and the sedimentary rocks "Huronian (Taconic)". However, he was familiar with Safford's work and recognized the complexity of the area, pointing out that the problems involved would only be solved by tracing the units across the state line from Tennessee. The history of subsequent geological work in the area has confirmed his judgment.

¹ References cited in parentheses are listed at the end of this report. The references are arranged alphabetically by authors and chronologically under each author.

Epidotization of the granitic rocks in the Hot Springs area drew the attention of early workers. In 1874, Bradley (pp. 519-520) defined and described the rock unakite, after the Unaka Range of the Blue Ridge. His specimens came from Bluff, Max Patch, and Walnut Mountains, all just outside the area described in the present report. Some thirty years later, T. L. Watson (1904, pp. 394-398; 1906, pp. 171-174) published excellent detailed megascopic and microscopic descriptions of the altered granitoid rocks near Hot Springs.

Brief references to the rocks of the Hot Springs area were made by Genth and Kerr (1881, p. 109), Britton (1886, p. 222), and Willis (1889, p. 293). In addition, there is an unpublished geologic map of portions of the Asheville quadrangle by Bailey Willis, labelled "April '89, Provisional sketch for further field study", in the files of the U. S. Geological Survey.

The first intensive geological study of the Hot Springs area was made by Keith and published in the Asheville folio (1904). For the first time, the presence of thrust faults almost completely surrounding the rocks of the area was recognized. The map and descriptions prepared by the present writer differ from those of Keith mainly in details.

In their brief report on the barite deposits of North Carolina, Stuckey and Davis (1933) for the first time ascribe a hydrothermal origin to the deposits in the Hot Springs area. The results of a more recent study of the barite deposits of both the Hot Springs area and the adjoining Del Rio district, Tennessee (see fig. 1) were published by the U. S. Bureau of Mines as a Report of Investigations (Dahners, 1949). Four diamond drill cores from the Stackhouse locality are described in this report.

Stose and Jonas were the first to recognize the presence of a structural window in the Hot Springs area and as a result of their work it is so indicated on the Geological Map of the United States (1932). However, they did not describe the Hot Springs window until twelve years later (Stose and Stose, 1944, pp. 385-386).

A more detailed discussion of the Hot Springs window and the surrounding area was published by Stose and Stose in 1947. In this paper the writers report the presence of mylonitized rocks in the area and present a possible explanation for the origin of the hot springs.

In a manuscript soon to be published as a bulletin of the Tennessee Division of Geology, Ferguson and Jewell describe the detailed geology and barite deposits of the Del Rio district, Cocke County, Tennessee, including the westernmost part of the Hot Springs window. Their detailed discussions of the structural and stratigraphic relations of the thrust blocks lying to the northwest of the Hot Springs area will be invaluable in future regional studies. In addition, the data presented on the mode of occurrence and origin of the barite deposits in the Del Rio district are pertinent to studies of barite deposits in Madison County, North Carolina.

PRESENT WORK

The field observations described in this report were made over a period of five months, between June and November, 1948. In the course of daily traverses, important outcrops were spotted on field maps, assigned numbers, and described in field notebooks in numerical order. Where exposures permitted, running commentaries on the rocks between field stations were recorded in the notebooks. Bedding trends and other structural trends were recorded on field sheets by symbols, and lithologies were indicated by arbitrarily assigned colors. When the field work was completed, over 1200 observations had been recorded on field sheets which had thus become outcrop maps. During the course of the field season, the writer and his assistant noted the most readily traceable lithologic units and these were mapped in detail along their strikes. These units were later utilized as formational boundaries. Discordant contacts between rocks of different lithologies were also traced along their strikes and mapped in detail.

Detailed stratigraphic studies were restricted to the rocks within the window. Contacts between rock units outside the window were mapped wherever possible, but little time was devoted to them. The rocks comprising the "Crystalline Complex", as used in this report, are heterogeneous and, in the writer's opinion, will require intensive study before they can be adequately understood or subdivided. The time necessary for such a study was not available to the writer.

The topographic base used throughout the study was that prepared from aerial photographs by the Tennessee Valley Authority and the U. S. Geological Survey (see p. 4). The maps are accurate and detailed enough to permit ready location of position in the field with the aid of a compass and Paulin altimeter.

Numerous road cuts, especially along Highways 25-70, 209, and the railroad, greatly facilitated field work. In addition, many of the streams have exposed almost continuous outcrops.² Between streams the mantle is fairly thick and the vegetation dense. Bedrock is concealed in most places, but there are a few well exposed ledges made up of resistant, almost pure quartzite. The dense growth of mountain laurel and rhododendron along the courses of many streams makes field work difficult even there. Inasmuch as the area lies outside the glaciated regions, float rock was mapped on ridge crests and other places where it was believed to be nearly in place.

In addition to the field studies, some 50 thin sections,³ about half of which were cut from mylonitized rocks, were examined microscopically in the laboratory. The petrographic descriptions which are included in this report are not presented to suggest that an exhaustive study has been completed by the writer, but rather to indicate some of the problems that remain to be solved.

ACKNOWLEDGMENTS

The writer is particularly indebted to Mr. John Rodgers for enthusiastic assistance, stimulating ideas and discussions, and helpful criticisms throughout the present study. It was he who drew the attention of the writer to the geologic problems associated with the Hot Springs area.

The field work for the present study was financed by the North Carolina Department of Conservation and Development from funds pledged for cooperative work with the Tennessee Valley Authority. The writer is appreciative of the cooperation received from Dr. Jasper L. Stuckey, State Geologist, and Mr. Charles E. Hunter, Dr. Benjamin Gildersleeve, and the late Mr. H. S. Rankin of the Tennessee Valley Authority.

Mr. Herman W. Ferguson, Assistant State Geologist of Tennessee, has been most generous in providing the writer with invaluable, unpublished, data on the geology of the Del Rio District, Tennessee, which is adjacent to the Hot Springs area on the west. The Tennessee portion of plate I is based almost entirely on his observations. The manuscript report, maps, and figures so generously loaned to the writer will soon be published as a Tennessee Division of Geology bulletin entitled "Geology and Barite Deposits of the Del Rio District, Cocke County, Tennessee" by H. W. Ferguson and W. B. Jewell.

The writer was visited in the field by Dr. and Mrs. George W. Stose, Drs. Philip B. King, J. B. Hadley, Robert A. Lawrence, and Ralph L. Miller, of the U. S. Geological Survey, Messrs. Charles E. Hunter, H. S. Rankin, Earl C. Van Horn, and Lewis Hash of the Tennessee Valley Authority, Professors Chester R. Longwell and John Rodgers and Miss Jean Lowry of Yale University, and Dr. Stuckey and Mr. Ferguson. Their assistance and stimulating discussions are gratefully acknowledged.

Mr. Joseph B. Cathey, Jr., helped the writer in the field from June until September, 1948. He was a most willing, conscientious and alert assistant. Both the writer and Mr. Cathey are heavily indebted to Mr. and Mrs. Hugh B. Lance, managers of the Montauqua Hotel in Hot Springs in 1948, for the many ways in which they facilitated their field work.

Funds provided by the Shell Oil Company, Inc., in the form of a fellowship at Yale during the academic year 1948-1949, enabled the writer to concentrate all his efforts on the preparation of this report.

The present report has been written in partial fulfillment of the requirements for the degree of Doctor of Philosophy at Yale University. The dissertation was written under the direction of Professors Rodgers and Longwell. The manuscript was read by both Mr. Rodgers and Mr. Longwell and in part by Mrs. Eleanora Bliss Knopf. The writer is grateful to all three for many valuable suggestions and to Professor Adolph Knopf for guidance during the petrographic study of the thin sections.

² Accounts of the best exposed sections are presented in the section on Description of Formations.

³ The thin sections and the rock specimens from which they were cut are on file in the offices of the State Geologist, North Carolina Department of Conservation and Development, Raleigh, N. C.

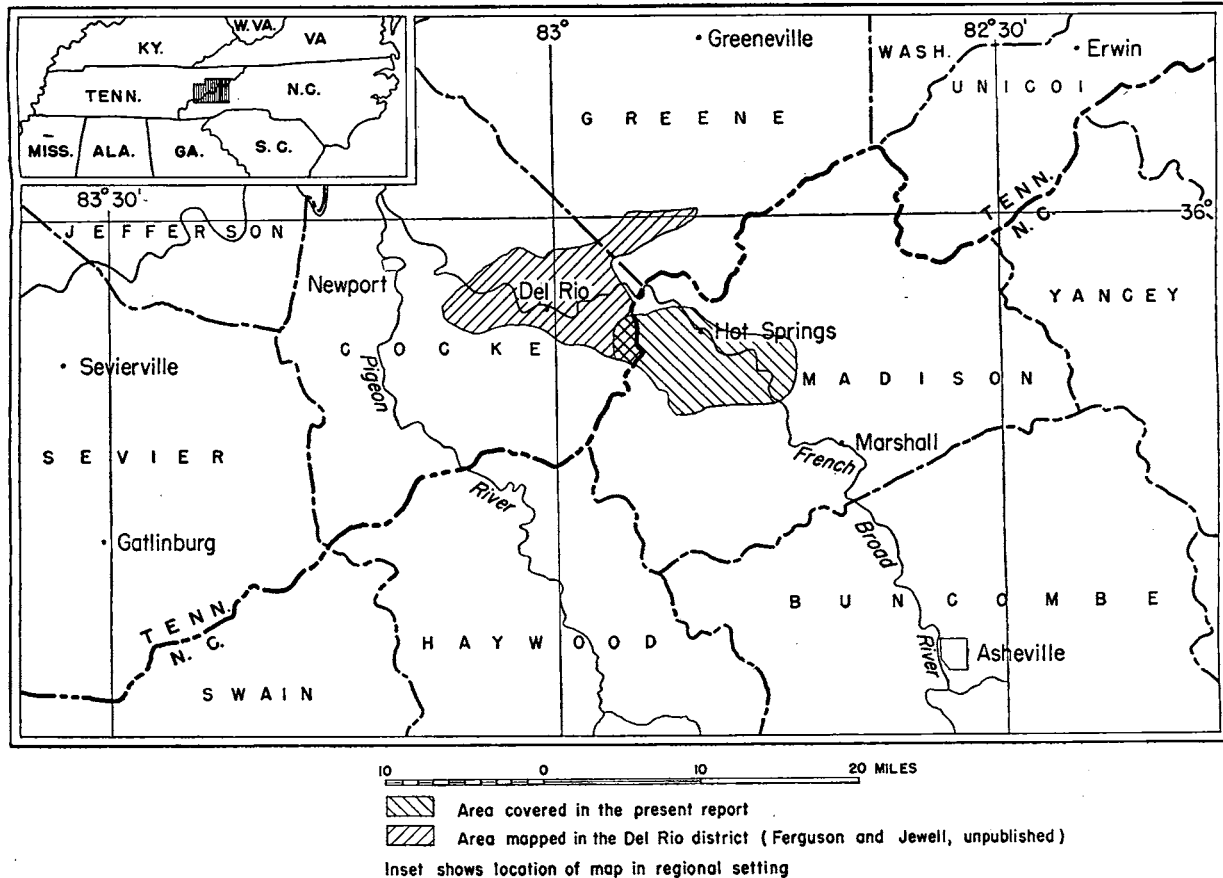


Figure 1. Index map of western North Carolina and eastern Tennessee

GEOGRAPHY

LOCATION

The area investigated lies in the western part of Madison County, North Carolina, along the North Carolina-Tennessee boundary (fig. 1). Part of the area laps over into Cocke County, Tennessee. The area studied extends approximately from $82^{\circ}40'$ to $82^{\circ}55'$ longitude, and from $35^{\circ}50'$ to $35^{\circ}55'$ latitude. The tract is elongate in an east-west direction, with a length of about $10\frac{1}{2}$ miles and a width of 5 miles, and thus includes about 55 square miles.

The area is covered by excellent and recent topographic maps prepared by the Tennessee Valley Authority and the U. S. Geological Survey. The maps are $7\frac{1}{2}$ minute quadrangle sheets on a scale of 1:24000 with contour intervals of 40, and in places 20, feet. The area lies in portions of the Paint Rock (182 NW),⁴ Lemon Gap (182 SW), Hot Springs (182 NE), Spring Creek (182 SE), White Rock (191 NW), and Marshall (191 SW) quadrangles.

TRANSPORTATION

The town of Hot Springs lies in the north central part of the area covered in this report, on the French Broad River. The population is about 900.

Hot Springs is 20 miles northwest of Marshall, N. C., the county seat, and 42 miles northwest of Asheville, N. C., along U. S. Highway 25-70. Newport, Tenn., lies 25 miles and Knoxville, Tenn., 72 miles west of Hot Springs along Highway 25-70. All these towns are also connected by the main east-west, single-track line of the Southern Railroad. One may reach Hot Springs from Greenville, Tenn., by driving 26

⁴ Numbers given here are the TVA topographic sheet numbers.

miles south along Tenn. Highway 70 and N. C. Highway 208 to the junction with U. S. Highway 25-70 at Hurricane on Big Laurel Creek. N. C. Highway 209 leads southward toward Lake Junaluska from Hot Springs.

A few graded dirt and gravel roads, some ungraded logging roads and many trails, in addition to the highways, make this area relatively accessible compared to other parts of the mountainous region.

TOPOGRAPHY

The Hot Springs area lies near the northwest margin of the Blue Ridge physiographic province. The mountains are part of the Bald Mountains, which are in the Unaka Range of the Blue Ridge Province. To the southeast lies the Blue Ridge Plateau on which Asheville, North Carolina, is situated.

Lithologically, and to some extent topographically, parts of the area under investigation are more closely allied to the Appalachian Valley of Tennessee, on the northwest. The rocks present more nearly correspond in age, lithology, and structure to those in the Valley than to the predominantly crystalline rocks of the Blue Ridge province. This is reflected in the topography.

Spring Creek Mountain, with an elevation of over 3440 feet on the knob north of Rector Butt, is the highest in the area studied. The lowest point, at an elevation of 1260 feet, is on the French Broad River north of Mine Ridge. Thus, the maximum relief over the entire area is about 2180 feet.

Streams throughout the area are swift, with many rapids and waterfalls. Valleys are generally narrow and V-shaped. Notable among these is the gorge cut by Spring Creek from Bluff, past Vann Cliff, to Stony Spur Cliff. Part of the large quantity of material removed from here was deposited at the mouth of Spring Creek to form the alluvial fan on which the town of Hot Springs is built. Drainage throughout the area is excellent, and, with local exceptions, is dendritic in pattern. All the streams in the area drain into the French Broad River, which flows northwestward and westward to join the Holston River and form the Tennessee River.

Upon superficial examination, one is struck by the lack of parallelism of ridges and of control by the geology of the major topographic features. This is not true in geologically related areas in the Valley province. However, closer study reveals that mountain tops, ridge crests and knobs are generally underlain by resistant quartzite and unsheared crystalline rock. There is a subtle parallelism between the details of the topography and geological contacts. Many streams, and even segments of the French Broad River, parallel outcrop belts of slate and faulted, and in some cases mylonitized, zones. Even where the larger topographic forms show little correspondence to the geology, smaller features are related to the variations in lithology within a formation. Spurs parallel the trend of resistant quartzite beds, whereas gullies and smaller streams run along the strike of less resistant zones and beds.

In general, the highest peaks lie in the southernmost portion of the area and are underlain by relatively undeformed crystalline rocks. Proceeding northwards, the highest points decrease in elevation but the slope of hillsides increases and the country is more rugged in the areas underlain by the basal clastic formations. Whereas in northeastern Tennessee (King et al., 1944, p. 16), the Shady dolomite underlies the lowlands and the Rome forms steep-sided knobby hills, here, the Rome underlies the lowest belt and the Shady belt forms a topographic transition zone of spurs leading up to the mountains underlain by the clastic rocks.

DESCRIPTIONS OF FORMATIONS

INTRODUCTION

The Hot Springs area is underlain by diverse groups of rocks. Table 1 summarizes the sequence of formations described in this report. In the area mapped by the writer, sedimentary rocks predominate. The youngest rocks are limestone, variegated siltstone and shale, and dolomite of Early and Middle Cambrian age. Underlying these are clastic rocks which include shale and siltstone, vitreous and feldspathic quartzite, conglomerate, and slate. The oldest rocks in the area are somewhat altered granitoid, gneissic and pegmatitic rocks which are of pre-Cambrian age.

Despite the fact that the entire area studied by the writer forms but a part of that described in the Asheville folio (Keith, 1904), the names applied to the rocks in the present report differ in almost every

TABLE 1. GENERALIZED SECTION OF THE GEOLOGIC FORMATIONS IN THE HOT SPRINGS AREA.

AGE	GRP.	FORMATION	MEMBER	SYMBOLS Pl. I	CHARACTER	FEET THICK- NESS
Middle Cambrian		Honaker limestone		Chk	White, gray, and blue-gray limestone with silty and shaly laminae and concentrically banded chert nodules.	-
		Rome formation		Cr	Red, maroon, and brown siltstone and shale with interbedded light gray and blue-gray dolomite and greenish shale.	-
Early Cambrian	Clastic Group of Lower Cambrian Series	Shady dolomite		Cs	Blue-gray, light gray, white, and ribboned dolomite with some interbedded limestone.	1975' (max.)
		Erwin formation	Helenmode member	Ceh	Weathered white and light-colored calcareous siltstone and arkosic sandstone.	100-150
				Ce	Dark green siltstone, silty and sandy shale, white vitreous quartzite, and purple ferruginous quartzite.	(total) 1700-2100
		Hampton formation	Upper shale member	Chu	Alternating dark green siltstone, silty and sandy shale, and thinbedded quartzite.	200-300
			Middle quartzite member	Chq	Crossbedded medium - to coarse-grained feldspathic quartzite and arkose with pebbly beds and vitreous quartzite.	500-750
			Lower shale	Chl	Interbedded dark green siltstone, argillaceous shale, and sandy and silty shale.	210-380
		Unicoi formation		Cu	Coarse feldspathic and vitreous quartzite, conglomerate (some with coarse slate inclusions—, siltstone, slate, and micaceous sandstone)	1400-2600 700
Unknown	Clastic Group of Unknown Age	Unconformity (?) Sandsuck formation		sds	Dark green and blue-green slate, shale, and well laminated siltstone with gray sandy and black slaty bands; includes conglomerate and limestone lenses.	(about) 700
		Snowbird formation		snb	Interbedded pebbly, vitreous, and feldspathic quartzites, arkose, shale, siltstone, slate, micaceous and calcareous sandstones, and mylonite.	1500-4600 (min.)
pre- Cam- brian		Unconformity (?) Crystalline complex		pCcx	Sericitized and epidotized graptoid, aplitic, pegmatitic, and basic rocks (undifferentiated in this report) and mylonite.	

case from those in Keith's report. Though at first it may seem an insidious attempt to confuse the reader, the writer hopes, and believes, that a greater degree of clarity is gained by the changes in the names. The reasons for the changes in terminology are discussed more fully in the descriptions, below, of the individual formations and groups.

Formations are described here in an order which differs from the conventional, the youngest rock being described first. This order merely reflects the field practice of starting with the best known formations (here the Rome and the Shady) and working down the section to rocks and horizons that are not as well known and are subject to some disagreement among various workers.

The size terms used in this report, e.g. granule, siltstone, are those suggested by C. K. Wentworth (1922) and conform to his definitions.

SIGNIFICANCE OF STRATIGRAPHIC UNITS USED

The names used in this report are taken from type sections from Alabama to Virginia. Because of numerous intervening faults, it is not possible to trace rock units continuously from the type areas to the Hot Springs area. Therefore, in applying these names to the rock units of the Hot Springs area, a certain amount of interpretation is necessary. In the absence of fossils, choices of stratigraphic names are based upon similarities of lithologies and upon comparable sequences of lithologies. The dolomite formation in

the Hot Springs area, for example, compares with the dolomitic rocks named "Shady" in other areas: it contains the same rock types; it is overlain by similar maroon siltstones and shales and it is underlain by beds similar to the clastic rocks underlying the Shady elsewhere. However, even the choice of names immediately implies a correlation between units of widely separated areas. Any attempt to avoid these implied correlations in objective studies would greatly burden the literature with an overwhelming mass of local names.

The formations used in this report are mappable lithologic units as distinguished from time-stratigraphic and time units (Schenk and Muller, 1941). Despite this restricted usage of the term formation, workers have for decades correlated, or implied correlations of, these units as if they were everywhere contemporaneous. The present writer is guilty of suggesting the same in table 3.

In recent years the importance of facies changes in sedimentary rocks has come to be realized in geologic thought. This was especially apparent at the recent conference sponsored by the Geological Society of America on "Sedimentary Facies in Geological History" (Longwell, chairman, 1949). There are as yet no criteria for accurately determining the geologic ages of unfossiliferous rocks, such as those in the Hot Springs area. In the light of the sedimentary facies concept, and in view of the great distances between local rock units and the type sections for which they are named, it seems desirable to point out that formational boundaries that are based on lithological character alone may not be the same age from place to place. Indeed, one may well inquire if a formation in one locality is not entirely older or younger than a similarly named formation in another locality.

Similarities of lithologies and comparable sequences of lithologies, taken together, do not constitute an adequate basis for correlation. This is well demonstrated by McKee's study (1945, pp. 11-36, fig. 1) of the Cambrian rocks in the Grand Canyon. There, paleontological evidence and lithologic key beds indicate that the Bright Angel shale (also called the Pioche shale) and the Tapeats sandstone (also called the Prospect Mountain sandstone) are progressively younger when traced eastward. At Grand Wash Cliffs, on the west, the Tapeats is Early Cambrian in age and the *Olenellus* zone is well above the base of the overlying Bright Angel shale. On the east, at Bright Angel Trail, the Tapeats sandstone is of Early and Middle Cambrian age. Thus, the base of the overlying Bright Angel shale is of Early Cambrian age on the west and of Middle Cambrian age on the east. Above the shale, the base of the Muav limestone is also progressively younger when traced eastward. Thus, the Bright Angel shale, a lithogenetic unit, clearly cuts across time-stratigraphic and time boundaries.

Although accurate data are not yet available, the present writer suggests that comparable conditions may exist in the lowermost clastic rocks of the Southern Appalachians. For example, not only may the base of the Hampton formation in the Hot Springs area not be correlative with the base of that unit in the type area, but the entire formation may possibly be younger or older than the Hampton formation in north-eastern Tennessee. The possibility is a real one which bears heavily on current and future stratigraphic and paleogeographic studies.

HONAKER LIMESTONE

Name.—The Honaker limestone was named by Campbell (1897, p. 2) for the town of Honaker, Russell County, Virginia. It is well displayed in road cuts on Va. Highway 71, half a mile south of Brookside Inn, Russell County, Va. (Butts, 1940, p. 70). It is there composed mainly of dark blue or gray massive fine-grained limestone, with some brown-weathering silty and shaly beds.

Limits and Thickness.—The base of the Honaker, although not exposed in the Hot Springs area, is placed above the uppermost beds of distinctive Rome red shale. Only the lower part of the formation is exposed in the area and therefore no estimate of the thickness of the formation can be made.

Distribution.—The Honaker limestone outcrops only in one small patch in the northernmost part of the Hot Springs window (pl. I). It is well exposed along Mine Hollow and gentle dips enable one to examine about 100 feet of section by climbing up the south side of the hollow. The possibility that these beds may be overturned is discussed in the section on geologic structure.

Character.—Near the mouth of Mine Hollow, on Shut-in Creek, the limestone is thin bedded, silty, and argillaceous, and weathers yellow to yellow brown. Along Mine Hollow and up the south side of the hollow,

the limestone is more massive and less argillaceous. On fresh surfaces the rock is light to dark gray, in some cases dark blue. Faint laminae appear on some of the darker beds which contain layers of slightly silty and argillaceous limestone. Caves and other solution cavities are common. On top of the spur adjacent to and south of Mine Hollow there is a considerable amount of float made up almost entirely of concentrically banded light gray to black subvitreous to waxy chert. The bands, though concentric, are wavy and folded.

Correlation.—With the exception of one stromatolite (see pl. IV, fig. 1), no fossils were found in these rocks. Despite the lack of reliable faunal evidence, the writer assigns these carbonate rocks to the Honaker limestone of northeastern Tennessee and western Virginia, rather than to the Shady as Keith (1904) did. The reasons for so doing are:

1. These rocks are predominantly limestone, whereas the Shady formation is made up almost entirely of dolomitic rocks in the Hot Springs area.
2. The thin bedded, yellow-brown argillaceous limestone of Mine Hollow is quite distinct lithologically from the rocks observed in known Shady.
3. The writer knows of no occurrence of stromatolites in the Shady, whereas *Cryptozoon* has been found in the Honaker (Butts, 1940, p. 74).
4. The abundant concentrically banded chert nodules found near Mine Hollow have not been found in any known Shady, but are common in the Honaker of eastern Tennessee.⁵
5. The structural evidence known to the writer does not support Keith's conclusion that the Shady dolomite is repeated along the north side of the window on the north limb of a syncline, whereas stratigraphic evidence opposes that conclusion. (See discussion of Rome formation.)

The lower part of the Honaker formation in Virginia and Tennessee is equivalent to the fossil-bearing Rutledge formation and therefore is Middle Cambrian in age (Butts, 1940, pp. 67-74).

ROME FORMATION

Name.—The Rome formation was named for Rome, Floyd County, Georgia (Hayes, 1891, p. 143). In the Hot Springs area, the name "Watauga shale" was used by Keith (1904, p. 7) for the same unit. The name "Watauga shale" was not proposed until 1903 (Keith, 1903, p. 5). The term "Rome formation" thus has priority, and the name "Watauga shale" is abandoned.

The Rome formation is known from Pennsylvania to Alabama and is well displayed in many places. As described by King et al. (1944, p. 15), it typically consists of:

. . . red, maroon, or brown shale, most of which is silty and well-consolidated. Green argillaceous, sericitic shale is also present, and is associated with dolomitic shale or shaly dolomite. Interbedded with the shale are beds of maroon-red, brown, and greenish brown siltstone, which in places grade into fine-grained sandstone. . . .

Interbedded with the shale, especially the green shale, are numerous beds of light-gray, shaly dolomite, mostly less than 2 feet thick. Some thicker beds and members of medium-bedded to massive blue-gray finely crystalline dolomite . . . are lithologically very similar to the upper beds of the Shady dolomite.

Limits.—The top of the Rome as mapped here is the contact between the uppermost clastic beds and the overlying continuous sequence of carbonate rocks which comprise the Honaker formation. The Rome-Shady contact is marked by transitional beds of silty and shaly dolomite and dolomitic shale, but the base of the Rome is taken as the base of the first thick body of the characteristic maroon shale.

Distribution.—The Rome formation underlies an east-west trending belt along the north side of the window (pl. I). Exposures are generally poor and in most cases the presence of the formation is suggested only by the occurrence of small maroon shale chips in the soil or by the characteristic maroon color of the soil. However float must be mapped with discretion because the Rome shale has been used locally as road metal. The best exposures are seen in the almost continuous outcrops along Stokely Hollow and in the road cuts paralleling the hollow from Highway 25-70 to Shaleville. Fairly continuous exposures were also

⁵ John Rodgers, personal communication.

observed along an abandoned road (not shown on the topographic map) parallel to and overlooking the railroad track northwest of the old dolomite quarries.

Character.—Although the Rome formation is an easily mapped lithologic unit, it is composed of diverse rocks. The rocks observed in the Hot Springs area closely resemble those of northeastern Tennessee (see quotation above). The maroon silty shales are most impressive and probably predominant. However, interbedded light to blue-gray, medium- to thick-bedded dolomitic rocks form a substantial part of the formation here. It was some of these dolomites, closely resembling those of the Shady, that led Keith (1904, areal geologic map) to believe that the Shady dolomite is repeated on the north side of the window as the north limb of a syncline. The dolomitic layers are the only ones which outcrop along the railroad just south of the Mine Ridge thrust fault, but traverses westward toward Shaleville and the south side of Brushy Mountain clearly indicate that the dolomite is interbedded with the characteristic maroon shale of the Rome. Therefore the dolomite is here mapped as part of the Rome formation.

The rocks making up the Rome formation are, to a large extent, incompetent. The shale is intricately folded (see pl. IV, fig. 2) and the writer found it impossible to learn anything about the over-all structure from a study of the trends of axial planes and axes of folds or the attitude of fault planes. Structural evidence, therefore, supports neither Keith's interpretation nor the present one. Moreover, the complexity of the detailed structures makes it impossible to ascertain the thickness of the Rome formation within the Hot Springs window.

Weathering.—The shale of the formation weathers to small chips and to silty clay. The dolomite beds form layers of buckfat clay and light yellow silty clay, depending upon the original composition. Solution cavities are common in the thicker interbedded dolomite and in some of the shaly dolomite.

Correlation.—No fossils are known from the Rome formation of the Hot Springs area. Lithologically similar rocks in Virginia (Butts, 1940, p. 63-67) have been found to contain Lower and Middle Cambrian fossils. Most of the formation is probably Early Cambrian in age.

SHADY DOLOMITE

Name.—The Shady dolomite was named by Keith (1903, p. 5) for Shady Valley, Johnson County, Tennessee. It is well exposed in Stony Creek Valley and near the Watauga River northwest of Iron Mountain (King et al., 1944, pp. 16-27). The formation consists predominantly of blue-gray, light gray, and white dolomite with a slight amount of interbedded limestone.

Limits.—The Shady is easily distinguished from the underlying clastic rocks and its base is placed above the siltstone, feldspathic quartzite and laminated clay which form the Helenmode member of the Erwin formation. The top of the Shady lies beneath the first occurrence of thick bodies of Rome maroon shale.

Distribution.—The Shady dolomite forms a belt parallel and adjacent on the south to the belt formed by the Rome formation (pl. I). Bedrock outcrops are few but close examination of residual clays proved useful in mapping the extent of the formation. The best dolomite exposures occur along the undercut north-east bank of the French Broad River opposite Hot Springs and in railroad cuts and quarries along the south-west bank of the river.

Character.—The Shady dolomite exposed within the Hot Springs window exhibits the several distinct rock types noted in the Shady of eastern Tennessee and southwestern Virginia. These distinctive rock types have been described well in Bulletin 52 of the Tennessee Division of Geology (King et al., 1944, pp. 16-27) and an abridged version follows:

Blue dolomite is the commonest and most widespread rock type in the Shady. 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 thick. Some is thin-bedded or laminated. . . . Coarsely crystalline secondary dolomite forms blebs in the more massive rock and forms stringers parallel to the bedding in the more laminated rock. The white color of . . . the blebs and stringers contrasts strongly with the surrounding dolomite.

The rock termed "white dolomite" is a . . . less common and widespread rock type. It is mostly white but is in part light-gray or has a pinkish to yellowish cast, and forms massive beds.

Some is compact, the grains not being visible to the naked eye; some is saccharoidal, the grains being a millimeter or more in diameter. Most of the white dolomite is much purer than any other dolomite in the Shady. . . .

Ribboned dolomite forms units of considerable thickness in some areas. . . . The ribboned appearance of the dolomite 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 lighter and contain more organic matter. The lighter layers are slightly silty. . . . Nearly all the lighter layers of the ribboned dolomite have been converted to white coarsely crystalline secondary dolomite. . . .

Many of the units of ribboned dolomite also contain limestone, although this is not as common as the dolomite. . . . The dark ribbons are pure limestone; the lighter ones are limestone in places but are more commonly dolomite. . . .

Using these fundamental rock types, it has been found (King et al., 1944, pp. 18-20, Fig 3; Rodgers, 1948, pp. 7-12; Ordway, unpublished; Ferguson and Jewell, unpublished) that the Shady section, when complete, may be subdivided generally into the following six members: lower white, lower blue, ribboned, middle blue, upper white, and upper blue.

A generalized section of the Shady dolomite in the Hot Springs windows appears in table 2. The writer presents it with reservations. The section was calculated from outcrops as plotted on field maps and is therefore by no means a measured section. Outcrops are not continuous and in several instances the boundaries between members were placed arbitrarily at unexposed horizons. Thicknesses presented in the table are maximum calculated thicknesses; minor drag folding makes determination of actual thicknesses difficult.

TABLE 2. GENERALIZED SECTION OF SHADY DOLOMITE IN THE HOT SPRINGS AREA.

Maroon shales of the Rome formation above.		Thickness
SHADY DOLOMITE:		Feet
(6) Upper blue member: Blue-gray to black, medium- to thick-bedded and massive dolomite; interbedded light gray dolomite common; includes some silty and shaly beds near the middle. Some irregular blebs and nodules of light- to medium-gray chert are present. Very well displayed in the two quarries along the railroad track on west bank of French Broad River and on the undercut bank opposite the town of Hot Springs. Approximately -----		650
(5) Upper white member: Buff-colored to white to light gray dolomite. Very finely crystalline near base and near top, but middle part is quite saccharoidal. Well exposed in Spring Creek near hotel and south of quarries on railroad track on west bank of French Broad.-----Approximately		600
(4) Middle blue member: Blue-gray to black, medium- to thick-bedded somewhat silty dolomite. Includes some blebs of white to buff-colored coarsely crystalline dolomite. Very well exposed at the old quarry on the east bank of the French Broad just north of Highway 25-70.-----Approximately		250
(3) Ribboned member: Medium to coarsely crystalline light gray to buff-colored dolomite in thick layers interbedded with finer-grained blue-gray to black dolomite. Some ribboned limestone is present in this member. Best exposed along lower Spring Creek and in south quarry on east side of river.-----Approximately		300
(2) Lower blue member: Light to dark blue-gray, black, generally thick-bedded to massive dolomite; includes some light gray and blue-gray dolomite near base. Best exposed in road cuts on U. S. Highway 25-70 on east side of French Broad River bridge and along Spring Creek.-----Approximately		150
(1) Basal ribboned member: Thinly interbedded white and light gray, very fine-grained dolomite. Poor exposures make determination of thickness difficult. Outcrops on north side of Camp Grounds road, 700 feet east of French Broad River-----Approximately		25(?)
Helenmode member of Erwin formation below.		
Total thickness of Shady dolomite-----Approximately		1975

Comparison with sections described by the writers cited above shows that the Hot Springs section differs in two respects. In northeastern Tennessee the basal beds of the Shady form the lower white member. The basal ribboned member in the Hot Springs area is not, properly speaking, ribboned dolomite as defined by King et al. (see above) in that there is not an alternation of dark blue-gray with light blue-gray dolomite, but rather an alternation of white and light gray dolomite. It may well be that these beds, and some of the light blue-gray beds of the lower blue member, correspond to the lower white member of northeastern Tennessee.

The second difference, that of apparently excessive total thickness, may be explained in part by the drag folds mentioned above. The possibility of strike faults repeating some of the beds within members is not excluded (see discussion of origin of hot springs). The total thickness of the Shady in northeastern

Tennessee is 1150 feet (King et al., 1944, p. 19). The maximum thickness known, in sections not subject to dispute, is the 1800 feet reported by Butts in Virginia (1940, p. 53). In view of these described sections, the 1975 foot thickness shown on table 2 is not beyond the realm of possibility, but it probably is somewhat greater than the actual thickness.

Jasperoid.—Jasperoid is a siliceous rock that is believed to have formed by the replacement of dolomite (Kesler, 1939, pp. 336-337). It is predominantly yellowish brown, but red, gray and black varieties are known. Jasperoid is widely distributed in the outcrop belts of Shady dolomite and sparingly present in Rome outcrop belts in northeastern Tennessee (King et al., 1944, p. 22; Rodgers, 1948, pp. 15-16), and it also occurs in the Shady dolomite near Cartersville, Georgia (Kesler, *op cit.*).

In the Hot Springs area, jasperoid is found in the residual clay of the Shady dolomite in many places, but it is known to occur in bedrock at only one locality. At this locality, on the north bank of the French Broad river, 1200 feet northwest of the Montauqua Hotel in Hot Springs, angular masses of jasperoid up to one foot in length are embedded in apparently unaltered dolomite and limestone. Associated with the jasperoid are half-inch long dog-tooth spar crystals, which have grown perpendicular to the walls of small cavities, and saddle-shaped dolomitic crystals. Manganese oxide dendrites appear on several bedding surfaces. Weathered dolomite surfaces here show intricate box-works whose very fine septa consist of thin veinlets of silica.

On fresh surfaces, the jasperoid found here is bright yellowish brown and saccharoidal in appearance. Microscopic study shows that the rock (0-48-347) is made up predominantly of mosaic quartz whose boundaries are transgressed by bands of particles of minute light brown, translucent iron oxide and black opaque manganese oxide (see pl. IV, figs. 5, 6).

One other noteworthy jasperoid locality was found in the Hot Springs area. A twenty-foot square mass of jasperoid is exposed in the bed of Shut-in Creek, about 100 feet north of the top of the Erwin formation. The jasperoid here is mottled light and dark brown and black and contains small cavities that are lined with waxy white chalcedonic silica. When studied microscopically, the rock (0-48-99A) is seen to consist predominantly of spherulitic silica (see pl. IV, figs. 3, 4). The fine radiating needles that make up most of the concentric bands are length slow, but the needles in the inner bands of some spherulites are length fast. Mosaic quartz fills the spaces between the spherulites. Irregularly shaped particles of brown iron oxide and black opaque manganese oxide are present throughout the thin section.

The origin of such jasperoid is not known with certainty. Workers in Tennessee (King et al., 1944, p. 24; Rodgers, 1948, pp. 16-17) suggest that the jasperoid there was formed by replacement of dolomite during weathering under earlier, unusual climatic conditions. On the other hand, Kesler (1939, pp. 336-337) concludes that the jasperoid in the Cartersville district, Georgia, is of hydrothermal origin. A more detailed study of the jasperoid in the Hot Springs area is necessary before its origin can be ascertained. Existing data do not eliminate either of the above possibilities.

Weathering.—The susceptibility of the dolomite in the Hot Springs area to weathering has resulted in the formation of many caves and other solution cavities. A thick residual clay mantle has also formed throughout most of the area underlain by the Shady. The clay and the character of the soil derived from it are in many cases diagnostic enough to be useful in mapping. The description that follows is taken from Tennessee Bulletin 52 (King et al., 1944, pp. 24-27):

. . . The clay is derived from the dolomite and was originally disseminated through it, especially in the blue dolomite and the ribboned dolomite and limestone. . . .

Most of the clay is brown to buff, dense, tough, 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 exhibiting 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 common. In places, the clay also contains nodules of hard manganese and iron oxides. . . .

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

Along the dip slopes of the underlying quartzite, weathering of the dolomite may extend deeper than elsewhere, and the residual clay may be thicker. . . .

The exposed surfaces of the residual clay are widely altered to red mealy soil. 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.

Correlation.—Inasmuch as no fossils were found in the formation in the Hot Springs window, the age determination is based on lithologic correlations with similar rocks in other localities. Fossils have been found sparingly in Alabama, Virginia and Pennsylvania (Butts, 1926, p. 65; Butts, 1940, pp. 54-56; Resser, 1938, pp. 24-25, 31). Identified fossils from the Shady in all localities are of Early Cambrian age.

CLASTIC GROUP OF LOWER CAMBRIAN SERIES

INTRODUCTION

Rocks Included.—The clastic rocks beneath the Shady dolomite are divided into two groups in this report: the clastic group of the Lower Cambrian Series above and the clastic group of unknown age below (see table 1). The older rocks of unknown age are discussed elsewhere in this report.

The clastic group of the Lower Cambrian Series corresponds to the basal clastic group of northeastern Tennessee (King et al., 1944, p. 27) and includes the Erwin, Hampton and Unicoi formations. Inasmuch as there are older sedimentary rocks present in the Hot Springs area, the word "basal" is not used here.

The Lower Cambrian clastic group is made up largely of interbedded siltstone and shale, vitreous, feldspathic and ferruginous quartzites, conglomerate, and slate. With few exceptions, the rock types of this group cannot be distinguished from those in the older group. Therefore, in the field it is difficult to assign outcrops to the proper stratigraphic units without tracing contacts along the strike or establishing the presence of comparable sequences of rock types.

As shown in plate III, the clastic group of the Lower Cambrian Series ranges in thickness from 6000 feet, along Shut-in Creek and East Fork Shut-in Creek, to about 5000 feet along Spring Creek. The range in thickness between sections may be greater in the ends of the window, but exposures there are not so good.

Terminology.—Two sets of formation names for the Lower Cambrian clastic rocks are in current usage in eastern Tennessee and western North Carolina (see table 3). The northeast Tennessee names, Unicoi, Hampton and Erwin, are used here for the same rocks which Keith (1904) and Stose and Stose (1947) named Cochran, Nichols, Nebo, Murray, and Hesse, all defined by Keith (1895) in the Chilhowee Mountain area, Blount and Sevier Counties, Tennessee. The Hot Springs area lies midway between the type localities for each group of names. The writer has not visited these type localities and therefore has had to rely entirely on the literature.

The choice of names used in this report has been made for the following reasons:

1. Recent detailed studies (King et al., 1944; Rodgers, 1948; Ordway, unpublished; Ferguson and Jewell, unpublished) have resulted in a comprehensive knowledge of the lithologic members of the northeast Tennessee formations in the type sections and elsewhere. There has been no detailed study of the stratigraphy of the Chilhowee Mountain rocks, although one is in progress now by H. W. Ferguson and G. D. Swingle.

2. If the northeast Tennessee formation names are used, their contacts can be readily mapped and their names are applicable in the Hot Springs area. This is true of several members of the formations as well.

3. Although a few Chilhowee Mountain formational contacts can be mapped in the Hot Springs area, the writer was unable to map the Murray and Hesse formations separately and could establish the Cochran-Nichols contact, as mapped by Keith (1904) in this area, only in a few well exposed places.

4. The units mapped here by Keith (1904) do not correspond lithologically to those mapped under the same names in the Chilhowee Mountain area (see table 3).

5. Inasmuch as Ferguson and Jewell (unpublished) have used the northeast Tennessee names in their report on the Del Rio district, it is deemed desirable to use the same units in the area adjacent to theirs on the east.

Correlation.—An attempt is made in table 3 to correlate the rocks of the Hot Springs area with those in other areas. These correlations are based upon lithological similarities only and the limitations discussed on pages 6-7 must be borne in mind.

Table 3. Stratigraphic terminology of the lower clastic rock units.

VIRGINIA AND EASTERN TENNESSEE					HOT SPRINGS AREA, NORTH CAROLINA						
SAFFORD 1869	BUTTS 1940 Virginia	KING et al. 1944 Northeast Tenn.	FERGUSON AND JEWELL (unpublished) Del Rio District, Tenn.	KEITH * 1895 Chilhowee Mtn., Tenn.	KEITH 1904 Hot Springs Area	STOSE AND STOSE 1947 (Along Spring Creek)	This Report				
CHILHOWEE SANDSTONE GROUP	ERWIN FORMATION	Helenmode Member	ERWIN FORMATION	Helenmode Member	ERWIN FORMATION	ERWIN FORMATION	ERWIN FORMATION	Helenmode Member	ERWIN FORMATION		
		Upper Quartzite Member		Upper Quartzite Member				HESSE SANDSTONE		HESSE	
		Middle Member		Middle Member				MURRAY SHALE		QUARTZITE	
		Lower Quartzite Member		Lower Quartzite Member				NEBO SANDSTONE		QUARTZITE	
	HAMPTON FORMATION	HAMPTON FORMATION	Upper Shale Member	HAMPTON FORMATION	NICHOLS	HAMPTON FORMATION	HAMPTON FORMATION	HAMPTON FORMATION	Upper Shale Member	HAMPTON FORMATION	
			Middle Quartzite Member		SHALE				NEBO QUARTZITE		Middle Quartzite Member
			Lower Shale Member		Lower Shale Member				MURRAY SHALE		Lower Shale Member
	UNICOI FORMATION	UNICOI FORMATION	UNICOI FORMATION	UNICOI FORMATION	COCHRAN CONGLOMERATE	UNICOI FORMATION	UNICOI FORMATION	UNICOI FORMATION	NEBO QUARTZITE (+NICHOLS)	UNICOI FORMATION	
					COCHRAN CONGLOMERATE				COCHRAN QUARTZITE		COCHRAN QUARTZITE
	OCOEE CGL & SL.	SANDSUCK FORMATION	SANDSUCK FORMATION	SANDSUCK FORMATION	SANDSUCK SHALE	UNICOI FORMATION	UNICOI FORMATION	UNICOI FORMATION	SANDSUCK FORMATION	UNICOI FORMATION	
SNOWBIRD FORMATION					NOT EXPOSED				SNOWBIRD FORMATION		SNOWBIRD FORMATION

Dashed lines: Members present in some sections but not mappable over entire area.
Dotted lines: Guide to units in Hot Springs area.

* Correlations by H. W. Ferguson (written communication).
No attempt is made here to show relative thicknesses.

The relations of the formations mapped by previous workers in the Hot Springs area (Keith, 1904; Stose and Stose, 1947) to the stratigraphic units of this report are shown graphically in table 3. The data were taken from the geologic maps published by those writers.

The correlation of the Chilhowee Mountain formations is a tentative one based on a written communication from H. W. Ferguson, who is currently engaged in a detailed study of the area. In addition, Ferguson has found evidence strongly suggesting an unconformity beneath the Cochran formation of the northwest side of Chilhowee Mountain.⁶ This possible unconformity is discussed more fully below (see p. 21). On the basis of this and other information, it appears likely that the base of the Unicoi (and the Cochran) is the contact which differs most in age from one locality to another.

Age.—The clastic group here described is a conformable sequence of rocks overlain conformably by the Shady dolomite. Except for some lingulellas and trilobites reported by Keith (1895, p. 3) from the Murray shale on Chilhowee Mountain, no fossils but the worm tube *Scolithus*, which is not an index fossil, have been found in the beds of this group in either Tennessee or North Carolina. Butts (1940), p. 40) has reported the presence of Lower Cambrian *Olenellus*, *Hyolithes*, and *Obolella* species in the Erwin formation of southwestern Virginia.

An age determination has been made on a specimen of the amygdaloidal basalt in the Unicoi formation. The specimen came from an exposure near the Tenn. Va. state line, two miles southeast of Damascus, Washington County, Virginia. The determination, made by Urry (Lane, 1935, p. 39) by means of the helium method, yielded a figure of about 450 million years.

The writer is further indebted to Mr. Ferguson for making this information available to him in a letter dated February 18, 1949.

Inasmuch as the group forms a conformable sequence of rocks and as the age determination of the Unicoi amygdaloid appears to be corroborative evidence, it seems logical for the present to assign the Hampton and Unicoi formations, as well as the Erwin, to the Lower Cambrian Series, as most previous workers have done.

Snyder (1947, pp. 146-152) and Resser (1938, p. 2), however, voice the conclusion of a group of geologists that the pre-Cambrian sediments pass into Lower Cambrian sediments with no break in deposition. For the sake of uniformity, Snyder suggests that the base of the Cambrian should, for the present, be taken as the lowermost fossiliferous horizon. While the present writer concedes the probable validity of the above conclusion, he sees little merit in assigning the Hampton and Unicoi formations to the pre-Cambrian merely because they lack fossils. Stronger and more positive evidence will be necessary to support such a stand.

ERWIN FORMATION

Name.—The Erwin quartzite was named by Keith (1903, p. 5) for the town of Erwin, Unicoi County, Tennessee. In the type area, however, this stratigraphic unit consists of interbedded siltstone and shale, white vitreous quartzite and ferruginous quartzite (King et al., 1944, p. 30). The quartzite beds are the most impressive because they are the best exposed parts of the formation, but they constitute only a small part of it. For this reason, the lithologic designation has been abandoned in recent Tennessee reports. In Virginia, however, the Erwin formation consists almost entirely of quartzite and is designated as such (Butts, 1940, p. 39). The best display of the formation near the type area occurs in the gorge of the Nolichucky River south of Erwin and southeast of Unaka Springs (King et al., 1944, p. 29).

The Erwin formation as mapped in the present report includes the upper part of the Murray slate and the Hesse quartzite as mapped by Keith (1904).

Limits.—The base of the formation is placed beneath a resistant ledge-forming, widely traceable white quartzite series of beds that overlie the upper shale member of the Hampton formation. In Tennessee (King et al., 1944, p. 30); Ferguson, unpublished), the lowest white fine-grained *Scolithus*-bearing quartzite is used as the base of the Erwin. Inasmuch as the writer was unable to find *Scolithus* tubes, save for one occurrence in the Hampton formation along Blood River, this proved impractical in the present study. The upper Erwin beds are easily distinguished from the overlying Shady dolomite.

Distribution.—The Erwin formation extends from Lovers Leap Ridge and Pump Gap on the east westward almost to Wolf Creek, Tennessee. The belt is 2 or 3 times wider to the west, in the vicinity of the state boundary, than in the east, near the French Broad River, because of decreased dips.

Resistant quartzite is fairly well exposed throughout the area, but the siltstone and shale are covered in most places by overburden. The best exposed and structurally least disturbed section occurs along the bed of Blood River, a small mountain stream midway between Hot Springs and Antioch. Other fairly continuous sections can be found along Shut-in Creek, in the bluff west of N. C. Highway 209 and south of Hot Springs school, and on the bluffs along Spring Creek.

Character.—The Erwin formation is made up predominantly of interbedded dark green siltstone, sandy and silty shale and thin-bedded quartzite. Most of the beds are an inch or two thick and are made up of alternating light silty and, in some cases, quartzitic laminae, and dark green to black shaly laminae. In places there is somewhat thicker-bedded dark green, non-quartzitic sandstone present among these rocks. Megascopically, the only identifiable minerals are quartz and, on some bedding surfaces, mica flakes.

A thin section (specimen 0-48-76) of a banded siltstone, collected from just below the middle of the formation along Blood River, was studied under the microscope. The white laminae are composed of about 85 per cent silt-size angular fragments; the silt fraction is composed predominantly of quartz and feldspar (only microcline and sodic plagioclase were identified), but detrital muscovite and biotite make up about 10 per cent of the fraction; tourmaline and detrital (?) carbonate are also present. The remaining 15 per cent of the white to light gray quartzose laminae consists of matrix material too fine-grained for petrographic study. However, at least sericite or illite is present. In the dark argillaceous laminae, the silt fraction (about two-thirds quartz and feldspar and about one-third detrital micas) forms only about 30 per cent of the rock. If secondary minerals are present at all, they form part of the extremely fine-grained matrix.

The vitreous quartzite beds, most prominent because of their great resistance to weathering, are white, gray, and buff-colored on fresh surfaces. The purest quartzite weathers to white surfaces, but most quartzite beds weather to various shades of brown. Grain size is not evident in most hand specimens due to the fine texture and excellent silica cementation. The lightest colored vitreous quartzite beds appear to consist of pure silica but chemical analyses and petrographic studies reveal the presence of at least 5 per cent impurities, generally in the form of fine-grained feldspar. Feldspar may form up to 15 per cent of the rock and scattered grains of muscovite, pyrite and heavy minerals may also be present.

A thin section (0-48-191) of a quartzite sample, collected from a ledge at the French Broad gaging station on the northwest side of Lovers Leap Ridge, was studied petrographically. Megascopically, the light gray vitreous quartzite resembles other quartzites in the area. The average grain size is about $\frac{1}{2}$ mm. with maximum lengths up to 3 mm. Feldspar appears to make up 5 per cent of the rock and small grains of pyrite and dark minerals are apparent.

Microscopic study showed the rock to be composed of approximately 75 per cent quartz, 20 per cent feldspar (almost entirely microcline), 4 per cent sericite, and minor amounts of chlorite, carbonate, pyrite, tourmaline, and detrital colorless mica. The most surprising thing learned from the petrographic study was the degree of cataclasis and sericitization in what appeared to be a very little deformed rock. Strain shadows are well developed in the quartz and many grains of quartz and feldspar have granulated margins. Whatever the original matrix was, it is almost entirely sericite now and sericite fills fractures in quartz and feldspar. Sericite appears to have attacked the albitic lamellae of microperthite and whatever plagioclase grains may have been present. In several places, small islands of feldspar, which extinguish together, are surrounded by a paste of sericite and finely comminuted feldspar and quartz. Fan-shaped aggregates of chlorite fill minute fractures in the rock and also form small irregularly distributed clusters. The carbonate and euhedral pyrite are also secondary.

Ferruginous quartzites similar to those found in the Hot Springs area have been noted in northeastern Tennessee. King et al. (1944, p. 31) describe them as follows:

The middle part of the Erwin formation contains beds of vitreous dark bluish to purplish quartzite. This color results from finely divided hematite in the cementing material. All gradations are present between strongly ferruginous and slightly ferruginous quartzite. Most of the ferruginous quartzite is medium-grained, but some is coarse-grained or even pebbly. Glauconite grains are present in many beds.

The writer has found no *Scolithus*-bearing quartzites in the Erwin formation of the Hot Springs area, though they are reported elsewhere.

Subdivisions.—Recent workers (King et al., 1944, figs. 5, 6, pp. 31-34; Rodgers, 1948, pl. 1, pp. 18-19; Ferguson and Jewell, unpublished) have subdivided the Erwin formation of eastern Tennessee into four mappable units: the Helenmode (at the top), the upper quartzite, the middle, and the lower quartzite members.

In the Hot Springs area, the Helenmode member is easily distinguished from the overlying Shady dolomite and the underlying thick quartzite ledges. Although it is not everywhere exposed, the writer was able to map this member.

The unit was named (King et al., 1944, p. 31) for the Helenmode pyrite mine in Stony Creek Valley, near Sadie, Carter County, Tennessee. In earlier reports the Helenmode member was called the "transition beds". The writer can add nothing to the lithologic description published by Stose and Schrader (1923, p. 25) which follows:

. . . They are . . . about 100 feet thick and embrace finely laminated clays, which evidently were originally calcareous shale, and soft mealy arkosic sandstones, some stained red and purple with iron, others of a greenish color, due 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.

The generally weathered condition of the Helenmode rocks is attributed to leaching by ground water. The massive vitreous quartzite beneath the Helenmode member forms an impermeable dip slope which restricts the flow of ground water to the more permeable and soluble "transition beds". The characteristic pink

color of the ledge-forming quartzites beneath the Helenmode is probably due to the iron compounds leached out of the overlying beds.

Except for the Helenmode member, the Erwin formation could not be subdivided in the Hot Springs window. Rock types alternate repeatedly throughout the formation. Outcrops are not continuous and quartzite layers lens out. In short, there are no lithologic units which can be traced and mapped throughout the area. Nevertheless, an attempt is made in plate III to show the horizons in sections A, B and C which may possibly correspond to the boundaries between members described by the above mentioned workers in Tennessee.

Local details of the lithology in the best exposed sections are summarized graphically in sections A, B and C of plate III. Noteworthy is the decrease in thickness eastward from 2100 feet along Shut-in Creek to 1700 feet along Spring Creek. The thickness of the Helenmode member is probably from 100 to 150 feet. Not indicated in the sections on plate III is the presence of some scattered rounded granule-sized fragments of quartz, quartzite and slate in some of the quartzite beds. These slightly conglomeratic zones are not restricted to particular stratigraphic horizons but are more numerous near the bottom of the upper quartzite member and lower in the formation.

Weathering.—Vitreous quartzite of the Erwin formation is little affected by weathering and forms the backbone of crests and spurs of ridges across the window. Ledges and cliffs are prominent and mechanical weathering is notable in their breakdown. Blocks and boulders derived from these ledges form a large part of the surficial deposits and slopewash in streams and above much of the Shady residual clay and Rome formation. Some of the poorer cemented quartzite weathers to form almost incoherent sand.

Siltstone and sandy and silty shale weather to form sandy and silty clays. The interlaminated quartzitic layers form discolored chips in the mantle.

The weathering phenomena of the Helenmode are discussed above.

HAMPTON FORMATION

Name.—The Hampton shale was named by Campbell (1899, p. 3) for the town of Hampton, Carter County, Tennessee. No specific type section was designated, but the formation is well displayed in the Doe River gorge through Iron Mountain, north of Hampton (King et al., 1944, p. 35, fig. 5 section B). The rocks in the type area are similar to those in the Erwin formation except for an increase of feldspar in the quartzite and for the presence of a larger proportion of shale. For that reason the lithologic designation has been abandoned in preference for "Hampton formation". The Hampton beds in southwestern Virginia, however, are made up almost entirely of shales (Butts, 1940, p. 37) and the earlier defined name applies there.

Limits.—In the Hot Springs area the base of the Hampton formation is distinctly marked by the top of the traceable uppermost vitreous quartzite of the Unicoi formation. The base of the lowermost quartzite above the upper shale member marks the top of the formation. In practice, the formation was delimited in the field as follows: the diagnostic ledge-forming, well crossbedded feldspathic quartzite beds of the middle member were traced along their strike across the window; intraverses across the strike, the first massive or thick-bedded vitreous quartzites found beyond the shale units were used as the limits of the shale members above and below the middle member.

Distribution.—The areas underlain by the Hampton formation are shown in the accompanying geologic map (p. I). The quartzite of the middle member is well exposed in many places but outcrops of the shale members are few. The best exposed complete sections occur in the bluffs along Spring Creek south of Hot Springs, along the bed of Blood River, and along the French Broad River. Fairly good exposures may be found in road cuts and in stream beds along Shut-in Creek.

Character and Subdivisions.—The lithologic character of the formation is represented graphically in sections A, B, C, and E of plate III. The rock types found in the Hampton formation are the same as those found in the Erwin and Unicoi formations. Dark green sandy and silty shale and medium- to coarse-grained feldspathic quartzite predominate. The formation is 1000 to 1300 feet thick.

In the Hot Springs area, the Hampton formation is easily subdivided into three members: the upper shale, the middle quartzite and the lower shale. The contacts between these members are so readily mapped that Keith (1904) used the same horizons as formational boundaries between the Murray slate and the Nebo quartzite and between the Nebo and the underlying Nichols slate. The members described in the present study correspond lithologically to those mapped and similarly named by Rodgers (1948, p. 19, plate I) and Ferguson and Jewell (unpublished) in eastern Tennessee.

In the Hot Springs window, the upper shale member consists of alternating dark green siltstone, silty shale and sandy shale, interlaminated with thin white to gray quartzitic layers. Dark green to gray sandstone is also present. The member is 200 to 300 feet thick.

The middle quartzite member includes a diverse group of rocks. Quartzitic rocks predominate and have a feldspar content ranging from a few per cent to 40 per cent and averaging 25 to 30 per cent in many beds. These medium- to coarse-grained feldspathic quartzites and arkoses⁷ exhibit well developed, intricate crossbedding in many places (see pl. V fig. 2). On fresh surfaces a speckled aspect is produced by the well distributed white feldspar grains embedded in colorless vitreous quartzite. Weathered surfaces are reddish brown to brownish red.

Colorless, white to gray vitreous quartzite with very little feldspar forms resistant ledges at the base and at the top of the middle quartzite member. Similar rocks are also found interbedded with feldspathic quartzite and arkose throughout the member. Among these rocks are found pebbly zones and beds containing rounded quartz and angular feldspar grains up to 7 mm. in diameter, slate chips up to 3 cm. in length, and fine dark mineral grains. The middle quartzite member also contains dark greenish sandstone which appears earthy even on fresh surfaces.

The only *Scolithus* tubes seen during the present study were found near the base of the quartzite member on both forks of Blood River. The cylindrical tubes, averaging about 2 mm. in diameter, are filled with dark blue-gray quartzite which stands out from the surrounding very light gray vitreous quartzite.

A dark gray quartzite with a narrow pebbly zone was collected along Shut-in Creek, about 1000 feet above the mouth of Clear Branch. Petrographic study of the rock (0-48-115) showed the pebbles to be strained quartz with well developed Böhm lamellae. The fine-grained sand and silt fraction makes up 95 per cent of the rock. About two thirds of the fraction is made up of angular quartz, with poorly developed strain shadows. Potash feldspar, many grains showing plaid twinning, predominates in the remaining third, but albite is also present; some feldspar grains contain thin bands of epidote which developed, before transport, either along cleavage cracks or in the albitic lamellae of micropertthite. Also present in the fraction are a few grains of grayish-green tourmaline, apatite, detrital muscovite and slightly bleached biotite, zircon, leucoxene, and ore minerals. The matrix, forming about 3 per cent of the rock, is a paste made up of sericite or illite, traces of chlorite, minor carbonate, and clay particles which could not be identified. The texture is clearly fragmental with no evidence of cataclasis.

The middle quartzite member ranges in thickness from 500 feet, along Spring Creek, to 750 feet, along Blood River.

In the lower shale member of the Hampton formation, the sand and silt fractions are a somewhat smaller part of the rock than in the overlying shale. Dark greenish shale, thick-banded bluish argillite,⁸ and poorly developed, fractured slate occur in this unit. Interbedded with these rocks are silty shale and laminated siltstone like those seen elsewhere in the section.

The lower shale member ranges in thickness from 210 to 380 feet.

Weathering.—The weathered products of the Hampton are similar to those described for corresponding rock types in the Erwin formation. The concentration of resistant quartzite in the middle member, however, results in a strong topographic expression. The crests of some of the higher portions of Lovers Leap Ridge and Deer Park Mountain are underlain by this rock. Noteworthy are the flatirons produced by the

⁷ Arkose is here used for "sandstone containing 25 or more per cent of feldspars usually derived from the disintegration of acid igneous rocks of granitoid texture" (Allen, 1936, p. 44). The arkoses in the Hot Springs area do not simulate a granite in appearance, but the writer believes that this is not a necessary condition in the definition of the term arkose (see Oriol, 1949).

⁸ Argillite is used here for rock "derived either from siltstone, claystone, or shale, that has undergone a somewhat higher degree of induration than is present in those rocks" (Twenhofel, 1937, pp. 95-96).

middle quartzite member on the north flank of Hot Springs Mountain, southeast of the Deepwater railroad bridge across the French Broad. Ledges and cliffs, talus slopes, and steep mountain and spur slopes are common in the belt underlain by the middle member. Gullies, stream segments and ridge saddles are restricted in most cases to the belts underlain by the weaker shale members.

UNICOI FORMATION

Name.—The Unicoi formation was named by Campbell in 1899 (p. 3) for Unicoi County, Tennessee. A type section was not designated but the sequence is probably best exposed in the gorge of the Nolichucky River, southeast of Unaka Springs in Unicoi County (King et al., 1944, p. 37, section G fig. 6). Typically it is made up largely of coarse vitreous and arkosic quartzite, conglomerate with some siltstone, shale, green graywacke, and amygdaloidal basalt.

The rocks mapped by Keith (1904) in the Asheville folio as the quartzite lentil and lower part of the Nichols slate and as the Cochran conglomerate are all included in the Unicoi formation in the present report.

Limits.—The top of the Unicoi is placed above the thick-bedded to massive vitreous and coarsely feldspathic quartzites that underlie the lower shale member of the Hampton formation. This boundary is quite sharp and distinct.

The lower contact is here defined as the base of the lowermost conglomeratic bed above the Sandsuck. In practice, the base of the formation is more difficult to recognize in the field than the foregoing sentence implies. Slates are interbedded with the Unicoi conglomerates and there are lenses of coarse conglomerate in the upper part of the Sandsuck. In traversing the rocks across the strike, it is difficult to choose the conglomerate whose base also marks the base of the Unicoi. Further difficulties arise when one considers the possibility of an unconformity between the Unicoi formation and the underlying rocks (see pp. 21-22). In the field, the base of the Unicoi was traced along the strike wherever outcrops and reliable float permitted. Some gaps were inevitable, due to relatively poor exposures. On the opposite side of these gaps, the lowermost conglomerate seen was taken as the base of the Unicoi, unless there was clear evidence that it pinched out between slates in which case it was assigned to the Sandsuck and the next higher, continuous conglomerate was used.

Distribution.—The Unicoi formation is the youngest formation to be exposed both within and outside the Hot Springs window within the area covered by this report. Within the window, it underlies a belt of non-uniform width from Wolf Creek, Tennessee, eastward to Big Laurel Creek. Outside the window, the formation underlies the northwestern part of the area, from Mine Ridge to Wolf Creek near Low Gap.

The Unicoi stratigraphy is best exposed in the sections along East Fork Shut-in Creek, Spring Creek, and the French Broad River, and in gullies on the southeast flank of Lovers Leap Ridge (sections A, C, and E, pl. III).

Character.—Within the Hot Springs window, the upper part of the Unicoi is lithologically similar to but considerably coarser grained than the rocks of the middle quartzite member of the Hampton. Arkose (see footnote, p. 17) and feldspathic quartzite predominate and crossbedding is exceptionally well developed. Feldspar grains make up 25 to 40 per cent of the rock in many cases, are angular, and range in size from microscopic to 20 mm., averaging about 2 to 3 mm. in many beds.

A thin section of such a rock (0-48-2A), collected from a road cut on North Carolina Highway 209, beyond the first bridge over Spring Creek south of town, was examined. Megascopically, all that was apparent in the rock was an abundance of angular white feldspar grains set in a glassy matrix. Microscopically, the rock shows a composition of about 66 per cent quartz, 30 per cent potash feldspar (almost all grains showing microcline twinning), and 3 per cent sericite, with some detrital colorless mica and microcline-bearing metaquartzite. The clastic texture is considerably obscured by authigenic quartz overgrowths which form part of the silica cement, but some outlines of the rounded clastic quartz grains are marked by trains of submicroscopic inclusions. The clastic quartz grains have inclusions of euhedral zircon, apatite, biotite, smoky bluish-green tourmaline, and sphene. All the quartz in the rock exhibits markedly undulose extinction; Böhm strain lamellae are abundantly developed and some granulation sutures are present. The silica cement, which fills fractures in microcline and quartz grains, forms curious zig-zag intergrowths with

itself in some places. Sericite appears to be the last-formed mineral and replaces other minerals (see pl. V, fig. 6).

Interbedded with these feldspathic rocks, and at the top of the formation, are fine-grained white, colorless, and gray vitreous quartzites which include scattered quartz pebbles in many places. These form the most resistant ledges of the formation. Though it is not apparent in hand specimens, feldspar forms at least a few per cent of these rocks. Some beds contain conglomeratic zones in which rounded quartz granules and pebbles up to $\frac{1}{2}$ inch in diameter predominate; slate chips and dark minerals are present as well.

Also present in the upper part of the formation are poorly sorted sandstone, fine-grained conglomerate, sandy and silty shale, and siltstone. Most of the shale units are too thin to be represented in sections A, C, and E of plate III.

The middle portion of the formation is made up largely of pebbly, poorly sorted, dark gray and greenish gray feldspathic quartzite and arkose. Quartz pebbles predominate, but jasper, feldspar and slate pebbles up to 1 inch in length are present. Interbedded with these pebbly beds is some light to dark gray vitreous quartzite.

The rock exposed in railroad cuts opposite Mountain Island is somewhat fractured and slickensided feldspathic quartzite. A specimen (0-48-303) with grains up to 2 mm. long but averaging 1 mm. in diameter was studied petrographically. The sand fraction, comprising 90 per cent of the rock, consists predominantly of quartz and microcline. Plagioclase (albite was identified), biotite, zircon, sphene, carbonate (in feldspar fractures), leucoxene, and saussurite are also present. The quartz is granulated around the edges and shows strong strain shadows; the feldspars have suffered slight microbrecciation. Pyrite cubes are present and chlorite occurs in fractures. The unexpected and most significant fact to issue from the thin section study was the large amount of sericite present. The matrix, a paste of sericite and granulated quartz, constitutes 10 per cent of the rock; locally sericite forms a greater portion of the rock and has replaced plagioclase along cleavage planes, leaving only a few remnants. Sericitization, apparently post-cataclasis in age, appears too strongly developed in this rock to be attributed only to low rank metamorphism of an originally argillaceous matrix. The writer suggests that the sericite and the pyrite cubes may be hydrothermal in origin.

The rocks in the lower part of the formation are considerably more mixed in composition. There are fewer beds of vitreous quartzite and cleanly sorted arkose, and the other rock types mentioned above predominate. Near the base of the formation, coarse conglomerate is interbedded with slate up to 200 feet thick. Although some poorly developed slaty cleavage appears in shales higher in the section, the argillaceous rock in this part of the formation is the youngest that may be called slate.

The conglomerate is one of the most distinctive rocks in the area and occurs at or near the base of the Unicoi. It is best displayed beneath the bridge on N. C. Highway 209, 1000 feet south of Odd Fellows Cemetery, and along the ridge slopes southeast of the bridge. Excellent exposures also occur along the sigmoid bends of Big Laurel Creek near the French Broad River (see pl. V, fig. 5).

In the coarsest conglomerate beds, the pebbles are up to 2 inches in length and form 35 to 45 per cent of the rock. Well rounded white to blue-gray quartzite and quartz pebbles predominate. Angular to sub-angular feldspar fragments are numerous and jasper pebbles and slate chips are also present. Size sorting is extremely poor and any attempt to set an upper limit for the matrix must be arbitrary, for the fragment sizes are gradational.

Other conglomerate beds contain fewer and smaller pebbles but slate inclusions make them diagnostic. In the Hot Springs area, only the lower Unicoi beds and the conglomerate lenses in the Sandsuck include these distinctive large chips of slate and the recognition of this fact proved to be useful stratigraphically. It is one of the few rock types that does not recur elsewhere in the section. In some places these inclusions of slate are as much as five feet long and several inches thick. Where bedding in the conglomerate is obscure, attempts were made to utilize the orientation of slate inclusions as a guide, but these proved misleading in many places. The attitudes of the slate inclusions appear to be haphazard, but on the hill slope southeast of the Spring Creek highway bridge, there is a suggestion of imbrication across the bedding. The bedding trends $N20^{\circ} W35^{\circ} NE$, whereas the slate fragments tend to parallel the joints in the conglomerate, $N65^{\circ} E80^{\circ} SE$. However, they do parallel the bedding in some outcrops.

Amygdaloidal basalt beds similar to those described by King et al. (1944, pp. 38-40), Ordway (unpublished), and Lowry (unpublished) in Tennessee, and by Butts (1940, pp. 31-34) in Virginia, were not found in the Hot Springs area. Moreover, the writer was unable to subdivide the Unicoi formation into mappable members comparable to those described by Ferguson and Jewell (unpublished) in the Del Rio district, Tennessee.

In the Hot Springs window, the Unicoi formation thickens southwestward, from 1400 feet on the south side of Lovers Leap Ridge to 2600 feet along East Fork Shut-in Creek. It is 2250 feet thick along Spring Creek.

Northwest of the window (see pl. I) and in the overlying thrust sheet are rocks which the present writer assigns to the Unicoi formation, as Keith did in his Asheville folio (1904). Stose and Stose (1947, fig. 1, pp. 632-634) assign these rocks to the Great Smoky quartzite of the Ocoee Series, or Snowbird as mapped by Keith. The writer has not studied the stratigraphy of the rocks surrounding the Hot Springs window in great detail, but has found striking lithologic similarities between these rocks and those in the Unicoi within the window.

The rocks exposed along Mine Ridge and in road cuts southeast of Grass Creek compare with those in the middle and lower Unicoi, as described above. Pebbly feldspathic quartzites predominate and are interbedded with coarse conglomerates and a few thin slate units. The pebbles in the conglomerates are predominantly quartz and have a maximum diameter of about 1½ inches. Large slate chips and inclusions and jasper pebbles are present and compare with those found within the window only in the lowermost Unicoi and conglomerate lenses of the Sandsuck. The rocks are badly fractured and folded and are stained red, brown and black by iron and manganese oxides.

The rocks exposed along Wolf Creek and westward have been studied and described by Ferguson (Ferguson and Jewell, unpublished) and need not be discussed in detail here. The writer has seen some of these rocks and agrees with Ferguson's conclusion that they are part of the Unicoi formation.

Weathering.—The rock types in the Unicoi similar to those in overlying formations weather in comparable ways. Noteworthy are the cliffs formed by vitreous and feldspathic quartzite and arkose on the northeastern flank of Hot Springs Mountain, opposite Mountain Island, and the steep ridge between Shut-in Creek and Jones Branch, southwest of the mouth of East Fork Shut-in Creek. Within the area mapped, Mountain Island is the only island in the French Broad River with moderate relief and steep ledges; it too is underlain by Unicoi quartzites.

Where exposures are poor, the basal contact of the Unicoi is difficult to map on the basis of float. Conglomerate beds break down almost completely and only the coarsest leave clues in the form of pebbles. Slate chips, on the other hand, persist and decompose less readily. Conglomerates bearing large slate chips and inclusions form heavily vegetated soils in which small slate chips are most apparent. Superficial study of float, then, is likely to lead the observer to map lowermost Unicoi rocks as Sandsuck slate, and proper precautions must be taken.

CLASTIC GROUP OF UNKNOWN AGE

INTRODUCTION

Rocks included.—The clastic group of unknown age, as used in this report, includes all the sedimentary rocks underlying the Unicoi formation in the Hot Springs area. The group includes the Sandsuck and Snowbird formations.

The group is made up of interbedded siltstone, shale, slate, conglomerate, sandy limestone, calcareous sandstone, feldspathic quartzite and sandstone, and arkose. Arkose and feldspathic quartzite predominate throughout much of the middle and lower part of the group.

Any estimate of the thickness of the clastic group of unknown age in the Hot Springs area must be based upon an interpretation of the Dry Pond Ridge contact (see pp. 39-41). Everywhere else in the area mapped, the lower part of the Snowbird formation is either cut out or concealed by thrust faults. If the Dry Pond Ridge contact is a nonconformity⁹ then the group ranges in thickness from 2200 feet near

⁹ The term nonconformity is used here for an unconformity in which the older rock is granitoid or gneissose in character.

Windy Gap, west of Piney Mountain, to 5300 feet along the east fork of Mountain Island Branch, and may be even thicker westward, within the window. On the other hand, if the Dry Pond Ridge contact is a thrust fault, then no estimate of the thickness is possible and the estimates cited above must serve as minimum figures.

Terminology.—The reasons for using the names Sandsuck and Snowbird in the present report are given below in the descriptions of these formations.

Correlation.—No attempt is made here to correlate the formations of this group with differently named formations which underlie the Unicoi or Cochran formations in other districts. The writer feels that if serious errors are to be avoided, any such attempt must be based on a more comprehensive knowledge of the pre-Unicoi rocks than is available at present. In this connection, the work being done now in the Great Smoky Mountain National Park by the U. S. Geological Survey, under the direction of Philip B. King, should prove fruitful.

Age.—As suggested by its name in this report, the precise geologic age of the lower clastic group is not known. In general, previous workers in this area assigned these rocks either to the Lower Cambrian Series or to the upper pre-Cambrian.

Safford (1869, pp. 182, 193-194) mapped these formations, and in some places the Unicoi also, as the Ocoee sub-group, which he stated was Eozoic in age. In the Asheville folio, Keith (1904, pp. 4-5) placed the Snowbird and overlying clastic formations in the Cambrian System. Stose and Stose (1944, pp. 408-409), in their paper on the Chilhowee group and Ocoee series, place the Snowbird formation in the Ocoee series, which they believe to be of late pre-Cambrian age, and the Sandsuck in the Cambrian Chilhowee group. In their paper on the Hot Springs area, however, Stose and Store (1947, pp. 627, 632) state that all the clastic rocks beneath the Shady dolomite within the Hot Springs window belong to the Cambrian Chilhowee group, whereas all the sedimentary rocks outside the window are part of the pre-Cambrian Ocoee series. A discussion of the age of the Ocoee series of the Southern Appalachians also appears in their 1949 paper (Stose and Stose, 1949, pp. 307-318). King (1949), however, redefines the Chilhowee group to include the rocks between the base of the Unicoi and the top of the Erwin formations and places the Sandsuck and Snowbird formations in the Ocoee Series. From regional stratigraphic considerations, King concludes that there is a reasonable physical basis for placing the base of the Cambrian in the Southern Appalachians at the base of the Chilhowee group, i.e. the base of the Unicoi formation.

No fossils have been found in the Snowbird, Sandsuck, or Unicoi formations in either North Carolina or Tennessee. In the Hot Springs area, the Sandsuck overlies the Snowbird formation conformably. Although the writer found no clear cut evidence proving the presence of an unconformity between the Sandsuck and Unicoi formations in the Hot Springs window, a possible unconformity is suggested by the comparatively abrupt change in the predominant rock types and no evidence was found to eliminate the possibility. Ferguson and Jewell (unpublished) also discuss the possibility of an unconformity beneath the Unicoi in the Del Rio district, Tennessee. During his field study of the Chilhowee Mountain area, Tennessee, Ferguson¹⁰ found that the truncation of Sandsuck beds by the overlying Cochran formation strongly suggests an unconformity. In her report on the southwestern end of the Mountain City window, Lowry (unpublished) states that the unconformity beneath the Unicoi cuts out the Sandsuck formation in the gorge of the Nolichucky River, so that Unicoi rocks rest directly upon the Snowbird formation. Thus, a sub-Unicoi unconformity is strongly suggested in two localities, and possible in two others.

If the presence of an unconformity between the Unicoi (or Cochran) and the Sandsuck formations can be proved beyond doubt in many localities, then this recorded break in sedimentation may come to be used as the boundary between the Cambrian System and the pre-Cambrian in the Southern Appalachians. There appears to be no other basis at present for separating unfossiliferous Cambrian rocks from relatively unmetamorphosed pre-Cambrian sedimentary rocks in the region (see p. 13). In anticipating the possible adoption of this practice, the writer believes that it may be well to examine briefly the precarious foundation on which it will rest.

¹⁰ Written communication, February 18, 1949.

The use of unconformities as time markers between rocks formed in different periods or eras is based upon the concept that diastrophism is the ultimate basis of subdivision and of correlation (Chamberlin, T. C.; 1909; Chamberlin, R. T., 1914). Essential to or implied in this concept are the following beliefs:

1. Diastrophism, i.e. orogenic pulses or epeirogenic movements resulting in eustatic changes of sea level, is world-wide and simultaneous in effect.
2. Periods of orogeny and marked epeirogeny are separated by long periods of quiescence.
3. Orogenic and epeirogenic movements are periodic and this periodicity is world-wide.
4. The effects of orogenic and epeirogenic movements on depositional and biologic environments make the stratigraphic and paleontologic records a function of diastrophism.

Assuming for the moment that the concept is valid, then one could argue that the unconformity beneath the Unicoi is the record of the world-wide revolution that brought the pre-Cambrian to a close; therefore, the rocks beneath the unconformity are of pre-Cambrian age and the rocks above are Paleozoic in age.

The use of diastrophism as the ultimate basis of subdivision is not pertinent to the present problem and will not be discussed further here.¹¹ However, the validity of diastrophism as the basis of correlation is relevant and an attempt is made to evaluate it in the light of some recently unpublished papers.

An examination of the geological literature has led Stille (1924, pp. 44-45) and Bucher (1933, pp. 414-416) to conclude that during geologic history, orogenic pulses have been abrupt, world-wide, simultaneous, and separated by long intervals of quiescence. If this conclusion is valid, orogenic movements may provide the most accurate means of correlation available. To test this idea, however, we must examine a portion of the geologic section that is well documented paleontologically and in which the ages of unconformities can be ascertained within adequate limits. Recent papers on the Laramie problem, i.e. the Cretaceous-Cenozoic boundary problem of North America, provide us with data which are admirable in this respect.

In central Utah, Spieker (1946, pp. 117, 150-156) recognizes three orogenic movements close in time to the Cretaceous-Cenozoic boundary. The first, indicated by exceptionally coarse conglomerates, occurred "between the Upper Jurassic and the Upper Cretaceous, probably early Colorado, here called the mid-Cretaceous movement"; the second, proved by a marked angular unconformity, occurred within Late Cretaceous time, between middle and late Montana times; the third, the pre-Flagstaff movement, is also indicated by an angular unconformity and may be early Eocene, but is more probably either middle or late Paleocene in age.¹²

In the Big Horn Basin, Wyoming, (Van Houten, 1944, p. 166) the Willwood formation overlies the Paleocene Polecat Bench formation and truncates folds along the western part of the basin. Inasmuch as the lower part of the Willwood contains fossils of late Paleocene age, the major orogenic pulse here clearly took place within Paleocene time.

In his report on the southern margin of the Absaroka Range, Wyoming, Love (1939, p. 104) states, "That the Laramide Revolution was not a movement affecting all the mountain ranges simultaneously has long been known. The beginning, the climax, and the end of the revolution must be arbitrarily chosen and may differ in time, even in localities only 100 miles apart." In support of this statement, Love (op. cit., pp. 103-106) summarizes the evidence from his own area and from other localities in the region; this evidence need not be repeated here.

Spieker (1946, pp. 144-145) concludes his evaluation of Stille's evidence for world-wide orogeny with the following statements:

It must be recognized . . . that most of the evidence on orogenic dates marshalled by Stille is inadequate to prove global episodicity; the ages of the limiting strata are generally too far apart. . .

It should also be noted that the times of at least two out of three strong orogenic disturbances recently determined in the western United States appear to have no counterpart in Stille's table. . . .

It seems that the hypothesis of orogenic simultaneity is not well enough established to be relied on either in correlation or the establishment of divisions in the scale. . . .

¹¹ This problem is discussed by Shepard (1923), Spieker (1946, pp. 142-156), and by Gilluly (1949).

¹² The ages presented here are based upon paleontological data which are also re-evaluated by Spieker (1946, pp. 146-149). Briefly, his conclusion is that although there is nothing in fossil occurrences that indicates contemporaneity beyond question, paleontological data still seem to afford the best means of correlation available.

With regard to the long periods of quiescence mentioned above, Spieker (op cit.) points out that the multiplicity of orogenic movements throughout the column, citing the complex structural development of California as an example (see Reed and Hollister, 1937, pp. 1597, 1691).

Thus, an examination of a fairly well documented, i.e. fossiliferous, portion of the geologic section indicates the following:

1. Many unconformities can be found near the paleontologically recognized Cretaceous-Cenozoic boundary in different areas, but few, if any, coincide exactly with the boundary in time, or with each other from one area to another.

2. The hypothesis of world-wide orogenic simultaneity is not documented well enough to support diastrophism as the ultimate basis of correlation.

Another view holds that epirogenic movements or the eustatic changes that they cause are a proper basis for correlation. Any attempt to utilize this view, however must begin by distinguishing epirogeny from orogeny on the basis of observable field evidence. Where an unconformity with minor discordance is present, for example, was this discordance produced by minor warping of orogenic or epirogenic origin? Where a break in deposition is apparent in non-fossiliferous rocks, was the break caused by local uplift associated with orogenic movements or by world-wide withdrawal of the sea? Until these and related questions can be answered satisfactorily, epirogeny forms as dubious a basis for correlation as orogeny.

Therefore, even though no other basis exists at present, it appears that use of an unconformity beneath the Unicoi as evidence for assigning the Sandsuck and Snowbird formations to the pre-Cambrian has little justification. From the evidence now available, the age of the lower clastic group is not known. If the unconformity is used as the boundary between pre-Cambrian and Cambrian sedimentary rocks, it should be recognized as an arbitrary one which is not necessarily correlative from one district to another.

SANDSUCK FORMATION

Name.—The Sandsuck formation was named by Keith (1895, p. 3) for the Sandsuck Branch of Walden Creek, Sevier County, Tennessee. In the type section, according to Keith, "There are no variations in the formation, and it consists of bluish-gray shale with lighter-gray bands when weathered the shales are dull-yellow in color." From recent studies of the type area, however, Ferguson¹³ concludes that the formation contains thick lenses of conglomerate.

In his report on the Asheville quadrangle, Keith (1904, p. 5) used the name "Hiwassee slate" for approximately the same rocks mapped as the Sandsuck formation in the present study. Keith named the unit for the first time in the Asheville folio, after a section cut by the Hiwassee River, Polk County, Tennessee. However, no detailed description of the Hiwassee formation in the type area has been published. The Hiwassee River flows through the Cleveland and Murphy quadrangles, but no publication on the geology of the Murphy quadrangle is available. In the Cleveland folio (Hayes, 1895, p. 2), the rocks beneath the Cochran conglomerate are mapped as the Sandsuck shale with an included conglomerate lentil.

In a correlation table on the last page of his Asheville report, Keith (1904) showed the Great Smoky conglomerate as being equivalent to the Cochran and the underlying Hiwassee slate as being equivalent to the Sandsuck. If these correlations are correct, then Hiwassee is clearly a synonym for the earlier defined Sandsuck and should be abandoned. On the other hand, if the base of the Great Smoky formation is considerably lower in the section than that of the Cochran (Keith, 1907, p. 11, cols. 2 and 3; Stose and Stose, 1947, p. 632), then Keith's usage of "Hiwassee" in the Hot Springs formation is inappropriate. The Sandsuck formation is clearly defined and described in the Knoxville folio (Keith, 1895, p. 3) as the shale underlying the Cochran conglomerate. Inasmuch as the Cochran is believed to correspond approximately to the Unicoi formation as used in the present report (see table 3), the term "Sandsuck" is used in the present report for the rocks between the Unicoi and Snowbird formations.

Limits.—In the Hot Springs window the top of the Sandsuck formation is placed beneath the lowermost Unicoi conglomerate beds which can be traced continuously along their strike (see p. 18). The base of the formation is more difficult to establish. Exposures are poor and the lowest Sandsuck rocks grade

¹³ Written communication, February 18, 1949.

lithologically into those near the top of the Snowbird formation. In the present field study, the lower limit of the Sandsuck formation was drawn immediately above the uppermost beds in which indurated feldspathic sandstone or quartzite predominates. Outside the window, the Sandsuck contacts were not traced along their strikes and only their approximate positions are indicated on Plate I.

Distribution.—Within the window, the Sandsuck formation is exposed in a narrow belt from East Fork Shut-in Creek eastward to Runion. West of Hot Springs Mountain, the belt is 2 to 3 times as wide as elsewhere because of decreased dips. North of the Window, the formation underlies the top and north flank of Brushy Mountain (see pl. I).

The Sandsuck formation is poorly exposed throughout the area. Only on the southeast flank of Hot Springs Mountain, along Mountain Island Branch, are outcrops relatively continuous. Elsewhere, exposures are scattered and it is difficult for the observer to piece the section together. Within the window, the upper part of the formation is better exposed in more localities than the middle or lower.

Character.—In the Hot Springs area, the Sandsuck formation consists predominantly of dark green to black silty and argillaceous shale and slate. The formation also includes coarsely conglomeratic lentils near the top, and light gray to blue-gray calcareous sandstone and sandy limestone, as well as thin-bedded light gray quartzite, in the lower half of the unit.

The shale and slate are argillaceous in the upper part of the Sandsuck (see pl. V, fig. 4). The silt and sand fraction is greater in the middle of the formation and increases downward in the section until it forms discrete lenses and beds, similar to those in the well laminated shaly siltstones of the Erwin and Hampton formations. Angular quartz and potash feldspar grains make up most of the silt and sand fraction.

The Sandsuck formation of the Hot Springs area is not unique in containing conglomeratic lenses. They have been described in Tennessee by Ferguson and Jewell (unpublished) and by Lowry (unpublished), and Ferguson¹⁴ has mapped them in the Chilhowee Mountain area at and near the type section. Pebbles in the conglomerate range up to 2½ inches in length and form 60 to 70 per cent of the rock in the Hot Springs area. Well rounded white to blue-gray quartz and quartzite pebbles predominate. Numerous angular to subangular feldspar fragments, a few granite and jasper pebbles, and many slate chips and inclusions are also present.

A thin section (0-48-307) of such a rock, from outcrops southeast of the third bridge up N. C. Highway 209, was studied in the laboratory. Quartz pebbles show wavy extinction and one contains an epidotized plagioclase crystal. Microcline, predominant among the coarse feldspar fragments, contains subrounded quartz inclusions and quartz- and chlorite-filled fractures. The quartz inclusions resemble the barrel-shaped dihexahedra found in microcline of the "Max Patch granite" (see p. 32). The sandy and silty matrix is of graywacke composition. Quartz, potash feldspar, and sodic plagioclase comprise about half the matrix. The remainder is made up of detrital muscovite and biotite, slate chips, ore minerals, epidote, tourmaline, and zircon. The rock has been sericitized and an unidentified brown stain is present throughout the matrix.

The Sandsuck conglomerate is distinguished lithologically from the conglomerate beds in the Unicoi by the proportion of pebbles. Coarse fragments make up about 65 per cent of the Sandsuck rock and only about 40 per cent in the coarsest Unicoi conglomerate. This observation must be considered a tentative one, however, inasmuch as it is based on a limited study of poorly exposed bedrock.

Noteworthy are the calcareous sandstone and sandy limestone found in the lower part of the Sandsuck formation. These form a gradational series lithologically similar to the calcareous and dolomitic rocks in the upper part of the Snowbird formation. In the Sandsuck formation the calcareous beds appear to be lenticular. On fresh surfaces the rocks are light gray to dark blue-gray and vitreous to subvitreous so that they resemble quartzite.

A light gray fine-grained calcareous sandstone sample was collected about 1000 feet up Raccoon Branch from Spring Creek. Petrographic study of a thin section (0-48-352A) showed the rock composition to be about 50 per cent quartz, 25 per cent carbonate, and 20 per cent feldspar, with microcline predominating although micropertthite and albite are present. The remaining 5 per cent is composed of detrital colorless mica, quartzite fragments, zircon, tourmaline, black metallic minerals, sericite, and pyrite. Except for moderately developed strain shadows in the quartz, the rock shows no evidence of cataclasis. The texture is

¹⁴ Written communication, February 18, 1949.

elastic, with fine-grained sand and silt particles, averaging $\frac{1}{4}$ mm. in size, dispersed through the carbonate cement. Most detrital grains are angular to subangular, and many are enveloped by a fine film of sericite. The amount of carbonate cement, which the acid test showed to be calcite, ranges from 10 to 50 per cent in one thin section, but averages about 25 per cent. The pyrite is secondary, strongly euhedral, and occurs in aggregates which form megascopically visible streaks in the rock.

Calcareous and dolomitic lenses have also been found in the Sandsuck formation in the Del Rio district (Ferguson and Jewell, unpublished), in the Clevelandquadrangle (Hayes, 1895, p. 2), and in the southwest end of the Mountain City window (Lowry, unpublished), all in Tennessee.

Weathering.—The Sandsuck shale and slate are green, brown, yellow, and yellowish gray on weathered surfaces and break down to form small chips in the soil. The conglomerate disaggregates, leaving pebbles, sand, and slate chips. The cement in the calcareous sandstone and sandy limestone is leached out by chemical weathering, leaving a loosely coherent or incoherent sand.

Sandwiched in between the resistant quartzites and arkoses of the Unicoi and Snowbird formations, the Sandsuck rocks are relatively vulnerable to weathering. Almost throughout its extent, the Sandsuck belt localizes gullies, streams, and segments of larger drainage features (see pl. I). The formation's susceptibility to weathering results in relatively few, poor exposures and makes it difficult to map.

SNOWBIRD FORMATION

Name.—The Snowbird formation was named by Keith (1904, p. 5) for Snowbird Mountain which is southwest of Hot Springs and lies in the Mt. Guyot quadrangle, on the boundary between Haywood County, North Carolina, and Cocke County, Tennessee. The Mt. Guyot quadrangle was mapped by Keith¹⁵ but neither the map nor a geologic report on the area has ever been published. Keith (op cit.) described the Snowbird as the oldest sedimentary rock in the region, resting "in its normal position on Archean rocks" and composed mainly of quartzite with interbedded conglomerate and arkose.

Use of the term "Snowbird" in the present report may be subject to some criticism. Because the formation includes diverse rock types and underlies a greater area (and presumably is thicker) than any of the other formations, it would seem desirable in detailed geologic work to divide the unit into several formations or members. However, during the limited time afforded their study in the field, the writer was unable to subdivide the Snowbird rocks in the Hot Springs area into distinct mappable units.

In their report on the Hot Springs area, Stose and Stose (1947) abandon the use of the term "Snowbird". For the sedimentary rocks below the Sandsuck formation within the window, they (op. cit., p. 627) ". . . propose the new name Vann quartzite from exposures at Van Cliff on Spring Creek, because the beds that lie beneath the Sandsuck shale in the Hot Springs area are not present or were not recognized in the type section in Chilhowee Mountain". They further state (op. cit. and Stose and Stose, 1944, pp. 379-380) that inasmuch as the name Snowbird was applied in its type locality to rocks of the pre-Cambrian Ocoee series, it should not be used for the rocks beneath the Sandsuck within the window because they are of Cambrian age and belong to the Chilhowee group.

Stose and Stose (1947, pp. 632-634) divide the sedimentary rocks outside the window into the Great Smoky quartzite and the Hurricane graywacke. The latter is defined by them (1949, p. 271) as follows:

The new name Hurricane graywacke is here applied to the lowest formation of the Ocoee series because of its fine exposures on Little Hurricane Creek and at the Hurricane settlement, N. C. (Fig. 5), 6 miles northeast of Hot Springs, N. C. The initial sediments of the graywacke in this vicinity and northeastward rest on granite gneiss of the injection complex. . . .

Overlying the Hurricane, according to Stose and Stose, are quartzites which they correlate with the Great Smoky formation, though Keith mapped them as Snowbird in the Hot Springs area and at the Hurricane locality. The Great Smoky conglomerate was originally defined by Keith (1904, p. 6) in the Asheville folio and named for outcrops in the Great Smoky Mountains, southwest of Pigeon River. Keith (op. cit. and 1907, p. 3) believed that "The formation corresponds in position and general character to the Cochran conglomerate . . .". Stose and Stose retain the name for the rocks for which it was named but extend it to

¹⁵ The map is in the files of the U. S. Geological Survey, Washington, D. C.

include much of what Keith called Snowbird. Stose and Stose place the Great Smoky formation in the pre-Cambrian Ocoee Series, far beneath the Cochran.

While the writer agrees (see p. 25) that continued use of the term "Snowbird" may be undesirable, he has not adopted the formation names used by Stose and Stose for the following reasons:

1. The writer knows of no evidence supporting the view that all the clastic rocks within the window are Early Cambrian in age whereas those outside the window are all pre-Cambrian. Indeed, the weight of evidence opposes this view:

a. The uncoi formation underlies area within and outside the Hot Springs Window (see pl. I and p. 20.

b. Both within and outside the window, the Unicoi is underlain by the Sandsuck formation, which, in turn, is underlain by the rocks called Snowbird in the present report.

c. The rocks named Vann by Stose and Stose do not differ lithologically from those which they call Great Smoky. They do differ in appearance, however, because at the type locality of the Vann and along N. C. Highway 209 the rocks are mostly within the zone of weathering.

Thus, stratigraphic sequence and lithologic similarity suggest that the rocks outside the window do not differ from the sedimentary rocks beneath the Sandsuck within the window.

The clastic section as given in the Stose and Stose report (1947) may be summarized as follows:

Lower Cambrian

Chilhowee group

Hesse quartzite

Murray shale

Nebo quartzite

Cochran quartzite

(includes Nichols shale and quartzite lentil of Keith)

Sandsuck shale

Vann quartzite.....[Snowbird of Keith and of this report]

Upper pre-Cambrian

Ocoee series

Valleytown formation.....[Not present in Hot Springs area]

Big Butt quartzite.....[Not present in Hot Springs area]

Nantahala slate.....[Not present in Hot Springs area]

Great Smoky quartzite.....[Snowbird of Keith (in Hot Springs area and near Hurricane) and of this report]

Hurricane graywacke.....[Snowbird of Keith and of this report]

The same section is given by them in a later paper as well (Stose and Stose, 1949, pp. 271-273, 298-302).

2. Calling the quartzites outside the window in the Great Smoky formation involves correlation over long distance with rocks that are not known well at present even in the type area. However, a geological study of the Great Smoky National Park is in progress now by the U. S. Geological Survey, under the direction of Philip B. King. The knowledge gained there probably will provide a much firmer foundation for correlations in the future.

3. The geology of the type area of the "Hurricane graywacke" is not known well enough to establish the position of "Hurricane" rocks relative to the Snowbird of Keith. In the Asheville folio, Keith (1904) maps the contact between the Snowbird formation and the Max Patch granite, along Big Laurel Creek and between the mouths of Big and Little Hurricane Creeks, as a thrust fault dipping gently to the east. On the other hand, Stose and Stose (1947), pp. 632-633; 1949, p. 271) state that "The initial sediments of the graywacke in the vicinity . . . rest on granite gneiss . . ." and are overlain by the quartzites. The implication here, then, is that at and near the mouth of Little Hurricane Creek the contact is an unconformity with the tops of the overlying sedimentary beds toward the south and southwest (see Stose and Stose, 1949,

fig. 5, p. 304). The present writer visited the locality several times during the 1948 field season and found that the sedimentary rocks there strike about east to east-southeast and dip 70 to 80 degrees to the north. Crossbedding, small scale channeling, and graded bedding all indicate the beds are right side up, i.e. the tops of the beds at the mouth of Little Hurricane Creek are to the north, and not towards the south. Although the writer did no detailed field mapping in this locality, he interprets the contact between the granitic and the sedimentary rocks as a thrust fault, in agreement with Keith. Supporting this view is a zone of sheared and slightly mylonitized rocks at and near the contact. Regardless of the nature of the contact, however, the fact that the tops of the sedimentary beds are to the north indicates that the "Hurricane formation" overlies, not underlies, the quartzites which Stose and Stose correlate with the Great Smoky formation. In the present writer's opinion, the uncertain structural and stratigraphic relations of the "Hurricane graywacke" at its type locality makes use of that name undesirable and use of "Snowbird" preferable at present.

Limits.—The top of the formation is placed above the first indurated feldspathic sandstone or quartzite beneath the Sandsuck slate and shale. The base of the Snowbird formation, according to Keith (1904, p. 5) is immediately above the granitic rocks. Whether the base of the Snowbird is exposed in the Hot Springs area depends upon the nature of the Dry Pond Ridge contact (see p. 39). If the contact is a nonconformity, then the base of the Snowbird lies immediately above it and the formation ranges in thickness from 1400 feet, near Windy Gap west of Piney Mountain, to at least 4200 feet, along the east fork of Mountain Island Branch. On the other hand, if the contact is a thrust fault, then the base of the Snowbird formation is nowhere present in the Hot Springs area, except perhaps on the Brushy Mountain thrust plate near the Tennessee state line, and the formation may be considerably thicker. In all other parts of the area, the base of the Snowbird is either cut out or concealed by thrust faults.

Distribution.—The Snowbird is the most widely distributed formation in the area mapped. It underlies most of the southern half of the Hot Springs window and surrounds the eastern half of the window. The Snowbird formation is also present in the western part of that portion of the Brushy Mountain thrust plate shown in plate I.

Good exposures of the formation may be found in many places. Especially noteworthy are the rocks exposed in the gorge of Spring Creek and in roads cut along N. C. Highway 209. The rocks along the highway, however, are in the weathered zone in many places and their appearance is not similar to that on fresh surfaces. Fairly continuous sections are exposed in gullies and streams on the west flank of Spring Creek Mountain, in the east fork of Mountain Island Branch, in road cuts east of Hot Springs on U. S. Highway 25-70, in the gorge of Big Laurel Creek, and in road cuts along the Walnut Gap-Stackhouse and Bearwallow Gap-Doe Branch roads.

Character.—In the Hot Springs area the Snowbird formation is made up of feldspathic sandstone, arkose, micaceous sandstone, siltstone, shale, slate, sandy limestone and calcareous sandstone. Intense shearing at or near thrust faults has converted some of the rocks to mylonite and phyllonite.

The calcareous sandstone is restricted to the upper part of the formation. The rock is uniformly coarse-to medium-grained, light to dark vitreous gray on fresh surfaces, occurs in beds from a few inches to two feet thick. The carbonate is predominantly calcite although dolomite may be present as well. In some places it makes up over 50 per cent of the rock so that the rock is a sandy limestone. Pyritiferous nodules, though present in other parts of the formation, are particularly common in these upper calcareous beds and are well displayed along N. C. Highway 209.

The upper part of the Snowbird formation also includes feldspathic quartzite and interbedded silty shale and shaly siltstone. Thin black argillaceous laminae alternate with light gray sandy and silty layers to give the siltstone and shale a banded appearance. The lighter colored silty laminae also occurs as lenticles and fill local small-scale channels up to 1 inch wide and $\frac{1}{4}$ inch thick. Well displayed slaty cleavage cuts across the bedding, dipping to the east and southeast at most places. At a few localities, however, the cleavage is absent, and at others it parallels the bedding. A specimen of well laminated siltstone, collected along East Fork Shut-in Creek, about 3000 feet northwest of Garenflo Gap, was studied petrographically (0-48-391). The lighter silty laminae are composed of about 60 per cent quartz, 20 per cent feldspar (mostly microcline, but sodic plagioclase and micropertite are present), and 20 per cent matrix which consists largely of sericite but includes small grains of slightly chloritized biotite, detrital muscovite, opaque iron

oxide, zircon, and apatite. The black argillaceous layers consist of about 70 per cent matrix, 25 per cent quartz, and 5 per cent feldspar. The sericite platelets trend in every direction but there is a perceptible preferred orientation parallel to the rock's cleavage, which forms a 55° angle with the bedding. Minor slip along the cleavage planes has resulted in microscopic faults with the relative displacement not everywhere in the same direction (see pl. VI, fig. 1).

In some places, especially near thrust faults, argillaceous beds of the formation have been altered to sericite phyllite (see pl. VI, figs. 5, 6).

The excessive apparent thickness of the well laminated siltstone and shale in the southwestern part of the window around Garenflo Gap raises a problem. Elsewhere in the Hot Springs window, these rocks form only about a third to a half of the upper 700 feet or so of the formation. In the section exposed along the upper part of East Fork Shut-in Creek and southeastward to Turkey Cove, however, these rock types predominate almost to the exclusion of others. Beds strike about N 60° E fairly consistently, except for those on the southwest flank of Lamb Knob and those near the Brushy Mountain thrust fault (see pl. I). North of Garenflo Gap the beds dip mostly 55° to 70° NW, but 15° and 20° dips are not uncommon. Southeast of Garenflo Gap the dips are mostly 55° to 65° SE. Trends obtained elsewhere show that the crest of an anticline is exposed from Garenflo Gap northeastward to Spring Creek. From these data, three explanations are possible for the apparently thick sequence of laminated rocks here:

1. Drag folding between the thrust fault and the competent beds of the lower Unicoi has crinkled the Sandsuck and upper Snowbird rocks so that they are repeated on the crest of the anticline, thereby concealing the underlying quartzitic sandstones and arkoses.
2. There is a facies change in the Snowbird, with a decrease southwestward in grain size and feldspar content and an increase in the mica content.
3. The writer did not recognize that these well laminated rocks form part of a separate fault block or slice beneath the Brushy Mountain thrust fault.

Although the second and third possibilities are not excluded by available data, the writer has used the first interpretation in the remainder of this report (see pl. II, section C-C).

The feldspathic quartzite in the upper part of the formation is dark gray to black, although some lighter gray beds are present, and medium- to coarse-grained with some sparsely distributed pebbly zones. One such rock, collected 2000 feet north of Stony Spur Cliff on N. C. Highway 209, was studied petrographically (0-48-159). The specimen is poorly sorted with grains up to 3 mm. but averaging ½ mm. in diameter. The rock consists of about 75 per cent quartz, 20 per cent feldspar, 2 per cent detrital colorless mica, quartzite, saussurite, and zircon, and 3 per cent of matrix, which consists of sericite and opaque minerals. The quartz shows strain shadows and Böhm lamellae, but is not granulated. The feldspar is predominantly microcline with many round inclusions of quartz, but includes micropertite, in which albite is partially replaced by sericite, and sodic plagioclase. The fabric is that of a poorly sorted clastic rock and sericite plates have grown perpendicular to grain surfaces (see pl. VI, fig. 2).

In the middle and lower portions of the Snowbird section exposed in the Hot Springs area, arkose and feldspathic quartzite and sandstone make up 75 to 85 per cent of the rocks. Interbedded with these are silty shale and sandy siltstone. Fresh outcrops of these rocks are best exposed along Camp Branch, in the gullies on the western flank of Spring Creek Mountain, along the east fork of Mountain Island Branch, and in the stream beds north and northeast of Lovers Leap Ridge. The arkose and feldspathic quartzite are mostly light gray to pink, medium- to coarse-grained and thick-bedded to massive. The rocks are poorly size-sorted and angular to subangular fragments predominate. Coarse fragments are present in many beds and some places attain such size and concentration that the rocks are breccias. It is difficult to distinguish these rocks from those in the upper part of the Unicoi except perhaps for the relative abundance of pink feldspar fragments in the Snowbird formation, whereas those in the Unicoi are predominantly, but not exclusively, white. This criterion is a sound one in the Hot Springs area only if used with discretion. In the more massive beds it is difficult to discern bedding trends except locally where dark gray bands are present in the rock. Where these bands are absent, joints may be mistaken for bedding surfaces.

Mylonites.¹⁶—Mylonitized Snowbird rocks are present near thrust faults in many localities. Superficially, almost all resemble vitreous quartzite in appearance but differ in the well developed shear planes which manifest themselves in large outcrops, hand specimens and thin sections. On closer megascopic examination, strung-out bands of quartz and feldspar are evident, as well as augen. The augen are formed by relict feldspar grains which are almost enveloped by long lenses of quartz.

The effects of cataclasis are far more striking when studied microscopically. Examined in the present study were thin sections cut from rocks collected 1200 feet up Raccoon Branch, west of Piney Mountain (0-48-506), at the head of the east fork of Coonpatch Branch (0-48-563), 2800 feet north-northeast of Anderson Cemetery on Spring Creek Mountain (0-48-1148), 3800 feet due south of Mill Ridge Church (0-48-973), and in a road cut near bench mark P 58, southwest of Tanyard Gap, on U. S. Highway 25-70 (0-48-BMP 58).

Specimen 0-48-506 is not, properly speaking, a mylonite, but it is included in this discussion because it shows the initial stages of mylonitization more clearly than the other rocks. Megascopically, the rock consists of white feldspar and quartz fragments up to 5 mm. long set in a very fine-grained black matrix. Petrographic study shows that the rock is composed of about 65 per cent quartz, 10 per cent microcline and sodic plagioclase, 5 per cent detrital biotite, opaque minerals, zircon, quartzite, and carbonate (which fills fractures in quartz and feldspar). The remaining 20 per cent consists of a fine-grained matrix of sericite, deformed biotite, chlorite, and minute particles of quartz and feldspar. Noteworthy is the presence of both clastic and cataclastic fabrics and the absence of a fluxion structure (see pl. VI, fig. 3). Although all quartz fragments show well developed strain shadows and some Böhm lamellae, many are not broken. Incipient mylonitization is reflected here by microbrecciation of corners and ends of quartz grains and the attenuation of trails of comminuted quartz. Some small quartz patches in the thin section are completely granulated. Feldspar is comparatively unaffected except for some few irregular fractures. Some of the biotite fragments are bent and show wavy extinction, but others have been completely shredded. Sericite and chlorite are not smeared out or shredded, thereby suggesting that they are post-deformational in age. From this thin section it appears that quartz is the first mineral to be pulverized whereas mica (biotite here) is shredded at about the same time or shortly thereafter. Feldspar appears most resistant to microbrecciation.

The other thin sections enumerated above are sufficiently alike to be described collectively, rather than individually. All contain about 60 to 70 per cent quartz and 25 to 30 per cent of feldspar which consists mostly of microcline containing round inclusions of quartz, but includes some micropertthite and albite. The remaining few per cent is made up largely of sericite and epidote and minor quantities of accessory minerals, each of which is present in some but not all of the rocks. These include apatite, zircon, monazite, tourmaline, magnetite (surrounded by bands of microcrystalline sphene in some rocks), pyrite, and chlorite. Biotite is present in minor amounts in only some of the rocks. Thus, the mineral composition suggests that these rocks formed by the microbrecciation of arkose.

By far the most striking microscopic features of these rocks are the degree of cataclasis and the well developed fluxion structure (see pl. VI, fig. 4; pl. VII, fig. 1). No detrital mineral has been spared. Quartz is almost completely granulated and strung out in attenuated lenticles which parallel the fluxion structure and curve around feldspar relicts. The crystal lattices of the microbrecciated components of these lenticles are oriented parallel to one another so that all the grains extinguish at about the same time. Indeed, rotation of the stage, with nicols crossed, shows that even these lenticles, as well as quartz relicts, show marked strain shadows. Biotite and muscovite, where present, are almost completely shredded. The only remnants of quartz and biotite to survive are those which are completely encompassed by feldspar as inclusions and some of those on the "lee" side of feldspar porphyroclasts. Some quartz inclusions were so well protected from shearing stresses by the enveloping feldspar that they do not even show strain shadows. Feldspar grains form the only large porphyroclasts remaining in the rock but even these are broken on corners and ends. Some are split approximately in half and granulated quartz fills the space between the fragments. Nevertheless, many feldspar grains have been comminuted and some porphyroclasts are granulated in part. Although most sericite plates parallel the streaks of other minerals, at least a few are randomly oriented;

¹⁶ Mylonite is defined as a strongly coherent, fine-grained, conspicuously laminated rock formed by extreme microbrecciation and milling of rocks during movement on fault surfaces, with little or no growth of new minerals (see Turner, 1948, p. 201; Waters and Campbell, 1935, pp. 474-476, 478).

most do not show the effects of shearing strain, suggesting that they are post-deformational (perhaps partly para-deformational) in age. The fluxion structure is produced by the parallelism of granulated quartz lenses, long trains of comminuted biotite, epidote, and accessory minerals, and by the growth of sericite in fractures paralleling these bands.

Phyllonite,¹⁷ formed by the cataclasis of rocks in the Snowbird formation, is present in at least three localities in the Hot Springs area. The rock was found just above the mouth of King Creek on the Walnut Gap-Stackhouse road, 2000 feet east of the French Broad River on U. S. Highway 25-70, and in the gullies of the second and third forks of Trent Branch. At all three localities the rock is yellowish green and has a silky luster. On a megascopic scale, polished sections and thin sections cut normal to the excellently developed cleavage show that alternating light and dark bands in the rock have been intricately and isoclinally folded so that the limbs and axial planes of the folds parallel the cleavage. This remarkable phenomenon, named *Umfaltungscleavage* (see Knopf, 1931, pp. 15-18), is well developed in the phyllonite here described. The origin of the light and dark bands is difficult to establish because of the degree of deformation. They were probably formed either by the sedimentary deposition of alternating laminae of dark and light minerals (similar to the banded shaly siltstone and sandstone found elsewhere in the area), or by the mylonitization of an unbanded rock with consequent development of elongated lenticles (see above), during an early stage in the deformation.

Microscopically, the effects of shearing are even more apparent. Study of a thin section (0-48-496) from a rock collected on the Stackhouse road showed that all the constituents of the rock are ground down to microscopic and submicroscopic size; the largest grains present now are 0.1 mm. in diameter. The writer was unable to make quantitative estimates of the mineral composition but did recognize the presence of quartz, feldspar (s?) with low refractive indices, sericite, and very small quantities of black accessory minerals. About half of the rock is composed of a platy pleochroic ($X = Y =$ golden yellow; $Z =$ deep brown) biaxially negative mineral with an optic angle of 0° to 5° and refractive indices (Y and Z) of about 1.65. Because of the pulverized nature of the rock and the difficulties encountered in trying to separate the mineral from others, the writer is unable to say whether it is biotite or stilpnomelane; nor did he find it possible to date the age of the mineral as para- or post-deformation. Although this mineral is distributed through the rock in streaks paralleling the isoclinally folded bands described above, the orientation of the mineral flakes parallels that of the cleavage. Some flakes, however, are randomly oriented and some are bent parallel to the folds. The suggestion is that the mineral's growth may have overlapped the latest phases of deformation. If this pleochroic mineral is biotite, it is also possible that its distribution can be accounted for in part by the comminution, reorientation, and perhaps even recrystallization, of some detrital biotite. Inasmuch as no other rock was found in the Hot Springs area with such a large proportion of dark minerals, it seems likely that most of the biotite or stilpnomelane has been introduced into the rock.

Weathering.—The lithologic character of individual beds in the Snowbird formation determines the manner in which they are affected by weathering. The mylonite in the Hot Springs area is a very resistant rock and, like the quartzite and arkose in the Snowbird formation, forms ledges and small cliffs. Feldspar grains and mica plates in all but the most quartzitic rocks are altered to clayey minerals, whereupon the rocks lose their vitreous appearance, become lithoidal and appear porous. Such alteration is present in the excellent exposures along N. C. Highway 209. Leaching of the carbonate in calcareous sandstone and sandy limestone leaves a loosely coherent, porous sand. Phyllonite, shaly siltstone, shale, and slate break down rapidly and in a manner similar to the argillaceous units in higher formations.

Some of the most rugged topographic features in the Hot Springs area are underlain by the Snowbird formation. Stony Spur, Long Mountain, the crest of Spring Creek Mountain, Mill Ridge, Divide Mountain, and Slaty Knob are all underlain by quartzitic or mylonitized arkose and feldspathic sandstone. Slaty Knob is a misnomer which can probably be attributed to the excellently developed shear planes in the mylonite present there.

¹⁷ A phyllonite, or phyllite-mylonite, is an intensely deformed rock which is, as a rule, indistinguishable from a phyllite. Unlike normal phyllites, however, it is formed by the mylonitic degradation of originally coarser rocks, rather than by the crystallization of new minerals. Phyllonitization does not necessarily mean retrogressive metamorphism, although many phyllonites are also diaphoritic (Knopf, 1931, pp. 14-21; Turner, 1948, pp. 215-217).

PRE-CAMBRIAN CRYSTALLINE COMPLEX

Name.—The pre-Cambrian crystalline complex, as used in this report, includes the rocks which Keith (1904) mapped as Max Patch granite and Cranberry granite in the Hot Springs area.

The Max Patch granite was defined by Keith (1904, p. 4) in the Asheville folio and named for Max Patch Mountain, Madison County, North Carolina, about 10 miles southwest of Hot Springs. Keith described the rock as a coarse granite, in places porphyritic, composed of orthoclase, plagioclase, quartz, biotite, and a little muscovite, with accessory magnetite, pyrite, and secondary epidote. The porphyritic varieties are dull whitish, according to Keith, and the massive varieties are spotted by large biotite crystals. Another variety is a coarse granite containing red feldspar and waxy green epidotized and saussuritized feldspar.

The Cranberry granite was defined by Keith (1903, p. 3) and named for the town of Cranberry, Mitchell County, North Carolina. In the type area, the formation includes granite of varying texture and color, schists and granitoid gneisses derived from the granite, and minor quantities of schistose basalt, diorite, hornblende schist, and pegmatite. In the Asheville folio, Keith (1904, pp. 3-4) described the granite as an igneous rock composed of quartz, orthoclase, plagioclase, biotite, muscovite, and in places, hornblende. Accessory minerals are magnetite, pyrite, ilmenite, garnet, and epidote. According to Keith, the two main varieties are a fine- even-grained rock and a light gray to white porphyritic granite. Keith states that the Max Patch granite is intrusive into, and therefore younger than, the Cranberry granite. Both formations have undergone deformation and metamorphism; all degrees are represented, according to Keith, from unaffected rocks to those completely altered to siliceous and micaceous gneisses and schists.

Stose and Stose (1947, pp. 626-629) refer to the same rocks as "granite gneiss of the injection complex of early pre-Cambrian age". In their earlier report on the pre-Cambrian rocks of western Virginia (Jonas and Stose, 1939, pp. 580-582), they state that the injection complex of that region

. . . comprises metamorphosed sedimentary rocks, intrusive diorite, granite, and mixed gneisses and migmatites formed by the injection and interaction of the granite on the older rocks.

The granitoid rocks in the Hot Springs area form a complex assemblage which, in the writer's opinion, require more study to be properly understood than has yet been afforded them. A detailed study of the granitoid rocks was not made by the present writer because they are not directly related to the structural problems or to the mineral resources of the area. However, in the course of the present investigation, some field and microscopic observations were made which showed that the rocks involved are considerably metamorphosed. No granite, in the restricted sense of the word, was found, nor could the writer ascertain, either from the literature (see above) or in the field, the lithologic distinction made by Keith between the "Max Patch granite" and the "Cranberry granite". On the other hand, the character, relations, and origin of the rocks involved are too obscure to permit one to say that the complex was formed by the injection into, and the interaction of granite on, older rocks. If the term "injection complex" is to retain any significance at all, the writer believes that it should be applied to rocks in which one (or some) is (are) known to have been injected into others. This is difficult to establish in the Hot Springs area.

For all of these reasons, the writer proposes to include all the rocks described in this portion of the report in the pre-Cambrian crystalline complex. Admittedly, this designation leaves much to be desired. The word "crystalline" is not used to imply that all the overlying sedimentary rocks are made up of non-crystalline particles, but rather to suggest that most of the unmylonitized rocks in the complex are coarsely crystalline. In choosing this non-committal formation name, the writer wishes to suggest also that the rocks do form a "complex" which is not understood.

Limits.—The pre-Cambrian crystalline complex includes all the rocks in the Hot Springs area which are not relatively unmetamorphosed sedimentary rocks. The relation of the formation to the sedimentary rocks in the section in the Hot Springs area is discussed below on page 34.

Distribution.—The crystalline complex underlies, and extends for an undetermined distance beyond, the southwestern, southern, southeastern, and eastern margins of the area covered in this investigation. The rocks are also exposed within the window from the eastern flank of Spring Creek Mountain to the Stackhouse barite mines, and from Dry Pond Ridge to just southeast of Doe Branch (see pl. I). Although well exposed in many places, continuous outcrops are rare except in road cuts along N. C. Highway 209, the Southern Railroad, and U. S. Highway 25-70 from Walnut to north of Walnut Gap.

Character.—The rocks included in the crystalline complex are so diverse in character that the descriptions which follow are presented as illustrative samples, rather than as the results of an exhaustive study of representative rocks. An attempt has been made not so much to establish the origin or to trace the metamorphic stages of the rocks involved, as to determine the approximate mineralogical and textural characteristics of the rocks, where relatively little deformed, as a clue to the origin of the mylonites in the Hot Springs area, i.e. to determine what the lithology of the mylonites may have been before microbrecciation.

One of the most distinctive rocks found in the complex is mottled pink, waxy green and black. Keith (1904, p. 4; see above) described this granitoid rock as a somewhat epidotized and saussuritized phase of the Max Patch granite. This rock is especially prevalent in road cuts along Charley Branch and upper Shut-in Creek, but occurs in many other localities within the area mapped. Two specimens (0-48-MPCB and 0-48-MPL), collected from a road cut along Charley Branch, one mile west of Bluff, were studied petrographically. Megascopically, the rock is coarse-grained (up to 2 cm., but averaging 1 cm.) and consists of pink feldspar, a light waxy green substance (saussurite) and black biotite (see pl. VIII, fig. 2). With the aid of a microscope, the mineral composition of specimen 0-48-MPCB was determined as 36 per cent saussurite, 25 per cent microcline, 25 per cent quartz, 8 per cent biotite, with the remaining 6 per cent made up predominantly of fracture-filling epidote and calcite, with chlorite, ore minerals, apatite, zircon, fluorite, and hornblende. Specimen 0-48-MPL contains about 37 per cent micropertthite, 30 per cent quartz, 30 per cent saussurite, 2 per cent chlorite, and 1 per cent accessories and carbonate. The quartz in both rocks shows marked strain shadows and is somewhat granulated, except for the subrounded dihexahedral quartz inclusions in the potash feldspar. In the first rock specimen, myrmekite is present and is altered to such an extent that it now consists of vermicular quartz between sericite and epidote masses (see pl. VIII, fig. 1); in addition, a few microcline grains have albitic rims (see pl. VII, fig. 5). The fabric in each rock is not hypidiomorphic equigranular but rather crystalloblastic and incipiently cataclastic. Biotite, in a few places, is pseudomorphous after subhedral hornblende; most other flakes developed in random orientation as a product of either metamorphism or hydrothermal alteration. At least some of the quartz in the rock is secondary, but it is difficult to estimate how much.

These rocks are probably more granitic in character and composition than any others found in the Hot Springs area, and yet it is difficult to name them precisely or to establish their original composition. The saussuritized nature of the plagioclase prevents one from determining its composition, whereas the percentage of the quartz has been increased since the rock originally formed, and at least part, possibly most, of the biotite is secondary.

Perhaps the most comprehensive petrographic reports published to date on the epidote-bearing "Max Patch granite" are those by Watson (1904, pp. 394-398; 1906, pp. 171-174; 1910, pp. 156-159). It was Watson's belief that the epidote in the rock formed by the interaction of biotite and feldspar and when this process was carried to an extreme, unakite,¹⁸ a rock with neither plagioclase nor ferromagnesian minerals, formed. Watson concluded that the unakite has a "distinct vein character which can be referred very likely to the segregation type". In her study of unakite in Virginia, however, Jonas (1935, p. 51) concluded that the rock formed through hydrothermal alteration. This conclusion is probably applicable to the epidote and sericite in the altered "Max Patch granite".

Another rock type, found 3000 feet south of Balm Grove Church on N. C. Highway 209 (0-48-282), on Leadmine Ridge and along upper Rocky Branch, and in the stream 2000 feet east of Sandy Bottom, resembles pink leucocratic granite or arkose, megascopically. Although the rock differs in coarseness from place to place, the average grain size is about 2 mm. Microscopic study of thin section 0-48-282 showed that the rock consists of about 45 per cent quartz, 30 per cent slightly sericitized microcline and about 25 per cent epidotized and sericitized sodic plagioclase, with a minor amount of zircon. Noteworthy in this rock is the absence of ferromagnesian minerals; where mylonitized, this rock is extremely difficult to distinguish from mylonitized arkose. The fabric is completely xenomorphic, with a suggestion of poikilitic inclusions. All the quartz, except for inclusions, shows marked strain shadows (see pl. VII, fig. 2), but only a minor proportion of it is sutured or granulated.

¹⁸ Unakite is a rock composed entirely, or almost entirely, of epidote, potash feldspar and quartz. The term was first proposed by Bradley in 1874 (pp. 519-520; his description is reproduced in full by Watson, 1904, p. 395) and named for the Unaka Range in North Carolina and Tennessee. The rocks for which he proposed the name came from Max Patch, Bluff, and Walnut Mountains, all within a few miles of the area mapped in the present investigation.

Another coarse-grained rock, found 1500 feet north of Doe Branch school (0-48-542), is mottled white and dark greenish gray. It is composed of about 45 per cent quartz, 35 per cent albite, and 18 per cent microcline; the remainder is made up of somewhat chloritized biotite, sericite, epidote, and magnetite surrounded by microcrystalline sphene. Mineral outlines are irregular and xenomorphic. A moderate amount of cataclasis is evident from the somewhat granulated quartz and, in places, fractured feldspar.

A porphyritic rock, collected at the second house northeast of Rector Butt, on Rector Branch (0-48-529A), is an unusual one. It is mottled dark green and white, and has an average grain size of about 3 mm., although some phenocrysts are as long as 2 cm. The rock is composed of about 55 per cent calcic andesine (An_{45} to 50), 20 per cent quartz, and 5 per cent microcline, and the remaining 15 per cent consists largely of secondary sericite, epidote, and biotite, but includes hornblende (?), magnetite, apatite, and zircon. The "primary" minerals are anhedral and appear as poikilitic inclusions in one another. Biotite fills fractures and replaces parts of hornblende (?), feldspar, and quartz; minute sericite and epidote trains are present throughout the feldspars (see pl. VII, figs. 3, 4).

Another unusual rock studied in this investigation resembles a basalt porphyry and occurs in a dike cutting epidotized "Max Patch granite". A thin section (0-48-484) was prepared from a specimen collected on N. C. Highway 209, 2700 feet north of Balm Grove Church. White phenocrysts of andesine, about An_{44} , up to 2 inches long, form about 10 per cent of the rock and are embedded in an aphanitic black groundmass. The groundmass consists of about 30 per cent calcic andesine laths (about An_{45}), 25 per cent biotite, chlorite and basaltic hornblende (in that order of abundance), and 35 per cent microcrystalline aggregates of epidote, sericite, biotite, and chlorite. Plagioclase laths form triangles, in places, enclosing ferromagnesian minerals in an intergranular fabric. This rock probably was included in Keith's (1904, p. 4) metadiabase.

Mylonites.—Insofar as the present stratigraphic, structural and economic study of the Hot Springs window is concerned, the most significant rocks of the pre-Cambrian crystalline complex are the mylonites. Were it not for their presence, it would be difficult, if not impossible, to trace thrust faults in granitic terrane.

Mylonite is best developed along the bases of the thrust sheets. The distribution of these deformed rocks is indicated by the wavy symbol on plate I. Closely spaced concentrations of these symbols indicate localities where the mylonites are best developed and thickest.

The mylonites differ in appearance from one locality to another. Where the rock is derived from epidotized pink and waxy green "Max Patch granite", the colors on fresh surfaces are helpful in distinguishing the rocks in the field. Most of the mylonites, however, are derived from other crystalline complex rock types and so closely resemble the sheared arkose and feldspathic quartzite found in the Snowbird formation that Keith (1904) mapped them as isoclinal folds of sedimentary rock in the Max Patch granite. The writer, too, was deceived by these rocks during the first half of the field season. Stose and Stose (1947, pp. 635-637), however, described these rocks as mylonite in their report on the hot springs.

The similarity of some of the crystalline complex mylonites to those of the Snowbird formation is so great that the writer finds it impossible to distinguish between some specimens of each, either megascopically or microscopically. In the field, however, there are at least two helpful criteria. Thin sheets of pegmatitic pink feldspar are not uncommon in the crystalline complex. Because feldspar is the mineral most resistant to microbrecciation, these sheets persist as thin and fairly continuous stringers of pink feldspar parallel to the shear planes in the mylonite. These are found only in the pre-Cambrian crystalline complex. On the other hand, the Snowbird formation is characterized by many argillaceous and silty beds. Near faults, these appear as black phyllitic bands amidst Snowbird mylonite. However, inasmuch as phyllonite has been observed in the crystalline complex, this second field guide must be used with discretion.

Two thin sections of mylonite clearly derived from epidotized "Max Patch granite" were studied (see pl. VIII, fig. 2). Specimen 0-48-263, collected along Spring Creek near Bluff, is made up of alternate bands and lenses of pink feldspar, white quartz, and light green saussurite. A fluxion structure is evident even megascopically, with the white and green bands curving around feldspar augen. Microscopically, the minerals determined are quartz, microcline, albite, epidote, sericite, biotite, zircon, and apatite. Quantitative estimates are difficult because of the degree of microbrecciation. Quartz shows strain shadows and appears

in finely sutured masses and in somewhat granulated lenses. Feldspars are fractured and, in places granulated, but appear to be the minerals most resistant to deformation and form augen in the microscopic fluxion structure (see pl. VIII, fig. 3). Trains of finely divided epidote, sericite, and biotite parallel the shear planes.

Specimen 0-48-753, collected 600 feet west of the point of intersection of U. S. Highway 25-70 with Hopewell Branch, just north of Walnut, closely resembles specimen 0-48-263 microscopically. Megascopically, however, it differs in that the feldspar grains are more equigranular rather than smeared out in lenses.

A mylonite of different appearance was found in a road cut on N. C. Highway 209, 400 feet south of the bend at Bluff (0-48-474). The rock has a light pinkish gray, vitreous aspect and closely resembles mylonitized feldspathic quartzite in the Snowbird formation. Microscopically, the rock is indistinguishable from the Snowbird mylonite described on page 108, both in mineral composition and fabric (see pl. IX, fig. 1).¹⁹

Similar mylonite specimens, some of which were photographed for this report (see pl. VIII, figs. 5 and 6; pl. VII, fig. 6), were collected in a road cut on N. C. Highway 209, 800 feet south of the bend at Bluff (0-48-475); at the junction of the Meadow Fork road with N. C. Highway 209 (0-48-479); along the stream 2000 feet northeast of Balm Grove Church (0-48-798); on Big Pine Creek road, 1000 feet southwest of Rector Branch road junction (0-48-1025); and in the gap between the two knobs, 3600 feet east of Bluff (0-48-466).

An even more remarkable rock was found along a thrust fault, 1600 feet N 78° E from Balm Grove Church (0-48-789). Megascopically, it is pale green, silky, and schistose, with sharp folds about an inch apart. Microscopic examination shows the rock is composed of 58 per cent quartz, 40 per cent sericite, 2 per cent leucoxene, zircon, and chlorite, and no visible feldspar. The quartz occurs in extremely long and thin lenses which show both strain shadows and Böhm lamellae, and in ultragranulated aggregates. The sericite plates parallel the rock's schistosity, in general, but at least a few are randomly oriented. The optic axes of the quartz in the lenses have a preferred orientation perpendicular to the schistosity, as in some of the mylonites mentioned above, but the lattice orientation of the quartz granules appears to be random—perhaps due to rotation. Noteworthy is the greater intricacy of structure in the rock than is apparent megascopically. Microscopic fan folds (see pl. IX, fig. 2), chevron folds, and faults are superposed on the broader megascopic folds.

The thickness of the mylonitic rocks of the crystalline complex, measured perpendicular to the shear planes, is unusually great. Along Meadow Fork it is at least 700 feet; south of Balm Grove Church, along N. C. Highway 209, at least 600 feet. Inasmuch as the microbrecciation decreases gradually with increasing distance from the thrust faults, it is difficult to measure absolute thicknesses and the estimates presented here should be taken as minimum figures. Somewhat sheared and mylonitized rocks, which cannot be classed as true mylonites, are not included.

Weathering.—The manner in which the rocks of the pre-Cambrian crystalline complex weather depends to a considerable extent on the type of deformation which they have undergone. The most susceptible are the fractured but unmylonitized rocks, such as those underlying the relatively flat strip along Charley Branch. The mylonitized rocks of the complex form ledges and steep slopes similar to those made of quartzite. The escarpment extending west-southwest from Rector Butt is underlain by mylonite. Undeformed and massive crystalline rocks are among the most resistant in the district and underlie the highest mountains near Hot Springs, e.g. Bluff Mountain, Max Patch Mountain, Walnut Mountains, but these lie outside of the area mapped for this report.

Age.—If the Dry Pond Ridge contact and the contact between the granitoid rocks and the Snowbird formation in the Brushy Mountain thrust sheet, near the North Carolina-Tennessee boundary,²⁰ are unconformities, then the crystalline complex is clearly pre-Snowbird and possibly Early or Middle pre-Cambrian

¹⁹ In view of this similarity, the petrographic description of this rock, as well as those enumerated in the next paragraph, is omitted here to avoid repetition.

²⁰ The latter contact, near the western margin of the area mapped, is not well enough exposed, nor was it studied over a sufficiently great extent for the writer to ascertain its nature. For the purpose of this report, however, it will be considered a nonconformity as mapped by Keith (1904) and as shown on plate I.

in age. If, however, these contacts are not unconformities, then another basis must be used to date the complex. The presence of pebbles of pre-Cambrian crystalline rock in conglomeratic beds of the Snowbird formation is evidence of the pre-Snowbird age of the complex. The relatively high grade of metamorphism of the complex in contrast to the comparatively low grade of metamorphism of the sedimentary rocks, supports this conclusion. Moreover, observations made by Keith elsewhere in the Asheville quadrangle (1904, p. 4) and in the Greeneville quadrangle (1905, pp. 2-3) are corroborative evidence of the pre-Cambrian age of the complex.

GEOLOGIC STRUCTURE

INTRODUCTION

The faulted and folded rocks of the Hot Springs area form one of the most remarkable structural units found in the Southern Appalachians. Keith (1904, p. 8) was the first to recognize the unusual nature of the faults in the area, but the nature of mylonites and their significance for structural interpretation was not well known at that time. Keith mapped a single fault almost completely around the area of the Hot Springs window, but did not join the ends on the southeast side. He believed that the thrust sheet on the north side had been overthrust from the north, and the one on the south side from the south. "The area inclosed by the fault plane thus represents a downthrown mass upon which the adjoining rocks were piled high from all sides." The fault's outcrop pattern was described as an almost complete oval and "its planes, if extended upward, would almost unite in a dome."

The lithologic similarity between mylonitized granitoid rocks and sheared arkose led Keith to map the former as long, thin isoclinal synclines of Snowbird rocks in the Max Patch granite. As a result, several thrust faults were overlooked and the many "whiskers" of Snowbird rocks on Keith's map make the geological structure appear overly complex.²¹

The first geologists to suspect the presence of a window in the Hot Springs area were Stose and Jonas, who indicated it as such on the Geologic Map of the United States (1932), but did not publish a description until 1944 (Stose and Stose, 1944, pp. 385-386). Their views are presented more fully, however, in their paper on the origin of the hot springs (Stose and Stose, 1947). In that paper they describe (pp. 624-625) the structural unit as ". . . the Hot Springs window of the Great Smoky overthrust block which has been domed and later eroded, exposing overridden rocks in an oval window". The long narrow isoclinal synclines of Snowbird rocks on Keith's map are interpreted by them as mylonite zones along subsidiary thrust faults which offset the trace of the Great Smoky thrust fault along the southern margin of the window. Their interpretation of the structure of the western part of the window is based upon Keith's map.

Stose and Stose, as well as Keith, were misled in their interpretation of the structure of the south-central part of the window by their belief that a belt of granitic rocks extends continuously from Bluff to the segment of the river between Stackhouse and Sandy Bottom; the present writer found that the western flank of Spring Creek Mountain, east of Bluff, is underlain by sedimentary rocks of the Snowbird formation.

In his report on the geology of the Del Rio district, Ferguson (Ferguson and Jewell, unpublished, points out that the Hot Springs window is framed on the west by two thrust faults, not one, and that one intersects and has overridden the other.

The results of the present investigation show that the Hot Springs window is framed by four thrust faults. It is possible, and in the writer's opinion, probable, that still another thrust fault is exposed within the window. If this is true, then the structure of the Hot Springs area may be described as essentially a complex "eyelid" window which includes a smaller, simple "eyelid" window. The general structure of the area, as well as the expression "eyelid window", are discussed more fully below.

THRUST FAULTS

Criteria used in recognition.—The correct interpretation of the geology of the Hot Springs area depends to a major extent on the proper understanding of certain of the contacts between formations. According

²¹ The writer does not present the foregoing as adverse criticism of Keith's work, but rather as an explanation of some omissions in an otherwise excellent piece of geological reconnaissance.

to the writer's interpretation, shown on plate I, the contacts in question are thrust faults. The criteria used to recognize faults in the Hot Springs area are the following:²²

1. Discontinuity of structure

a. Strata, as well as formational boundaries, on one or both sides of the contact strike and/or dip into the contact. If the strata of both sides are discordant with the contact, then the contact is a fault; if only on one side, then the contact may be an unconformity, unless it is the younger beds that are markedly discordant.

b. Faults present on one side of the contact are truncated by the contact. This may be true of unconformities, but if the fault is on the side underlain by younger rocks, then the contact is probably a fault.

2. Discontinuity of stratigraphic sequence

a. Omission of beds: one or more stratigraphic units present elsewhere in the region is absent at the contact. This may also be true of an unconformity.

b. Older rocks rest on younger rocks, or younger rocks dip towards or beneath the contact with older rocks. This is one of the best criteria known.

3. Evidence of shearing

a. Mylonites are present along the contact. Although known to be associated with some steeply dipping faults (Waters and Campbell, 1935), most mylonites are found along or in the vicinity of thrust faults (Crickmay, 1933, p. 161; Turner, 1948, p. 11). Thus, mylonites are good suggestive evidence of thrust faults.

b. Slickensides are found on the rocks along the contacts which may be thrust faults. However, slickensides were found in many places throughout the Hot Springs area on surfaces along which there had apparently been only a negligible amount of slip. In this area, therefore, slickensides are of questionable value as a criterion of thrusting.

c. Broken, brecciated and sheared, though unmylonitized, rocks are present at or near some contacts. Blocks range in size from a fraction of an inch to tens of feet in median diameter. Although rocks are somewhat mashed and broken elsewhere in the area, the degree of mashing and brecciation is increased with proximity to the contacts in question.

4. Silicification and mineralization is not in itself proof of faulting and its use as a criterion in the present study involves a degree of circular reasoning. It will be shown below that in all but four localities barite mineralization is restricted geographically to known thrust surfaces or to sheared rocks adjacent thereto. From this and other considerations, it is concluded that the thrust faults localized the movement of mineralizing fluids. Therefore, the presence of barite along a contact of unknown character suggests that it may well be a thrust fault.

5. Lack of evidence proving the contact is an unconformity is a poor criterion because it is negative, but it proved helpful in the field. The absence of such criteria of unconformities as basal conglomerates, fossil weathered zones, and others discussed by Krumbein (1942) makes the thrust fault interpretation at least tenable.

In the descriptions which follow, local names are applied to the structural units illustrated in figure 2. The writer regrets the necessity of burdening the literature with more names, but the scarcity of detailed mapping in the mountain region of North Carolina and Tennessee makes it unwise to attempt anything but tentative correlations with structural units recognized elsewhere.

Mine Ridge thrust fault.—The Hot Springs window is bounded on the north and east by the Mine Ridge thrust fault, which forms more than half of the frame of the window. The fault crops out along the southern flank of Mine Ridge, for which it is named, and its trace is the locus of numerous old iron mines and prospect pits. At least four barite prospect pits are present on Mine Ridge, fairly close to the fault.

²² More complete discussions of the criteria for the recognition of faults are presented by Billings (1933, pp. 158-162; 1942, pp. 155-171, 249-250), and some of the following material is abstracted from his discussions.

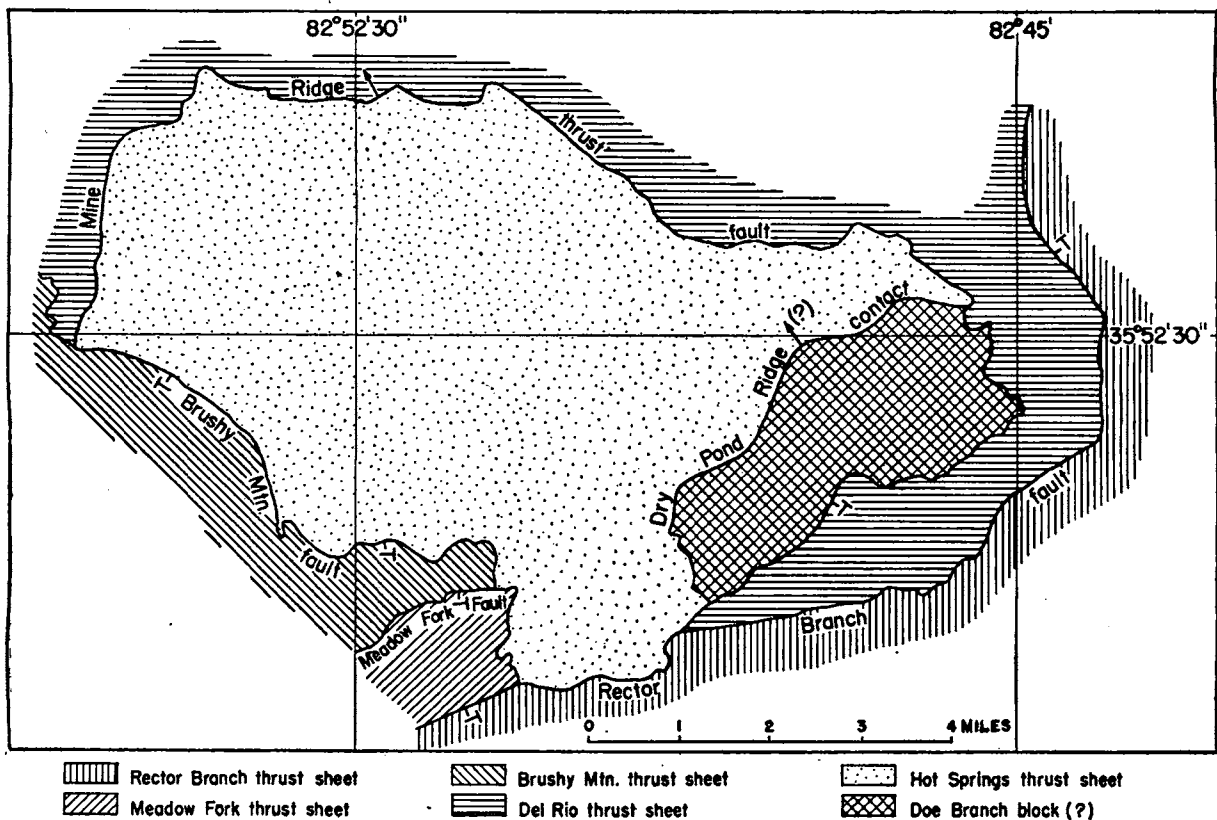


Figure 2. Generalized structure map of Hot Springs window, N. C.

The Mine Ridge thrust fault is the best documented and most evident one in the Hot Springs area. Its outcrop extends from upper Wolf Creek northward to Mine Ridge, eastward across the French Broad River, and southeastward along lower Silver Mine Creek; it curves around from north of the mouth of Big Laurel Creek to the Stackhouse mines and toward Doe Branch school, and extends from there southwestward to Coley Gap. The fault trace is truncated along Wolf Creek by the Brushy Mountain fault and at Coley Gap by the Rector Branch thrust fault. The fault trace separates the rocks of the Snowbird, Sandsuck and Unicoi formations outside the window from the predominantly younger rocks within and it truncates contacts between the younger formations inside the window. On the northern side of the window, younger rocks dip and strike towards the older rocks overlying the thrust fault, and on the southeastern side of the window Snowbird rocks above the fault overlie pre-Cambrian crystalline rocks.

The rocks above the fault are considerably fractured in the northwestern and western parts of the area and mylonitized in the eastern half of the area. Mylonite has been found as much as 2000 feet north of the fault trace on the southern flank of Mill Ridge. Where the vitreous quartzite beds of the upper Erwin lie beneath the thrust surface and near the fault trace, they are considerably fractured and form a fault breccia. Sharply angular fragments of quartzite, ranging in size from minute slivers to blocks several feet long, are imbedded in a ferruginous matrix (see pl. V, fig. 1). This breccia is well exposed along the Camp Ground road, about 1200 feet from U. S. Highway 25-70, and in ledges on the northernmost slope of Lovers Leap Ridge. Near Runion, the Sandsuck rocks are considerably folded and crinkled near the fault, and in places are subphyllitic in character. That these rocks belong to the Sandsuck formation is clearly shown by exposures of overlying basal Unicoi conglomerate along Big Laurel Creek.

The fault surface and fractures in adjacent rocks are the loci of mineralization in much of the area. Limonite and barite are present on Mine Ridge. Most of the barite mines in the Stackhouse area, the most productive in Madison County, are located precisely on the Mine Ridge thrust fault. Barite, specular hematite, fluorite, and secondary quartz have also been found near the thrust fault in railroad cuts east of Sandy Bottom and in prospect pits near Doe Branch School.

The Mine Ridge thrust fault forms the base of the Del Rio thrust sheet, named by Ferguson (Ferguson and Jewell, unpublished) for the town of Del Rio, Cocke County, Tennessee. Although the thrust sheet is broken into eight subsidiary thrust blocks in the Del Rio district, according to Ferguson, it does not appear to be faulted in the area mapped by the present writer.

The northwestern limit of the Del Rio thrust sheet is not known with certainty. Ferguson (Ferguson and Jewell, unpublished) believes that the sheet may be delimited by the Meadow Creek Mountain thrust fault in the northwestern part of the Del Rio district, Tennessee. If so, then the Meadow Creek Mountain thrust fault is the northernmost portion of the Mine Ridge thrust fault. However, the presence of several other thrust faults between the Hot Springs window and the Meadow Creek Mountain fault makes it difficult to prove which is the northwestern continuation of the Mine Ridge thrust surface.

In the Hot Springs area, only the Unicoi, Sandsuck and Snowbird formations are present in the Del Rio thrust sheet. However, in the area mapped by Ferguson, other formations up to and including the Rome are present as well. The Del Rio sheet overlies the Hot Springs sheet and has been overridden by both the Brushy Mountain and the Rector Branch thrust sheets. The Snowbird rocks in the segment of the sheet exposed east of the window are particularly broken and mylonitized. Lying between the underlying Mine Ridge and overlying Rector Branch thrust faults, the rocks have been sheared along a great number of slip planes parallel to the bedding. Some incipient crush breccias are also present close to the faults.

Brushy Mountain thrust fault.—The Brushy Mountain thrust fault was named by Ferguson (Ferguson and Jewell, unpublished) for exposures on Brushy Mountain, Cocke County, Tennessee, along the western edge of the area covered by plate I. In the course of his investigation of the Del Rio district, Ferguson traced the fault as far east as the old barite mine north of Bluff. The fault can be traced only a short distance beyond the mine to the point where it is truncated by the Meadow Fork thrust fault. As noted by Ferguson, mylonite zones up to 9 feet thick are well developed along the fault through much of its extent and in them mineralizing solutions deposited barite, quartz, hematite and sericite. The old barite mine and prospect pits north of Bluff are located in the fractured rocks immediately beneath this fault.

The trace of the Brushy Mountain thrust fault truncates the trace of the Mine Ridge fault and also truncates sedimentary contacts within the Hot Springs window. All along the fault in the area mapped in this study, sedimentary rocks within the window dip toward (under) the older crystalline rocks outside the window. The heavily silicified mylonite zone is more resistant to weathering than adjoining rocks and forms easily traceable ledges along much of the fault trace. The rocks adjacent to the fault appear more broken and mylonitized in the Bluff area than elsewhere. In addition to the mineralization mentioned above, four "talc" prospects were found in the crystalline rocks near the fault. Petrographic, chemical and x-ray analyses show this "talc" to be almost pure sericite.

The trace of the Brushy Mountain thrust fault may be offset by a tear fault paralleling the Bluff-Turkey Cove road, with movement of the southwest block relatively to the northwest. Although the position of the fault can be located by exposures on either side, the fault itself is not exposed here, nor is silicified mylonite evident anywhere from the junction of the Charley Branch road southeastward to about Steve Branch. However, inasmuch as no positive evidence was found supporting the idea of a tear fault, the concealed portion is indicated on Plate I as a segment of the Brushy Mountain thrust fault.

Above the Brushy Mountain fault is the Brushy Mountain thrust sheet, named by Ferguson (op. cit.) for the same topographic feature as the fault. The sheet is present only in the southwestern part of the area mapped by the present writer and includes here only pre-Cambrian crystalline rocks and part of the Snowbird formation. The Brushy Mountain thrust sheet overlies the Del Rio and Hot Springs thrust sheets and underlies the Meadow Fork thrust sheet. Southwest of Garenflo Gap, stream erosion has cut through the Brushy Mountain fault to expose the Hot Springs sheet in a very small window (see pl. I).

Meadow Fork thrust fault.—The most convincing evidence for the Meadow Fork thrust fault is the thick development of mylonite along the mouth of Meadow Fork, for which the fault is named. Keith (1904) mapped this zone as a narrow isoclinal syncline of Snowbird extending six miles southwestward from Punchedon Camp Branch. Field and petrographic observations made during the present study show the rocks to be mylonitized pre-Cambrian crystalline rocks adjacent to a thrust fault whose outcrop truncates the trace of the Brushy Mountain thrust fault and is in turn truncated by the trace of the Rector Branch thrust

fault. The mylonite belt overlies relatively undeformed pre-Cambrian crystalline rocks and somewhat sheared Snowbird rocks. It is highly probable that the Meadow Fork thrust fault extends at least as far southwest as the syncline shown on Keith's map, and possibly even farther.

The only mineralization noted near this fault consists of aggregates of almost pure sericite found at an elevation of 2040 feet along the stream west of Coonpatch Branch.

The Meadow Fork thrust sheet is here defined as the thrust sheet above the Meadow Fork fault and below the Rector Branch fault. In the area covered in the present investigation, it consists entirely of pre-Cambrian crystalline rocks which are in part mylonitized.

Rector Branch thrust fault.—The Rector Branch thrust fault is named for the branch which follows the fault trace closely for over a mile in the south central part of the Hot Springs area. The trace of this thrust fault truncates the traces of both the Meadow Fork and the Mine Ridge thrust faults, as well as some bedding trends of Snowbird rocks in the southern part of the area. Projected dips, as well as outcrops in several road cuts along U. S. Highway 25-70, show that the pre-Cambrian crystalline rocks overlie the Snowbird formation along this fault throughout much of its extent. Mylonitized rocks, ranging in thickness from about 50 feet along U. S. Highway 25-70, north of Walnut Gap, to at least 600 feet at Spring Creek, parallel the fault outcrop everywhere in the Hot Springs area. Traces of specular hematite are present near the fault on Levi Branch and the Gahagan barite mine is located in the fractured crystalline rocks adjacent to the fault north-northeast of Walnut Gap.

The Rector Branch thrust fault probably continues northward, outside the area mapped in this study, at least as far as Little Hurricane Creek, as shown on Keith's (1904) geological map. It is possible that the fault continues southwestward across and beyond the Hogback Mountain, but more detailed field work is necessary to test this hypothesis. On his map of the Asheville quadrangle, Keith shows a thrust fault on the southeastern side of Snowbird rocks south of Kind (Balm Grove Church on Plate I of the present report). The rocks are not sedimentary but mylonitized crystallines and the present writer places the fault outcrop on the northwestern side of this belt because it is that side that truncates the Meadow Fork fault, as mentioned above.

The hanging wall of the Rector Branch thrust fault is here designated as the Rector Branch thrust sheet. Inasmuch as the Rector Branch thrust fault was used as the approximate southern limit of the area covered in this investigation, the writer can say little about the thrust sheet except that, where seen, it is made up of pre-Cambrian crystalline rocks.

Dry Pond Ridge contact.—Within the Hot Springs window, the contact between the Snowbird formation and the pre-Cambrian crystalline rocks is difficult to interpret. Because it parallels the southeastern flank of Dry Pond Ridge, the name Dry Pond Ridge contact is here used to facilitate discussion of its character. The mapped extent of the contact is shown in figure 2 and plate I.

Keith (1904) and Stose and Stose (1947, p. 628) show the Dry Pond Ridge contact as an unconformity on their maps. On the basis of the following lines of field evidence, however, the writer questions this interpretation:

1. The rocks along the contact, especially the underlying crystalline rocks which have no bedding surfaces along which to slip, are considerably fractured and in many places mylonitized. These shearing phenomena are evident in the accessible road cuts along Woolsey Branch, below the mouth of King Creek.

2. At least four occurrences of barite are present at or near this contact. Barite, fluorite, and quartz fill fractures in the crystalline rocks exposed in the railroad cut 1000 feet southwest of Stackhouse station. Two barite prospect pits lie in a gully about half a mile northeast of Goforth Cemetery (on Spring Creek Mountain) and another lies about a mile west-northwest of Doe Branch School (see pl. I). As stated on page 36, the other occurrences of barite found in the Hot Springs area are known to be along thrust faults or in the fractured rocks adjacent thereto.

3. The sequence of Snowbird rocks exposed above the contact along the east fork of Mountain Island Branch is thicker than that along Raccoon Branch (west of Piney Mountain). Although this difference of thickness would easily be explained by faulting, the possibility that the sediments were deposited on an

uneven surface cannot be eliminated with available data. However, the lowest beds found in the former locality are only slightly pebbly and are comparable to other beds in the formation; in no way do they resemble the basal conglomerate one might expect on such an uneven surface.

The nature of the contact is difficult to determine primarily because younger beds overlie older. This is always true in unconformities which have not been overturned, and crossbedding indicates that the sequence is right side up here. Nevertheless, it by no means eliminates the possibility that the contact is a thrust fault. Billings (1933) cites many known examples of younger rocks thrust upon older.

It may be argued that the evidence of shearing along the contact and the occurrence of barite is not conclusive proof of a thrust fault. In rocks subjected to extraordinary stresses as those of the Hot Spring area obviously have been, one might expect a certain amount of shearing along a surface of weakness such as an unconformity. The minor slip planes developed along this surface, one might further argue, would localize later mineralizing fluids.

Although this line of reasoning is tenable, the writer nevertheless believes that the Dry Pond Ridge contact is a thrust fault. A third possibility is that a major thrust may have developed and followed along an unconformity.

Inasmuch as none of these interpretations can be proved conclusively with existing data, both interpretations are presented on plate II. Interpretations 1 of structure sections A-A' and B-B', show the Dry Pond Ridge contact as an unconformity; interpretations 2 of sections A-A', B-B', C-C', and D-D' show it as a thrust fault and may also serve to illustrate the third possibility, that the contact is an unconformity along which thrusting developed.

Stose and Stose (1947, p. 639) and Ferguson (Ferguson and Jewell, unpublished) conclude, from different lines of reasoning, that the rocks exposed within the Hot Springs window probably comprise a separate thrust sheet. If the Dry Pond Ridge contact is a fault, as the writer believes, then all the rocks west and northwest of the contact, within the window, are part of a thrust sheet which is here named the Hot Springs sheet for the town of Hot Springs. The crystalline rocks exposed between the traces of the Dry Pond Ridge contact and the southeastern part of the Mine Ridge fault are designated as the Doe Branch block. No data are available to indicate whether the Doe Branch block is part of still another thrust sheet or part of the autochthonous rocks underlying the Hot Springs area.

On the other hand, if the Dry Pond Ridge contact is an unconformity, then it cannot be proved that any or all of the rocks within the window form part of a thrust sheet, because the base of the sheet is not exposed. As pointed out by Ferguson (*op. cit.*), however, it is probable that the rocks within the window comprise a thrust sheet, even if the contact is an unconformity, for the following reasons:

1. The rocks of the Del Rio thrust sheet closely resemble those of the Bald Mountain sheet in northeastern Tennessee, according to Ferguson.
2. The rocks of the Hot Springs window closely resemble those of the Shady Valley sheet in northeastern Tennessee.
3. Inasmuch as the Bald Mountain sheet overlies the Shady Valley sheet, and the Del Rio sheet overlies the rocks of the Hot Springs window, it is probable that the beds underlying the Del Rio sheet are structurally equivalent to the Shady Valley sheet, and therefore part of a thrust sheet.

Because the writer believes the Dry Pond Ridge contact is a thrust fault, both the Hot Springs sheet and the Doe Branch block are named in figure 2, although the latter is queried.

More formations are exposed in the Hot Springs sheet than in any other within the area mapped. All the sedimentary rocks from the Snowbird to the Honaker formations are represented, and the sheet may possibly include, as mentioned above, pre-Cambrian crystalline rocks as well. In general, the sedimentary rocks of the Hot Springs sheet trend about east-west. In the northern part of the area, the bedding dips steeply to the north and is slightly overturned in places. In general, dips decrease southward within the window. Most of the larger folds shown on plate I, and many of the minor folds, plunge to the northeast.

The Hot Springs thrust sheet is overlain on the west, north, east, and southeast by the Del Rio thrust sheet, and on the southwest and south by the Brushy Mountain, Meadow Fork and Rector Branch thrust sheets.

Attitudes of the thrust faults.—Although the thrust faults can be accurately located within a few feet in many places, the attitudes of the fault surfaces can be measured at only four localities within this area. The well developed banding in the mylonite, however, suggests a means of determining the dips of the faults. In many places the bedding of sedimentary rocks and the banding of mylonite below a thrust fault parallel the mylonite banding above it. It appears logical to assume that these well developed s-planes parallel the thrust surface.

This assumption was tested at the localities where the thrust surfaces can be observed. At the road cut on U. S. Highway 25-70, 400 feet west of the gas station in the old granite quarry and 2200 feet south-east of Walnut Gap, the shear planes in both overlying crystalline rocks and underlying sedimentary rocks trend $N40^{\circ}W\ 30^{\circ}NE$. The surface of the Rector Branch fault is not a plane but curves, with dips decreasing downward in the road cut. The average attitude of the fault, however, is about $N40^{\circ}W\ 25^{\circ}NE$. The Brushy Mountain thrust fault is exposed at Beck Branch and in Turkey Cove, northwest of Bluff. At both localities the fault surface parallels the banding of the silicified mylonite and trends about $N65^{\circ}E\ 45^{\circ}SE$. The most important barite vein exploited in the area lies along the Mine Ridge thrust fault in the Stackhouse mines. Shear planes in the adjacent rocks parallel the vein and the thrust fault which dips 55 degrees to the east.

Thus, the assumption appears to meet field tests at localities where it can be tested. Nevertheless, the assumption must be considered only tentatively true and is used here as an expedient. Although mylonite banding parallels fault surfaces in many localities (e.g. Peach and Horne, 1930, p. 150; Waters, 1932, p. 626; Crickmay, 1933, p. 171), and a few occurrences are known where it does not (Waters and Campbell, 1935, p. 484). The exceptions, however, are restricted to mylonite masses that are only a few or a few tens of feet thick. On the other hand, the possibility that the mylonites may have developed along subsidiary imbricate surfaces of weakness which do not parallel the main thrust faults (Peach and Horne, 1930, pp. 117, 120-121) cannot be cast aside.

Nevertheless, it is the writer's belief that the great thicknesses and fairly consistent trends of the mylonites in the Hot Springs area suggest that they do parallel the thrust surfaces. If this is true, then the thrust faults in the Hot Springs area dip 40 to 50 degrees in most localities (see mylonite dips on pl. I), although 20 degree dips are recorded.

Relative direction of movement.—The following points support the conclusion that the relative movement of each thrust fault in the Hot Springs area was approximately from the southeast to the northwest with respect to the underlying rocks:

1. Most of the thrust faults dip to the south, southeast, and east. One notable exception is the Dry Pond Ridge contact, if it is a thrust fault, which dips to the northwest and west, but it is possible that the root zone for this fault is concealed beneath the southeastern part of the Del Rio sheet. The other exception is the northern part of the Mine Ridge thrust fault which dips to the north and northwest, but the root zone is exposed in the southeastern part of the area mapped. An attempt is made on pages 46-48 to explain the northward dips of these faults.

2. In general, cleavage planes dip to the southeast and east (see p. 43).

3. Axial planes of drag folds in the Shady dolomite, just below the Mine Ridge thrust fault, dip to the southeast (see p. 43).

4. Almost all the thrust sheets described northwest of the piedmont in the Southern Appalachians are believed to have moved relatively to the northwest (e.g. Butts, Stose, and Jonas, 1932, p. 7; Butts, 1940, pp. 440-464; King et al., 1944, p. 11). From these and other structural features, it has been concluded (Chamberlin, 1928, p. 90) that the region was subjected to stresses which might be described as a couple in vertical planes trending NW-SE. Forces near the surface were directed northwestward while deeper in the crust they were directed southeastward. According to this interpretation, it is not likely that any of the thrust sheets in the Hot Spring area moved relatively to the southeast.

Therefore, it is concluded from both field observations and regional considerations that the movement of the thrust sheets in the Hot Springs area was relatively to the northwest. Inasmuch as the writer does

not know whether the hanging wall or the footwall was the more active element, he can contribute nothing on the problem of overthrusting vs. underthrusting.

It does not appear possible, on the basis of existing data, to determine the magnitude of the net slip and breadth. However, it is likely that the minimum figure would be a few, or possible tens of, miles.

OTHER FAULTS

In addition to the thrusts, four other faults were mapped in the course of the present investigation (see pl. I). These are such local features that they are not named in this report.

The most extensive of these faults is the one trending northwest from the southwestern end of Deer Park Mountain across Shut-in Creek to Dry Branch. Although the fault surface itself was not seen in any outcrop, the writer believes the fault well substantiated by the abrupt offset of the Hampton formation (especially the easily traceable middle quartzite member) and of the upper ledge-forming quartzites of the Erwin formation. The apparent relative displacement of the southwest block is to the northwest. The truncation of formational and member contacts occurs along a comparatively straight line despite the moderately rugged topography, thereby suggesting that the fault has a steep dip.

Another fault with a smaller relative displacement, but in the same direction, outcrops in a gully on the south flank of Canebrake Ridge, 3600 feet west of the intersection of Little Bottom Branch with N. C. Highway 209. Although the fault is exposed in the gully, the deformed rocks adjacent to it make determination of the fault's attitude difficult. The presence of the fault is easily recognized where the lower Unicoi conglomerate beds, on the northeast side of the gully, are in contact with the Sandsuck slate along a line nearly perpendicular to the strike of the bedding of both.

The other two faults strike northeast and the apparent relative displacements of the southeastern blocks are to the northeast. The fault 1700 feet east of the mouth of Little Bottom Branch was recognized by the slight offset of the basal uncoi conglomerate beds across their strike. The evidence for the fault on the western end of Lovers Leap Ridge is the abrupt change from Hampton middle quartzite beds to upper Hampton shale beds along a contact normal to the strike of the bedding.

Although all four of the faults described here have steep dips, the lack of other data makes it difficult to classify them except as dip faults. The writer does not know if they are strike-slip (tear), dip-slip, or oblique-slip faults.²³ The first described fault above, however, offsets nearly vertical beds for a considerable distance and its displacement is probably at least partly strike-slip. The noteworthy consistency of the relative displacement of the four faults described above suggests that they are genetically related and that they may all be strike-slip faults.

The writer was unable to find any evidence in support of the cross fault inferred by Stose and Stose (1947, pp. 641-644) in their discussion of the origin of the hot springs (see pp. 16, 43; pl. I).

FOLDS

The magnitude of the folds developed in the strata of the Hot Springs area ranges from submicroscopic to several miles. Inasmuch as the largest folds are quite evident on the geologic map (pl. I) and in the structure sections (pl. II), the discussion which follows will deal predominantly with the others.

The rocks of the Honaker formation are horizontal, or nearly so, where exposed in Mine Hollow, whereas the underlying rocks, as far down in the section as the Unicoi formation, dip steeply to the north. Efforts to find stromatolites in place, to determine the tops of the beds by the convexity of the internal laminae (Shrock, 1948, p. 286), were unsuccessful. Therefore the writer does not know if the beds are right side up or upside down. For this reason, the fold in which the Honaker appears is illustrated as an "anticline" in Interpretation 2 of structure section B-B' (pl. II) and as a syncline in Interpretation 1 of the same section. Both interpretations are possible. However the writer believes the "anticline" interpretation the more likely because one would expect vertical beds to be affected by the northward drag near the overriding thrust fault.

The word anticline is placed in quotes above because in this interpretation the structure is really an upside-down syncline. A normal anticline is a fold with older rocks toward the center of curvature. In the

²³ The fault terms mentioned here are used as defined by Reid et al. (1913, pp. 170, 176-177).

fold shown in Interpretation 2 of structure section B-B', one passes into younger rocks in going towards the center of curvature. Upside-down synclines are not unknown. One, produced by similar tectonic conditions, is shown adjacent to the Iron Mountain thrust southeast of Erwin on plate 7 of Tennessee Division of Geology Bulletin 52 (King et al., 1944). Another, larger overturned syncline in the northern Muddy Mountains, Nevada, is described by Longwell (1949, pp. 941-944).

Similar folds may be present in at least two other localities in the Hot Springs area. The folded upper Erwin strata exposed in the long road cut beneath the Hot Springs school, on U. S. Highway 25-70, are described by Stose and Stose (1947, pp. 630, 641-642) as an anticline. Although the beds are arched up, the possibility that the sequence is overturned is suggested by the downward pinching out of quartzite beds which somewhat resembles coarse upside-down crossbedding. Moreover, in the poorly exposed but critical portion of the outcrop, on the north side of the large fold, there is a strong suggestion that the strata swing up again. South of the axis of the fold, all strata dip steeply to the north and are right side up. Nowhere, south of the U. S. Highway bridge across Spring Creek, are dolomitic rocks of the Shady formation present in the fairly continuous exposures along the bluffs of Spring Creek, as one would expect if the fold were a normal anticline.

The other overturned syncline seen during the present study is well exposed in rocks of the Erwin formation along the western bluff of Spring Creek at the bend 1300 feet west of the French Broad gaging station.

Drag folds in the Shady dolomite are exposed along the east bank of the French Broad River opposite the town of Hot Springs. The folds measure tens of feet from crest to crest and their limbs trend approximately N-S 30-35°E and E-W 50-70°N. The axial planes of the folds thus dip to the southeast. The proximity of these folds to the Mine Ridge thrust fault suggests that they were formed as a result of drag along that fault surface.

In the area mapped, the Rome formation is highly contorted (see pl. IV, fig. 2). Folds are intricate and range in magnitude from a few inches to at least tens of feet. The multifarious trends of the axial planes of the folds make it difficult to determine the relation of these folds to the broader structural features of the area. There appears to be no observable pattern.

Incompetent beds in other formations, i.e. thinly bedded siltstones and shales, are intricately folded near the thrust faults. Microscopic crinkles (see pl. VI, figs. 5, 6) are superposed on broader folds which measure several feet to tens of feet from crest to crest. Local folding is evident in incompetent beds almost everywhere in the area with the notable exception of the comparatively undeformed section along Blood River.

The drag fold interpretation of the Snowbird rocks along upper East Fork Shut-in Creek is discussed on page 28.

CLEAVAGE AND JOINTS

Cleavage is present in the fine- and very fine-grained clastic rocks beneath the Shady formation in many, but not all, localities in the Hot Springs area. The cleavage appears to be best developed in the rocks of the Sandsuck formation.

In general, the cleavage planes strike to the northeast and dip about 50 degrees to the southeast. There are many exceptions to this rule, however. In some places, e.g. in the Sandsuck beds between Raccoon Branch and Hot Springs Mountain and the slate in the Snowbird along Coonpatch Branch, the cleavage parallels the bedding which does not dip to the southeast. At others, e.g. along N. C. Highway 209 northeast of the mouth of Little Bottom Branch, the cleavage intersects the bedding and dips to the east. Where the bedding does dip to the southeast or east, as in the eastern part of the Del Rio thrust sheet, cleavage closely parallels the bedding.

The nature of the cleavage differs with the lithology. In the predominantly argillaceous beds, cleavage planes are very closely spaced and parallel the planes of the preferentially oriented sericite plates (see p. 27. In rocks with larger silt and sand fractions, cleavage planes are not so numerous and somewhat resemble closely spaced joints.

In some shales and slates, cleavage surfaces are folded and crinkled. A well exposed example is in the small road metal quarry on N. C. Highway 209., 800 feet northeast of the mouth of Little Bottom Branch. The small crinkles in the cleavage here appear to have developed by minor slip along the bedding (which is about perpendicular to the cleavage) after the cleavage planes formed in the rock.

Several hundred observations of joint trends were recorded during the present investigation, but no clear-cut pattern emerged when these were studied in the office, nor did they appear to bear a significant relation to the general structure. For this reason, joint trends are not recorded on the geologic map (pl. I).

METAMORPHISM

One of the most surprising facts to emerge from the petrographic study of some of the rocks of the Hot Springs area is the overwhelming predominance of mechanical (kinetic) metamorphism over thermal metamorphism. This is amply demonstrated by cataclastic fabrics in the thin sections described above and illustrated in the accompanying photomicrographs. The quartz in all but the two jasperoid rocks examined shows undulose extinction; Böhm lamellae are evident in many grains. Microbrecciation and granulation of mineral components, especially quartz and detrital mica, are evident in almost all thin sections and increase with proximity to the thrust faults where such great thicknesses of mylonite are present.

Two minerals, sericite and chlorite, generally indicative of low rank metamorphism, are present. Chlorite occurs in a few rocks only, but sericite is present in all the thin sections examined, again excepting the jasperoid specimens. Before the rocks in the Hot Springs area can be assigned to the sericite-chlorite metamorphic zone, however, the origin of the sericite must be determined.

At least some of the sericite and chlorite present in the siltstone, shale, and slate is probably an alteration product of the original argillaceous cement and a result of low rank regional metamorphism. However, a hydrothermal origin is suggested for much of the sericite by the following observations:

1. Feldspar and quartz have been replaced by sericite to some extent in almost all the rocks.
2. Sericite forms up to 10 per cent of some quartzite and arkose specimens in which argillaceous material was originally present in negligible quantities.
3. Local concentrations of almost pure sericite, barite, and other minerals show that hydrothermal solutions were operative at least along or near thrust faults.

It is possible that the wide distribution of sericite throughout the area may be explained by both neomineralization²⁴ and the introduction of material by hydrothermal solutions, but it is difficult to determine to what extent each process has been operative.

ORIGIN OF THE HOT SPRINGS WINDOW

Introduction.—From the foregoing discussion, it is evident that the Hot Springs window is not a simple window which has formed by erosion cutting through a single thrust sheet to expose the underlying, overridden rocks. The frame is made up not of one, but of four different thrust sheets. Moreover, the existing data which suggest that the Dry Pond Ridge contact is a thrust fault also indicate that a smaller window, framed by two different thrust sheets, may be exposed within the Hot Springs window.

Complex windows such as these are not unknown in the geological literature, although comparatively few have been described. In the Southern Appalachians, the Draper Mountain structure is described by Cooper (1939, p. 71) as a "breached anticlinal compound fenster" which has been "formed by the crenulation of two thrust sheets and subsequent erosion through both of them". The breached window is almost completely framed by the Pulaski and the Max Meadows thrust faults.

Engadine window.—The Hot Springs window is closely analogous in form to the classic Engadine window of the Central Alps. A discussion of this Alpine structure is presented here because the writer believes it sheds some light on the sequence of tectonic events which led to the formation of the window in the Hot

²⁴ Neomineralization is defined by Knopf (1931, p. 5) as the transformation of old mineral constituents into minerals of new and different composition.

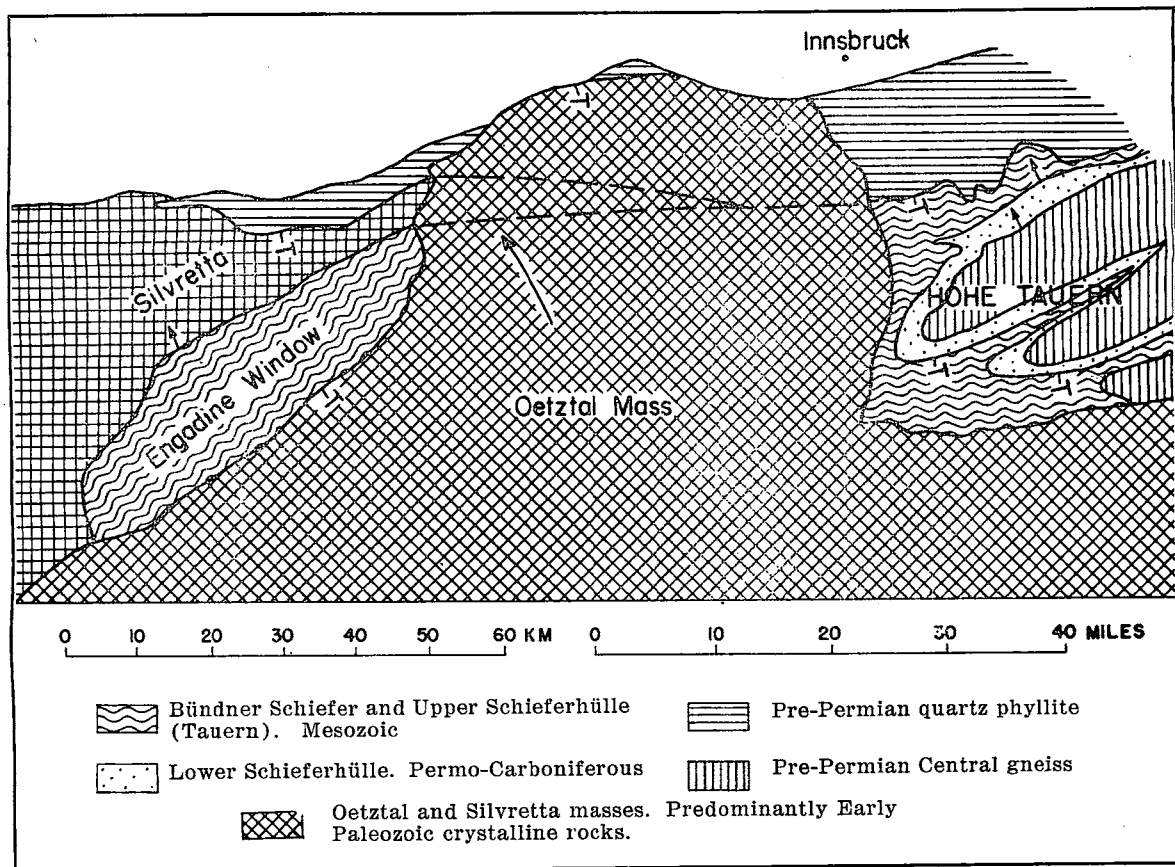


Figure 3A. Generalized structural map of the western Tyrol, showing the Engadine window and part of the Tauern. (Modified from Sander, 1921)

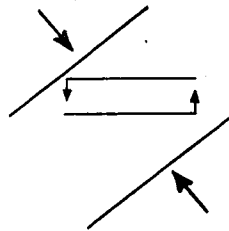


Figure 3B. A simplified sketch of the tangential forces applied to the earlier formed east-west structural zone (as indicated by arrow in above map). The stresses in the NW-SE direction resulted in the counterclockwise rotation of the structures in the Engadine window. (After Sander, 1921, p. 194)

Springs area. Much of the material which follows was drawn from a detailed study by Hammer (1915) and from summaries by Sander (1921, pp. 193-195, 198, 213-214) and Klebelsberg (1935, pp. 139-146).²⁵

The Engadine window is subovate in form and trends NE-SW in a region (only part of which is represented in fig. 3A) where E-W trending structures predominate. The rocks within the window are named the Bündner Schiefer and are predominantly schistose, including calcareous, mica, and chlorite schists and phyllite of Mesozoic age. The Bündner Schiefer forms a large symmetrical anticline whose limbs dip steeply and uniformly to the northwest and southeast; the axis of the anticline trends NE-SW and passes almost through the middle of the window.

²⁵ Less comprehensive summaries of the geology of the Engadine window have been published in the English language by Collet (1927, pp. 27, 215, 230-231) and by Heritsch and Boswell (1929, pp. 27-28, 66, 70-76, 102-105, 153-154).

The frame on the north side of the window consists of the Silvretta mass of Early Paleozoic gneisses. The Silvretta mass is a rootless thrust sheet which has moved from the southeast to the northwest. The Oetztal mass frames the window on the southeast and is made up of rocks similar in age and lithology to those in the Silvretta. The older rocks of both the Oetztal and Silvretta masses rest upon the younger Bündner Schiefer above thrust surfaces which dip steeply (40° or more) away from the window. Only in a few localities do thrust surfaces dip more gently. Mylonite is fairly well developed along the base of both thrust sheets. Northeast and southwest of the window, the Oetztal mass has been thrust over the Silvretta. Thus, the Silvretta gneiss has been thrust over the Bündner Schiefer and both have been overridden by the Oetztal gneiss.

Definition of eyelid window.—The Engadine fenster then, is not a simple window but one framed by two different thrust surfaces. For this reason, Sander (1921, p. 193) proposed the term shear-window (*Scherenfenster*) and defined it as a window whose rocks are directly overlain by more than one thrust sheet. Sander emphasizes that the term is descriptive and not genetic. Shear-window is rather an unfortunate term, however, inasmuch as shearing is implicit in the formation of any and all windows.

Another term is suggested by Sander's description (1921, p. 212) of the ends of the window. He points out that the framing thrust sheets overlap, as in an iris diaphragm. A more literal translation of the components forming the word *Irisblende* can be interpreted as "eyelid". The writer has heard several geologists use the expression "eyelid window" but he has been unable to find any reference to it in the geological literature. Therefore it is here proposed that *eyelid window* be defined as Sander defined *Scherenfenster* and that the latter term be abandoned. The proposed name has the merit of suggesting the analogous form of two eyelids (thrusts) over the enclosed eye (rocks within the window). The analogy may be criticized, however, because it suggests movement from opposite sides of the window, whereas all known examples are believed to have formed by thrusting in one direction.

Origin of the Engadine window.—Sander's interpretation of the origin of the Engadine window (1921, pp. 193-196, 212-214, 219), though not the only one published,²⁶ is in some ways applicable to the Hot Springs window. Sander stresses the significance of the data which suggest that the Bündner Schiefer of the Lower Engadine is connected directly with the Schieferhülle of the Hohe Tauern (as shown by the dashed lines in fig. 3A), although the continuity of this structure is masked by the overlying Oetztal thrust sheet. This continuous structure, as well as other data, indicate that the first orogenic pulse in the region produced marked east-west trending deformation zones. One of these zones was the anticlinal mass extending from the Engadine to the Tauern areas.

The subsequent orogenic pulse may be subdivided into two subphases. During the first, the Silvretta-Oetztal mass was thrust northwestward as a unit and rode over the resisting Engadine-Tauern structural zone. During the second subphase (which was probably continuous with the first in time) the frictional resistance along the major thrust surface, beneath the Silvretta-Oetztal mass, was too great and the Oetztal subsidiary thrust sheet split off and rode over the base of the main mass. The sliver left beneath the Oetztal mass is the Silvretta thrust sheet. The tangential force couple that emplaced the Oetztal thrust sheet acted in a NW-SE direction in the Engadine area (see fig. 3B), producing a counter-clockwise rotation of the underlying Bündner Schiefer mass so that it no longer parallels the closely related east-west zones. Sander and other Austrian geologists emphasize that the present imbricate structure is the result of the formation of subsidiary thrust sheets when the frictional resistance became too great along the main movement horizon. They deny that it formed by the piling up of far-travelled thrust masses developed from recumbent folds.

Similarity between Hot Springs and Engadine windows.—Lest the reader question the relevance of the foregoing pages on the Engadine window of the Alps in a report devoted to an area in North Carolina, the structural features of the Hot Springs window which are analogous to those of the Engadine window are summarized below:

1. The window is framed by more than one thrust fault.
2. Both the axis of the elongation of the Hot Springs window and the general bedding of the rocks within the window strike across the regional structure of the Southern Appalachians. The general bedding

²⁶ Two more recent, but conflicting, interpretations are those by Staub (1937, pp. 98-108) and by Krasser (1940, pp. 181-185).

and the axis of elongation of the window strike about east-west whereas regional structures strike predominantly NE-SW.

3. Fault surfaces around the window dip steeply (40° to 50°) away from the window.

4. Mylonite is present along portions of each of the thrust faults.

5. The Hot Springs thrust sheet within the window may be arched over the granitoid rocks of the Doe Branch block. This cannot be proved inasmuch as the rocks beneath the Mine Ridge thrust sheet and southeast of Doe Branch are concealed. However, trends of the Dry Pond Ridge contact and the overlying sedimentary rocks suggest that a southwest plunging anticline may be present within the window.

6. Reference to a regional geologic map (see Geologic Map of the U. S., 1932; or Stose and Stose, 1949, pl. 1) indicates that the Hot Springs window lies along the projected axis of the Mountain City window in northeastern Tennessee. Except for the Grandfather Mountain window, the rocks in the above windows constitute the southeasternmost exposures of known Cambrian formations in this segment of the Appalachians. The geometric similarity of the Hot Springs and Mountain City windows to the central Alpine structural units suggests that they form a tectonic belt similar to the Engadine-Tauern structural belt. If so, then analogy suggests that the Hot Springs-Mountain City structural belt may have formed before it was overridden by thrust faults, rather than by later arching (see below).

Conclusions.—Any attempt to describe the sequence of tectonic events which led to the formation of the Hot Springs window must, of necessity, be based on a certain number of assumptions as well as on available field observations. There are serious gaps in our knowledge of the mountain region. What, for example, is the relation of the thrust faults in the Hot Springs area to those of northeastern Tennessee (King et al., 1944, pp. 10-13)? Does the Hot Springs thrust sheet form an arch over the Doe Branch block, the southern limb of which is concealed by overlying thrust sheets? Are the Brushy Mountain and Meadow Fork thrust sheets not exposed outside the eastern half of the window because they have been overridden by the Rector Branch sheet, or do their present eastern limits mark the line of a partially concealed tear fault? The answers to these and other similar questions would probably establish or disprove the validity of the conclusions that follow.

It is the writer's belief that the Hot Springs window was formed in much the same way as the Engadine window, according to Sander's interpretation. The steps in its formation are conceived to be about as follows: If the Dry Pond Ridge contact is a thrust fault, an early tectonic event was the thrusting of the Hot Springs sheet over the Doe Branch crystalline rocks. If this was preceded by an early orogenic pulse which produced a NE-SW trending structurally resistant anticlinal belt from the Mountain City to the Hot Springs areas, then the thrust sheet curved in overriding the Doe Branch block. If not, then after the movement of the Hot Springs sheet, forces applied in a NW-SE direction compressed the rocks between the two areas, including the rocks of the Doe Branch block and the Hot Springs sheet, to form a large anticline with steeply dipping limbs. The second alternative is the more probable because of the large angle between the bedding of the rocks in the Hot Springs sheet and the Mine Ridge thrust surface.

The first phase was followed by the relative northwestward movement of the Del Rio sheet along the Mine Ridge thrust fault and across the arched Hot Springs sheet, truncating the latter and partially severing it from its root. The absence of the Del Rio sheet beneath overlying thrust faults in the southwestern part of the area and the decrease in the width of the sheet as exposed southwestward from Bearwallow Gap suggest that the Del Rio sheet may wedge southward. Thus the remaining thrust sheets may be interpreted as imbricate blocks of the same mass or as parts of another major thrust mass which bevelled off the Del Rio sheet. The former of these possibilities is illustrated in the structure sections on plate II.

The incongruous east-west trends of some of the structures in the Hot Springs area are attributed to the clockwise rotation of earlier structures by forces applied in a north-northwest direction during the thrusting of the Brushy Mountain-Meadow Fork-Rector Branch mass along the Brushy Mountain thrust fault. As this large mass met increasing frictional resistance along its base and as it impinged against the structural front already developed, it ruptured, forming the Meadow Fork thrust fault and the west end of the Rector Branch thrust fault.

In the accompanying structure sections (pl. II), the major thrust fault underlying this upper mass is depicted as a horizontal surface from which imbricate sheets were upthrust. The representation of the

faults beneath the surface profile is, of necessity, diagrammatic. The thrusts may dip more steeply even at the depths shown and are probably by no means smooth and planar. However, the structure sections do illustrate the general structural relations that are believed to exist.

The structural features described in this report cannot be dated accurately from evidence in the Hot Springs area. Inasmuch as all the rocks have been affected, it is only possible to say that the deformations are post-Honaker, or post-Middle Cambrian, in age. The thrust faults in the Southern Appalachians are generally attributed by most geologists to the Late Paleozoic (Appalachian) orogeny, but the possibility that at least some may have been formed during the Taconic, or possible even the Acadian, orogenic pulses is by no means eliminated.

MINERAL RESOURCES INTRODUCTION

Although no mining activities are currently in progress, the Hot Springs area contains a variety of mineral resources. Barite, dolomite, and limonitic iron ore have been the chief products of the area. Barite and dolomite may be worthy of further development at the present time, but mining of the limonite is no longer feasible. Other resources that have only potential value at present are shale (for lightweight aggregate), high silica quartzite, building stone, and limestone.

The hot springs form the most important mineral resource of the area. For this reason a description and chemical analyses of the springs are presented below. A hypothesis, based on inferences drawn from geologic observations and from conclusions in the preceding portion of the report, is presented as a possible explanation of the origin of the hot springs.

Previous references to the mineral resources of the Hot Springs area are scattered through many publications. Throughout the remaining portion of this report, an effort has been made to utilize pertinent information from some of these references and to mention others in order to provide a convenient bibliographic index to the literature bearing on the Hot Springs area.

BARITE

GENERAL STATEMENTS

Introduction.—The date of the first discovery of barite in the Hot Springs area is not known, but its presence was noted by Maclure as early as 1818 (p. 37). Notable barite mining did not begin until about 1884, however, when a crushing mill was erected in the town of Warm Springs, as it was then known (Arthur, 1914, p. 562). From then until about 1927, barite was mined at intervals, with the greatest production during the years 1904 to 1916. Most of the production was from the Stackhouse and Gahagan mines and from the A. G. Betts property.

During the most productive years, crude barite was processed in a mill at Stackhouse operated by the Carolina Barytes Company. The company was organized by Henry J. Moore in 1903 and the mill was erected early in 1904. The mill was equipped with crusher, jig, burrstone grinders, dryer, screens, and bleaching vats. To meet the growing demands for finer-ground barite, the burrstones were replaced with a steel-ball mill. This mill reduced the barite to required fineness but contaminated the ground material with iron. For this reason it was replaced by a Raymond roller type mill which proved satisfactory. Power for running the mill was obtained by building a small wooden dam across the French Broad River, which produced 165 to 250 horsepower, varying with the season. During a flood in 1916, the mill and dam were washed away, and they have not been replaced since.²⁷

Properties and uses of barite.—Barite (barium sulphate, BaSO_4), also known as barytes and heavy spar, can be easily recognized in the field by its physical properties. It is extremely heavy for a non-metallic mineral (specific gravity: 4.3-4.6) and can be readily scratched with a knife (hardness: 2.5-3.5). Coarsely crystalline barite breaks along excellent cleavage planes (cleavage: (001) perfect; (110) perfect; (010) imperfect) into blocks of characteristic shape. Pure barite is white but slight impurities may result in various shades of yellow, green, blue, brown, red, or dark gray to black. The streak is white and the luster pearly, subvitreous, or stony. Pure barite contains 65.7 per cent barium oxide and 34.3 per cent sulphur trioxide. The mineral is soluble in acids.

²⁷ The data presented in this paragraph were furnished by Charles E. Hunter of the Tennessee Valley Authority in a 3-page unpublished report dated January 3, 1949.

Barite is currently used in the manufacture of a great many products because it is heavy, inert, stable, and white (when ground). Its greatest single use is as the chief constituent of lithopone paint. Ground barite is used as a filler in rubber, linoleum, oil-cloth, paper, plastics, resins, glass, and ceramic enamels, and as a flux in brass smelting. Large quantities of finely ground barite have been consumed by the petroleum industry in recent years; when mixed with a suspending medium, it produces a heavy mud which is used to control high gas pressures in the drilling of deep wells.

Distribution.—Barite was observed by the present writer in many localities within the Hot Springs area. In addition to the Stackhouse and nearby mines (described below), barite was found in minor quantities in railroad cuts 1000 feet south of Stackhouse and at the river bend east of Sandy Bottom. Elsewhere in the area, barite prospect pits and mines were found 900 feet southwest of Doe Branch school, about a mile west-northwest of Doe Branch school, in a stream valley about half a mile northeast of Goforth Cemetery (on Spring Creek Mountain), half a mile north-northeast of Bluff, on both ends of Mine Ridge, and half a mile north-northeast of Walnut Gap.

Occurrence.—As pointed out by Stuckey (1942, p. 107), the principal barite deposits are localized along thrust faults or in the fractured rocks adjacent thereto. Possible exceptions are the four barite exposures along the Dry Pond Ridge contact which may be either a thrust fault or an unconformity (see p. 39).

Barite occurs in veins, pods, and stringers, and as small disseminated aggregates in the country rocks. Extensive shearing and brecciation and some mylonitization is evident in the country rocks of all occurrences. Barite fills fissures at some places, fills breccia openings in others, and replaces mylonitized rock in still others.

Varieties.—Three varieties of barite are present in the Hot Springs area:

1. Saccharoidal white crystalline barite was found in the Stackhouse and adjoining mines, at the Gahagan mine, and in prospect pits along the Dry Pond Ridge contact.
2. Laminated fine-grained pink barite with finely disseminated fluorite was found in the Gahagan, Stackhouse and adjoining mines.
3. Coarsely crystalline light to dark gray vitreous barite was found in prospect pits on Mine Ridge and along the Dry Pond Ridge contact.

Before any significance can be attached to the occurrences of these different types, a more detailed study of the barite deposits is necessary.

Associated Minerals.—Associated with the barite are quartz, fluorite (see pl. IX, figs. 3 and 4), sericite, specular hematite (see pl. IX, figs. 5 and 6), pyrite, chalcopyrite, and calcite. Stuckey and Davis (1933, p. 8) report the presence of argentiferous galena in the barite north of Bluff, but this mineral was not observed by the present writer. Quartz and fluorite are present in all barite deposits in considerable amounts; the others in comparatively small amounts. The proportions of the minerals present, however, are different from one locality to another. Along the Brushy Mountain thrust fault, for example, barite predominates on Brushy Mountain (Ferguson and Jewell, unpublished) and at the prospect pits north of Bluff, but almost pure sericite and silica predominate in the mineralized zone between these localities.

Insufficient field and laboratory data are available to the writer to permit precise determination of the paragenesis. One thin section across a veinlet exposed in the railroad cut south of Stackhouse (0-48-488), however, shows that quartz was the first to be deposited in that fissure and was followed by fluorite and then barite. Stuckey and Davis (1933, p. 6) state that the deposition may have been in the following order: quartz, sericite, sulphides and hematite, and then fluorite and barite contemporaneously. According to Stuckey and Davis, cross-cutting relations suggest that there was also a later generation of quartz and barite.

Origin.—The problem of the origin of the barite deposits in the Hot Springs area has been reviewed by Stuckey and Davis (1933, pp. 7-9) and need not be discussed at length here. From a study of the field and microscopic evidence, Stuckey and Davis conclude that the barite and associated minerals are of hydrothermal origin. This conclusion is supported by subsequent studies of somewhat similar deposits in Virginia (Edmunson, 1938, pp. 16-24) and in the Del Rio district, Tennessee (Ferguson and Jewell, unpublished). Field and microscopic observations by the present writer are in accord with the above conclusion. The structural control of deposition leaves no doubt that mineralization was post-deformation in age.

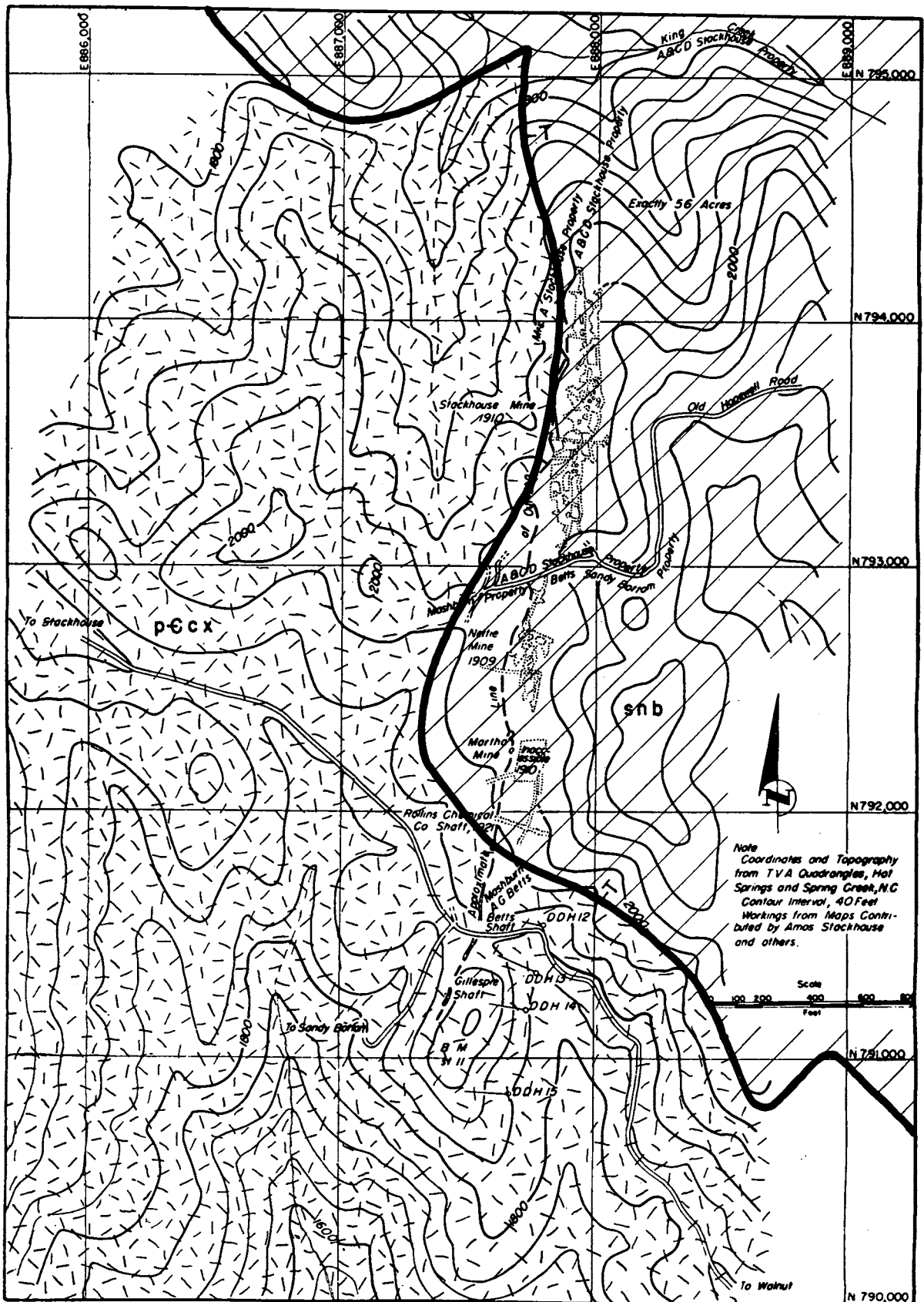


Figure 4. Map of Stackhouse area, showing barite workings and location of the Mine Ridge thrust fault. (After L.A. Dahners, U.S. Bureau of Mines; geology by S.S. Oriol)

STACKHOUSE AREA

General statement.—The most important barite mines in the Hot Springs district are those in the Stackhouse area (see fig. 4). The mines are located along a narrow north-south belt that is about a mile long and roughly parallels the trace of the Mine Ridge thrust fault. In view of the revived interest in these deposits, manifested by recent test drilling, a description of the mines is included in this report.²⁸

Stackhouse mines.—The Stackhouse mines (see fig. 4) about a mile east of Stackhouse station (pl. I), are located on the largest barite vein discovered in the Hot Springs area. Three-fourths of the barite production in the area came from this property, and the largest and best mine was the Klondyke.

The vein on this property lies along the Mine Ridge thrust fault. It dips about 55 degrees to the east and is enclosed by a hanging wall of silicified slates of the Snowbird formation and by a footwall of pre-Cambrian granitoid rocks. In the immediate vicinity of the Klondyke shaft, the vein was worked to a depth of 350 feet. Near the shaft, on the second level, the vein has a reported maximum thickness of 13 feet. The average vein thickness of the deeper workings is approximately 2 feet.

Betts property.—The A. G. Betts Sandy Bottom property extends from the French Broad River, half a mile east of Sandy Bottom, northward for a distance of half a mile to the Stackhouse property (see fig. 4). In the northern portion of the property, the barite vein occurs along the Mine Ridge thrust fault and dips about 50 degrees to the east. In the southernmost barite workings, however, the vein occurs in pre-Cambrian crystalline rocks and dips about 55 degrees to the southeast. The barite shipped from the Betts property contained about 95 per cent barium sulphate.

Recent prospecting.—As part of the strategic minerals program during World War II, the U. S. Bureau of Mines conducted a diamond drilling project in 1944 in the Del Rio district, Tennessee, and in the Hot Springs area (Dahners, 1949; Ferguson and Jewell, unpublished). The purpose of the project was to prospect for extensions of known barite veins. Four holes were drilled on the A. G. Betts property approximately in a straight line with and south of the Stackhouse mines (see D.D.H. 12-15 on fig. 4). The drill cores were studied by the U. S. Geological Survey and logs prepared.

No extensions of commercial barite were discovered. Dahners (1949) concludes that the vein is represented by a zone of unconsolidated material which could not be cored and adds that sludge samples show no more than a trace of barite.

No accessible barite exposures were found during the Bureau of Mines study, but crude barite found on the dumps appears to be of higher grade than that from the Krebs-Williams area in the Del Rio district, according to Dahners. Samples from the Krebs-Williams area assayed 83.8 per cent barite, 7.9 per cent fluorite, and 6.3 per cent quartz.

Conclusions.—The absence of significant amounts of barite in the drill cores recovered by the U. S. Bureau of Mines can best be explained by reference to fig. 4. The richest barite deposits in the Hot Springs area are those occurring along the Mine Ridge thrust fault in the Stackhouse mines. Although smaller barite fissure veins do occur in the fractured rocks near thrust faults, the geometric relation of these fissures to thrust faults is not sufficiently understood to make predictions possible. The drilling sites chosen for prospecting were unfortunate because they are within the Hot Springs window and on the most probably autochthonous structural unit exposed in the area. None of the drill holes passed through a thrust fault. If drilling had proceeded on sites northeast of those selected, at places where Snowbird and not pre-Cambrian crystalline rocks outcrop, then the holes would have passed through the Mine Ridge thrust fault. In so doing, the chances for striking a barite vein would have been considerably better.

OTHER AREAS

Gahagan mine.—The Gahagan mine is located about half a mile north-northeast of Walnut Gap and about 500 feet east of U. S. Highway 25-70 (see pl. I). The barite vein worked here has an average thickness of 4 to 5 feet, has pre-Cambrian crystalline rock on both hanging wall and footwall, and dips steeply to

²⁸ Most of the data presented below are taken from an unpublished 3-page report by Charles E. Hunter for the Tennessee Valley Authority dated January 3, 1949, and from Stuckey and Davis (1933). Additional information on the barite deposits has been published by Betts (Drane and Stuckey, 1925, pp. 40-43) and by Keith (1904, p. 9).

the east. An estimated 30,000 tons of crude barite has been produced in this mine, according to Mr. B. W. Gahagan.

Two varieties of barite, saccharoidal white crystalline barite and pink laminated barite, occur in separate lenses and in fissures extending into granitoid wall rocks. The lenses are closely connected by stringers but may have formed during different periods of mineralization. A so-called "muck seam" of non-uniform thickness occurs between the barite and the hanging wall. It is composed of plastic clayey fault gouge stained by iron and manganese oxides.

The vein on the Gahagan property was worked to a maximum depth of 200 feet where thinning of the vein and a higher percentage of fluorite and pyrite reduced both quantity and quality of the barite.

Long Mountain mines.—The Long Mountain barite deposits are located on the southeastern spur of Long Mountain, about half a mile north-northeast of Bluff. These deposits occur as fissure veins in broken and somewhat mylonitized Snowbird feldspathic quartzite and slate a few hundred feet north of the outcrop of the Brushy Mountain thrust fault. Coarsely crystalline vitreous barite and saccharoidal barite are present. Black and purple fluorite is abundant and occurs in alternate bands with barite. The mines were worked by the Rollins Chemical Corporation to depths of 200 feet in veins about 6 feet thick.

Mine Ridge prospect pits.—Two barite prospect pits were found at the crest of the easternmost portion of Mine Ridge and one was found at the top and one at the bottom of the westernmost slope of Mine Ridge. The sites of these pits suggest that there may be a continuous mineralized zone along the crest of Mine Ridge, but this could not be proved because of relatively poor exposures. Both saccharoidal white crystalline barite and coarsely crystalline light gray vitreous barite were found at all four pits. These deposits occur in fractured arkose and conglomerate of the Unicoi formation. The deposits may be genetically related to the barite veins found along the thrust fault at the base of the Moccasin Gap member of the Unicoi in the Del Rio district (Ferguson and Jewell, unpublished), but more detailed field study is necessary to prove or disprove it.

CONCLUSIONS

The Stackhouse area, as a whole, probably still contains large reserves of barite. The best grades and largest amounts of the remaining barite occur below the old workings which have partially collapsed and are filled with water. The northern end of the Stackhouse vein, however, has not been worked and barite could be mined here at less cost than anywhere else in the area. It is doubtful if the Gahagan mine could ever be worked again at a profit. The Long Mountain mines, Mine Ridge prospect pits, and the prospect pits along the Dry Pond Ridge contact require further study before conclusions can be made regarding their value.

In the writer's opinion, any future prospecting for barite in the Hot Springs area should be restricted to rocks along the thrust faults shown on plate I and figure 2, and along the Dry Pond Ridge contact. Test drilling may prove useful in locating veins and in ascertaining thicknesses and quality of barite.

CARBONATE ROCKS

Shady dolomite.—High magnesium dolomite²⁹ has been extensively quarried in the Shady belt of the Hot Springs area. Chief production was from the two G. C. Buquo Lime Company quarries, no longer in operation, about a mile northwest of Hot Springs station. Another abandoned dolomite quarry is located on the east bank of the French Broad River about 1200 feet northeast of Hot Springs station.

The property formerly worked by the G. C. Buquo Lime Company is the most favorable for mining operations in the area. Immediately adjacent to the main east-west line of the Southern Railroad, it includes high bluffs which are easily worked. Beds strike east-west, about perpendicular to the quarry face, and dip 75 degrees to the north. Individual beds range from a few inches to three feet in thickness. The absence of persistent horizontal joints detracts somewhat from the ease of quarrying and maintaining quarry benches.

²⁹ Defined as a dolomite containing 40 per cent or more magnesium carbonate, 53 per cent or more calcium carbonate, and less than 7 per cent impurities (Cooper, 1944, p. 235).

During operations, the total production was processed at a grinding plant on the same property. The dolomite was pulverized to sizes such that 100 per cent passed through a 10-mesh, 85 per cent through a 50-mesh, and 50 per cent through a 100-mesh screen (Loughlin, Berry, and Cushman, 1921, p. 52). The grinding plant has since been razed.

The rock exposed in the Buquo quarries is chiefly the upper blue member of the Shady dolomite. The chemical analysis shown in column 1, table 4, is said to represent the average output of the G. C. Buquo Lime Company (op. cit., pp. 53, 150). Analyses of rocks collected at the Buquo quarries by Earl C. Van Horn, during an economic investigation by the Tennessee Valley Authority, are shown in columns 2 to 6, table 4.

TABLE 4. ANALYSES OF SHADY DOLOMITE IN THE HOT SPRINGS AREA.

Column 1. Average composition of output of the G. C. Buquo Lime Company (Loughlin, Berry, and Cushman, 1921, pp. 53-150).

2-7. Compositions of chip sample aggregates collected by Earl C. Van Horn, Tennessee Valley Authority, and analyzed by Philip N. Sales, North Carolina Minerals Research Laboratory, August, 1948. Each analysis represents numerous chip samples taken from many beds; aggregate samples were pulverized and quartered to prepare the final samples for each analysis.

2. Average composition of northern half of beds exposed in northwest Buquo quarry.
3. Average composition of southern half of beds exposed in northwest Buquo quarry.
4. Average composition of northern third of beds exposed in southeast Buquo quarry.
5. Average composition of middle third of beds exposed in southeast Buquo quarry.
6. Average composition of southern third of beds exposed in southeast Buquo quarry.
7. Average composition of beds exposed in quarry on east bank of French Broad River, 1200 feet northeast of Hot Springs station.

	1	2	3	4	5	6	7
SiO ₂		4.1	3.0	2.3	3.6	7.4	2.3
R ₂ O ₃		1.4	1.0	0.9	0.9	2.8	0.8
(Fe ₂ O ₃).....		(0.27)	(0.30)	(0.33)	(0.20)	(0.42)	(0.27)
CaO.....	33.31	30.0	30.2	30.0	30.1	27.8	30.2
MgO.....	18.87	19.1	20.1	20.5	20.2	19.5	20.1
Ign. loss.....		45.1	45.7	46.5	45.5	42.2	46.5
CO ₂	46.76						
H ₂ O.....	.05						
Insoluble.....	.75						
Totals.....	99.74	99.7	100.0	100.2	100.3	99.7	99.9
Calculated CaCO ₃	59.50	53.6	53.9	53.6	53.7	49.6	53.9
Calculated MgCO ₃	39.65	39.9	42.1	42.9	42.3	40.8	42.1
Total calculated CO ₂		44.4	45.7	46.0	45.7	43.1	45.7
Calculated CaCO ₃ in dolomite.....		47.5	50.1	51.0	50.3	48.6	50.1
Calculated dolomite.....	86.85	87.4	92.2	93.9	92.6	89.4	92.2
Calculated free calcite.....	12.30	6.1	3.8	2.6	3.4	1.0	3.8
Total calculated carbonate.....	99.15	93.5	96.0	96.5	96.0	90.4	96.0

The results of physical tests made on two samples of Shady dolomite from the Buquo quarries are reported by Loughlin, Berry, and Cushman (1921, p. 145) as follows:

	A	B
Weight per cubic foot (pounds).....	178	178
Absorption per cubic foot (pounds).....	.13	.22
Per cent of wear.....	4.2	5.5
French coefficient of wear.....	9.5	7.2
Cementing value.....	---	21

The quarry on the east bank of the French Broad River is not as favorably located as the other two. Rock must be loaded on motor vehicles and carried across the river before it can be dumped into railroad cars. However, the distance to the railroad is small and roads are excellent.

The rock in this quarry is part of the middle blue member of the Shady dolomite. A chemical analysis of chip samples collected at this quarry appears in column 7, table 4.

The dolomite quarried in the Hot Springs area has been crushed for agricultural purposes and has been used for concrete stone. High magnesium dolomite is also used in the manufacture of epsom salts, explosives, high-magnesium lime, sulphite pulp, rock wool, and whiting substitute, as blast furnace flux, and in coal mine dusting. The physical tests show that the dolomite in the Hot Springs area is also well suited for road material.

It is probable that the dolomite quarries in the Hot Springs area, if reopened, could be operated profitably. Reserves are in terms of millions of tons; transportation and power facilities are favorable. Moreover, if a purer carbonate rock with a higher magnesia (MgO) content is desired, it can perhaps be found in the upper white member of the Shady dolomite. A favorable quarry site for this rock may be the bluff exposed about 200 feet north of the present quarry on the east bank of the river.

Honaker limestone.—Field observations made during the present study suggest that a possible source of limestone, composed predominantly of calcium carbonate, is the rock exposed along Mine Hollow and on the knob 1200 feet west of the confluence of the hollow with Lower Shut-in Creek. No chemical analyses of this, the Honaker limestone, are available, but the rock contains comparatively little dolomite. Careful sampling and chemical analyses are necessary before the rock can be considered for use in the preparation of Portland cement.

SHALE FOR LIGHTWEIGHT AGGREGATE

Introduction.—Increased interest in lightweight concrete aggregate in recent years has resulted in numerous investigations of the properties of bloated shales and clays. Two of these studies, one by the U. S. Bureau of Mines at Norris, Tenn. (Conley et al., 1948, pp. 31-65), and the other by the North Carolina State College Minerals Research Laboratory in Asheville, N. C.,³⁰ have used samples from the Rome formation of the Hot Springs area as raw materials. The current nation-wide shortage of lightweight aggregate makes a review of these two investigations pertinent in a discussion of the mineral resources of the Hot Springs area.

Lightweight aggregate.—Lightweight aggregate is a material which may be substituted for the rock, sand, and gravel commonly used as the major constituent of concrete. Three types of material are currently in use: (1) natural substances, including volcanic scoria, pumice, and diatomaceous earth; (2) by-product aggregates, including air-cooled slags, cinders, sawdust, and coke-breeze; (3) specially processed materials, including expanded clays and shales. The materials in the first two groups are not available in large enough quantities to meet current demands in the southeastern states and therefore it is probable that new plants will be erected to process shales and clays.

Lightweight aggregate is used to reduce the dead weight of concrete in the construction of large buildings and bridges. Reduced weight permits a reduction in the cost of steel frameworks which more than offsets the difference in price between lightweight and ordinary aggregate. Lightweight aggregates are used principally in the manufacture of prefabricated building units in which nailability and ease of channelling, as well as reduced weight, are desired. Savings in labor costs here offset the higher cost of lightweight aggregate. The increased heat and sound insulation imparted by lightweight aggregate makes it desirable in all types of construction, even where weight is not a critical factor.³¹

Tests on Rome shale.—Tests made at the Asheville laboratory to determine the bloating behavior of the maroon shale in the Rome formation show that the material is suitable for the production of lightweight aggregate. The samples were collected at a road cut on the south side of U. S. Highway 25-70, one mile west of Hot Springs school.

The investigation included crucible firing tests on small samples, simulated rotary kiln (pan firing) tests, and heap roasting tests at temperatures of 2200° to 2400° F. Laboratory tests indicate that a hard, strong product with excellent pore structure can be made from the Rome shale by the rotary kiln process, which is generally used. The bloated aggregate weighs approximately 50 pounds per cubic foot when

³⁰ Unpublished 3-page report by Benjamin Gildersleeve, Tennessee Valley Authority, Asheville, N. C., dated January 4, 1949.

³¹ More detailed information on lightweight aggregate may be found in papers by Moyer (1942), Sullivan et al (1942), and Ingram (1947).

crushed to 3/8 inch or smaller size. Heap roasting tests also produced a clinker that weighs 50 to 60 pounds per cubic foot, when broken and crushed to aggregate size, and that is entirely suitable for lightweight aggregate. However, the heap roasting process may not be an economically sound method because of relatively high labor costs, the need to discard fines of the crushed shale and fuel, and the incomplete burning of the heap which necessitates recycling of the unburned portion.³²

Results of the tests by the U. S. Bureau of Mines at Norris, Tenn., are not as favorable (see Conley et al., 1948, pp. 50-51, 62-63). Rome shale samples became coated with viscous material when fired with the oil flame in rotary kiln tests. The coating formed at a temperature of about 2100° F. before any appreciable bloating took place and the kiln charge rolled into a dense glassy mass that could not be removed from the kiln without cooling and breaking. Stationary kiln tests, however, showed that the material produced has the properties needed for lightweight aggregate.

The unsatisfactory results obtained in the Bureau of Mines rotary kiln tests are attributed to the presence of small amounts of lime. The lime acts as a flux, forming viscous glass coatings on the shale particles and adhering to the kiln walls at temperatures below bloating. The site at which the samples used by the Bureau of Mines were collected is not described (Conley et al., 1948, p. 32). As pointed out on page 9 of the present report, the Rome formation includes limestone and dolomite and some shale beds are calcareous. The different conclusions reached from test data at the two laboratories clearly demonstrate that more careful sampling techniques are necessary in future studies.

Conclusion.—The satisfactory results obtained by tests on some of the Rome red shale indicates that the Hot Springs area is a potential source of raw material for lightweight aggregate. Reserves are large and transportation and power facilities favorable. However, further tests on carefully collected samples are necessary before a site for large scale operations can be chosen.

IRON

Approximately 30,000 tons of iron ore have been mined in the Hot Springs area, but no operations have been reported since 1917. The most important deposits in the area are those along the Mine Ridge thrust fault on the southern flank of Mine Ridge. Most of the limonitic ore mined here was wash ore that yielded 1 part of commercial ore to 4 parts of materials mined.³³ The limonite found here is believed to have been deposited by meteoric solutions trickling down from overlying ferruginous rocks which have since been eroded away (Bayley, 1925, p. 5).

It is probable that the cost of concentrating the iron ore in the Hot Springs area is too great and estimated reserves too small to warrant reopening the mines and erecting a plant to process the materials.

MANGANESE

Manganese ore has been produced from at least two mines in the Hot Springs area. The first, no longer visible because of slumping (and therefore not indicated on pl. I), is located on the east side of Shut-in Creek about 4000 feet south of U. S. Highway 25-70 (Pratt and Berry, 1919, p. 86; and statements by local residents). The other mine, consisting of two open pits, lies on the spur 3200 feet southwest of the confluence of Dry Branch with Shut-in Creek. Several car loads of ore are reported to have been shipped from each mine. Analyses of manganese ore from the Hot Springs area (Weeks, 1890, pp. 304-305; reprinted by Harder, 1910, p. 77) show an average manganese content of 42.98 per cent, but unfortunately the exact source of the samples is not described.

The manganese deposits in the Hot Springs area consist of local concentrations of manganese and iron oxides in the residual clays of the lower Shady formation. Inasmuch as they are very similar in occurrence and probably in origin to the manganese deposits of northeastern Tennessee, the reader is referred to the comprehensive discussion by King et al (1944, pp. 48-70) for further information.

³² The data collected in the above described tests may be obtained from the North Carolina Minerals Research Laboratory, 180 Coxe Avenue, Asheville, N. C.

³³ Fairly full descriptions of the workings and the ore have been published by Bayley (1925, pp. 7-10), Keith (1904, p. 10), and Pratt and Berry (1919, p. 45).

QUARTZITE

Building stone.—Quartzite from the clastic formations below the Shady dolomite has been used locally as a building stone. The rock is difficult to work but this disadvantage is offset by its local abundance and by its durability. The rock has been used in the construction of many homes and business establishments in the region.

High silica quartzite.—During a Tennessee Valley Authority investigation for high silica refractory material in 1948, Mr. Earl C. Van Horn collected samples of some of the quartzite beds in the Hot Springs area. Chemical analyses of these rocks, made at the North Carolina Minerals Research Laboratory, are presented below in table 5.

TABLE 5. CHEMICAL ANALYSES OF HIGH SILICA QUARTZITE.

Lab. No.	Location	Formation	Tonnage	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃
483	East Fork Shut-in Creek, 500 feet south of confluence with Shut-in Creek.	Top of Unicoi	10,000 prob. min.	96.7	3.0	0.12
484	Blood River, 3000 feet south of U. S. Highway 25-70	Erwin	5-10000 possible	95.6	4.0	0.18
485	N. C. Highway 209, 1000 feet south of Hot Springs school.	Erwin	100,000 possible min.	94.3	4.3	0.48
486	Shut-in Creek, 5600 feet south of Church of God.	Erwin	10,000 possible	86.2	8.6	1.3

Sample 486 is too low in silica to be considered for use in the preparation of high silica refractory brick. Although the other three quartzite samples are of potential value, it is unlikely that the rocks will be quarried until more easily worked and purer quartz rocks and sands are no longer available.

SOILS

An adequate recent study of the soils in the Hot Springs area has been made by the U. S. Department of Agriculture in cooperation with the North Carolina Department of Agriculture in a soil survey of Madison County, N. C. The results of this study appear in the report by Golston et al (1942), which can be purchased from the Superintendent of Documents, Washington, D. C.

HOT SPRINGS

Introduction.—The hot springs constitute the most valuable mineral resource in the area covered by the present report. Since their discovery, the springs have attracted visitors from many states and have been an important source of revenue for the town and the county.

The hot springs are said to have been discovered by two soldiers from the Watauga settlement in 1778 (Arthur, 1914, pp. 491, 539). In pursuing some Cherokee Indians who had stolen some horses, the soldiers crossed the French Broad River and were surprised to find the water warm near the southern bank, close to the mouth of Spring Creek. The next year the springs were visited by invalids and in a short time the locality became a famous resort.

Since the discovery of the springs, several hotels have been built, one after the other, near the mouth of Spring Creek to accommodate visitors. The present red brick structure, the Montaqu Hotel, was erected in 1927 after a larger wooden building had been destroyed by fire.

Many visitors suffering from rheumatism, arthritis, and other afflictions have stated that they were aided considerably by bathing in the springs. Claims which have been made regarding the efficacy of the springs are well illustrated by the following quotation from a prospectus for the Hot Springs Hotel published by Joseph Pettyjohn in 1885:

. . . It is the wildest fallacy to suppose that artificially-heated waters can ever possess any of the virtues of the waters of these springs. The efficacy of this wonderful fluid, medicated mysteriously in subterranean recesses, in effecting the cures of the most inveterate diseases, is simply miraculous. Science cannot explain it; art cannot imitate it. . . . With primitive man and with the savages of the unfrequented parts of the earth, their power to heal or to benefit are as well known as by the learned chemists who profess to analyze and give their constituent parts without, however, being able to compound the same thing exactly, or by the savants and scientists who differ with each other as to their origin. But whether thermal waters are heated by volcanic action or by the internal heat of the earth (which is thought by some theorists to be a mass of molten matter at the centre), or by passing over iron or sulphur pyrites forming chemical combinations that produces heat, matters but little to the afflicted ones, so long as the great central fact remains that they effect cures when all else have failed. . . .

The present writer is unqualified to evaluate the medicinal properties of the springs and is concerned only with their physical and chemical properties and the problem of their origin.

Location.—Some 20 thermal springs have been reported on the property of the present Montauqua Hotel, Hot Springs, N. C. All emerge through the alluvial fan on which the town is built. Most of the springs emerge within a few hundred feet of the southwest bank of the French Broad River at an elevation of about 1300 feet. The bath house and the spring house, erected by the hotel owners, are built above the largest springs. A few springs flow directly into the river.

All the thermal springs emerge in the belt underlain by Shady dolomite (see pl. I).

Temperature and flow.—The temperature of the springs now in use range from 96 to 104° F. Other springs have been reported (Stearns et al., 1937, p. 170) with temperatures from 92 to 117° F. No careful year-round studies have been made of the springs, but temperatures are reported to be unaffected by seasons.

The flow of water is known for only one of the springs. The spring entering the spring house has a flow of about six gallons per minute (Stose and Stose, 1947, p. 640). This water is pumped from the spring house to the hotel and to the bath house for use in showers and bath tubs. The 16 concrete, 6 by 9 foot bathing tanks in the bath house are fed directly by other springs that emerge beneath the bath house. Water enters these tanks between marble slabs at the bottom and overflows through pipes to the river. No estimate of the flow of the springs beneath the bath house has been made. The flow of all the springs is reported to diminish during dry spells.

Chemical analyses.—Chemical analyses of the mineral constituents of the hot springs are shown in tables 6 and 7. These analyses are by no means recent or adequate. The analyses in table 6 have been converted to parts per million by Fitch (1927, p. 532) from the analyses published by Peale (1886, p. 78) in terms

TABLE 6. ANALYSES OF THE SPRING WATER AT HOT SPRINGS, N. C.
(From Fitch, 1927, p. 532)

Hypothetical combinations	Parts per million			
	Analyst, Chandler and Pellew		Analyst, Adelmarrh	
	Bathing spring	Drinking spring	Warm spring	Hot spring
Potassium chloride (KCl).....	5.30	8.56		
Sodium chloride (NaCl).....	15.57	18.82	40.09	
Magnesium chloride (MgCl ₂).....	3.76	6.33		34.08
Calcium chloride (CaCl ₂).....	170.81	152.96	195.42	51.47
Potassium sulphate (K ₂ SO ₄).....	6.16	0.04		
Sodium sulphate (Na ₂ SO ₄).....	154.50	152.27	72.55	
Magnesium sulphate (MgSO ₄).....	22.93	139.10	130.72	128.33
Calcium sulphate (CaSO ₄).....	699.46	693.63		300.45
Sodium bicarbonate (NaHCO ₃).....			102.00	
Ferric oxide (Fe ₂ O ₃).....			40.03	
Sodium Silicate (Na ₂ SiO ₃).....	51.16	54.40		
Calcium silicate (CaSiO ₃).....	102.32	108.82		
Silica (SiO ₂).....			65.36	
Total solids.....	1,231.97	1,342.93	647.17	514.33

TABLE 7. ANALYSIS OF HOT SPRING WATER BY CHANDLER AND PELLEW.
RECALCULATED TO IONS BY DUNNINGTON (WATSON, 1924, p. 375).

Cl.....	2.21
SO ₄	48.51
CO ₃	15.99
Na.....	1.00
K.....	2.45
Ca.....	18.94
Mg.....	3.36
Fe ₂ O ₃11
Al ₂ O ₃09
SiO ₂	7.34
	100.00 per cent.

Salinity: 735 parts per million.

of grains per gallon. An unfortunate feature of these analyses is that they are expressed in terms of hypothetical combinations, whereas the major mineral constituents of water are present in the form of ions. The analysis shown in table 7 was recalculated from earlier published analyses by Chandler and Pellew and appears in Watson's paper (1924, p. 375) on the thermal springs of the southeastern Atlantic states. The need for new analyses is clearly shown by the discrepancies present in tables 6 and 7. Nevertheless, the figures are useful qualitatively and, to a limited degree, quantitatively.

The mineral compositions of these springs compare with those of the hot and warm springs in Bath County, Virginia (Reeves, 1932, p. 19). The waters in both have a high sulphate, bicarbonate and calcium content, whereas the chloride and sodium content is comparatively low. The high sulphate content of the Virginia springs that issue from limestone is attributed (Reeves, 1932, p. 17) to the alteration of pyrite to ferrous sulphate by the action of oxygen. In contact with water, the ferrous sulphate is hydrolyzed and ferric oxide is precipitated with the formation of free sulphuric acid. The acid reacts with other constituents, especially carbonate, to form an alkaline water of high sulphate content. The salinity of the North Carolina thermal springs is slightly greater than those in Virginia.

No attempt has been made as yet to determine the gas content of the hot springs in North Carolina. A considerable amount of gas escapes from the springs in both the spring house and the bath house. However, the gas content is probably similar to that in the Virginia springs. The gases found there are those in the atmosphere, nitrogen, carbon dioxide, and oxygen (Reeves, 1932, p. 20).

Origin.—Observers who have considered the problem of the origin of the hot springs in North Carolina have concluded that the spring waters are of meteoric origin (Weed, 1905, p. 186; Watson, 1924, pp. 383-384; Stose and Stose, 1947, pp. 642-644). This conclusion is supported by the reduction in flowage during dry spells, by the lack of known volcanic activity in the region, and by the similarity in chemical character of these waters to both the warm and cold springs in Virginia.

Although available data are inadequate to eliminate radioactivity and chemical processes as possible sources of heat, the similarity of the hot spring of North Carolina to those in Virginia suggests that their temperatures are due to downward increase of temperature with depth (Reeves, 1932, pp. 28-35), i.e. the geothermal gradient of the earth's crust. Indeed, this is the tentative conclusion reached by Weed, Watson, Stose and Stose (op. cit.), and the present writer, who support the hypothesis of artesian circulation. However, descriptions of the inferred artesian system responsible for the hot springs differ considerably.

The data recorded by Van Orstand (1928, p. 509) in deep wells in West Virginia and Pennsylvania show an increase of 1° F. for every 60.8 to 71.4 feet of depth and there is no reason to assume that appreciably different gradients exist in the area considered here. The mean annual temperature of the air at the surface in the Hot Springs area is about 50° F. The depth necessary to raise the temperature of surface water to the maximum recorded temperature of 117° F., at the rate of 71.4 feet per 1° F., is about 4800 feet. However, groundwater, shielded from the sun's rays, is cooler than the surface air, as pointed out by Stose and Stose (1947, p. 644), and some heat is probably lost in the slow ascent of the water to the surface. These factors, as well as possible contamination of the thermal spring water with groundwater, make a higher temperature allowance necessary. A depth of 5,500 to 6,000 feet would probably be sufficient to account for the temperature of the hot springs.

Weed (op. cit.) concludes that the springs come up along a fault plane (the Mine Ridge thrust fault), affording a quick exit for waters which have seeped down through permeable sandstones to considerable depths. In discussing the various hypotheses that have been offered for the origins of the springs in southeastern United States, Watson (op. cit.) expresses the view that a solution of the problem must await more detailed geologic observations. Stose and Stose (1947, pp. 642-644) point out that the springs do not emerge along the thrust fault on the north side of the Hot Springs window, for that fault outcrops 1,500 to 2,000 feet north of the springs. They suggest that water may enter porous beds in the Vann formation (Snowbird of the present report) at Vann Cliff, descend to a depth of 5000 feet in a syncline beneath the Shady dolomite, and emerge along an approximately north-trending vertical cross fault.

The present writer joins Stose and Stose in rejecting Weed's interpretation because the springs do not emerge along the Mine Ridge thrust fault. Nevertheless, he does not believe that their tentative explanation of the origin of the springs is a likely one for the following reasons:

1. No evidence was found during the present study to support their inferred cross fault (see p. 42).
2. Inasmuch as the northernmost belt of carbonate rocks is probably part of the Honaker formation (see p. 7), the Shady formation and underlying rocks are not folded in the form of a syncline as believed by Keith (1904).
3. The rocks along Vann Cliff appear porous only where weathered near the present surface. Freshly exposed, similar rocks at other localities are quartzitic in character and impermeable.

Despite the number of geologic studies and observations made in the Hot Springs area, the origin of the hot springs remains a problem. The explanation suggested and illustrated in section D-D' on plate II is presented with reservations as a tentative hypothesis. It is based on the thrust fault interpretation of the Dry Pond Ridge contact, which is itself not proved (see pp. 39-41). If the contact is a thrust fault, then meteoric water may enter fractures in the rocks along the fault at an elevation of about 2200 to 2600 feet, southeast and east of the east fork of Mountain Island Branch, and flow through the fractures to considerable depths. Inasmuch as no deep well data are available in the Hot Springs area, the dip of the fault, if it is a fault, and its depth beneath the town of Hot Springs is not known. However, a depth of 4000 to 5000 feet below sea level is not unreasonable. At this depth, artesian water flowing along the fractured rocks may escape upward along joints, bedding surfaces, and solution cavities in the Shady dolomite. Inasmuch as exposures of Shady dolomite are relatively few at the surface, the possibility of a strike fault in the Shady cannot be eliminated. This is another possible exit for water in the inferred artesian system. Whether the springs emerge through joints and solution cavities or along a steeply dipping strike fault, the passage of the water through carbonate rocks is marked by the increase in carbonate and calcium content.

Although the foregoing attempt to explain the hot springs is based on what the writer believes to be reasonable inferences from geologic observations, it must be regarded as nothing more than a tentative hypothesis. The hypothesis accounts for the high temperature and composition of the springs. The difference in elevation between the place where water enters the system, at 2200 to 2600 feet, and where it emerges, at about 1300 feet, provides an adequate head for the artesian flow. Nevertheless, the inherent weaknesses of the hypothesis are apparent. Probably the greatest is the lack of conclusive evidence to prove the Dry Pond Ridge contact a thrust fault.

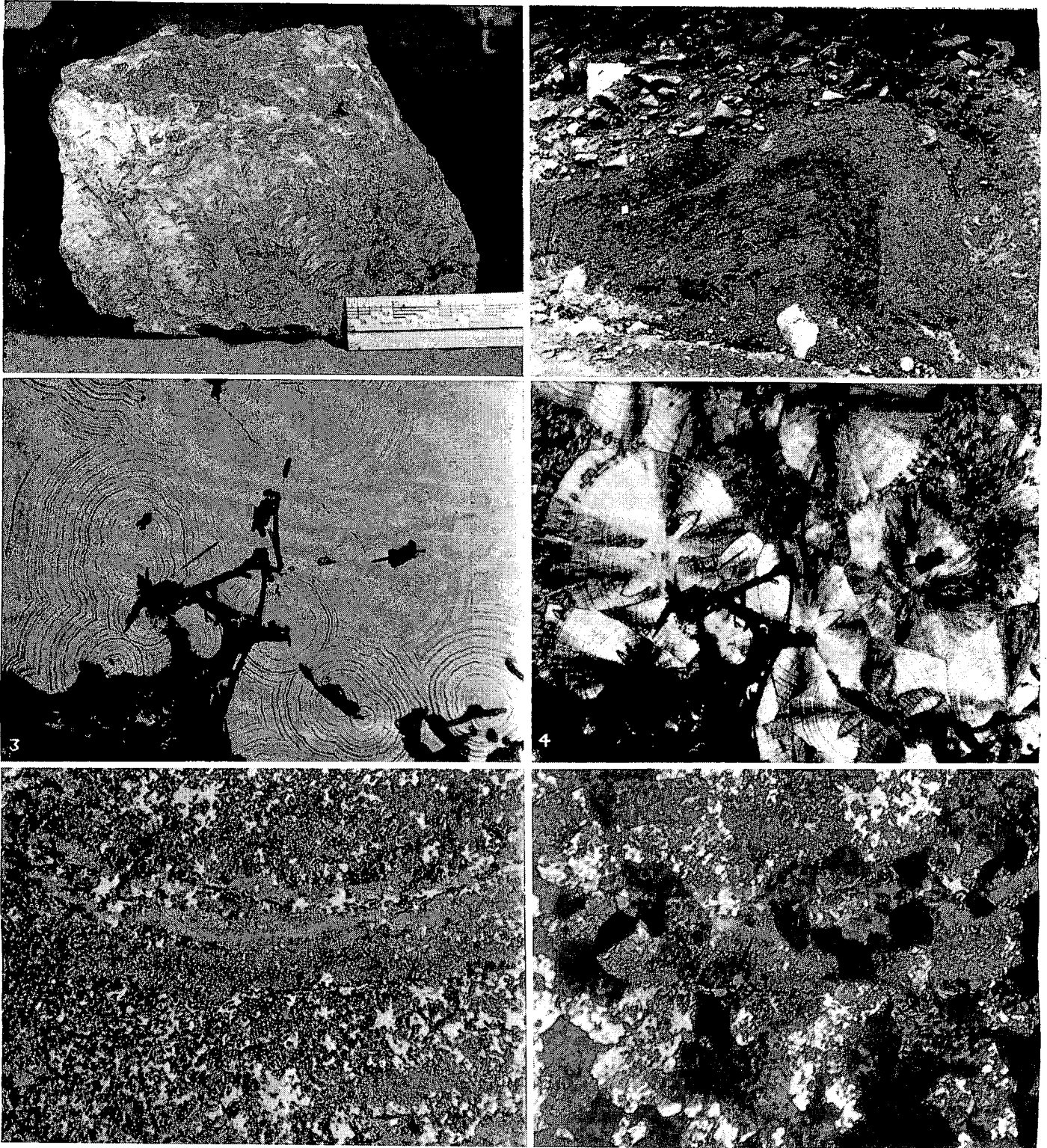


PLATE IV. HONAKER STROMATOLITE, FOLDED ROME SHALE BEDS, AND PHOTOMICROGRAPHS OF SHADY JASPEROID.

Figure

1. Stromatolite found in the Honaker limestone near Mine Hollow; black septa are chert, white are limestone.
3. Photomicrograph of spherulitic jasperoid from the Shady formation, 100 feet north of the top of the Erwin formation along Shut-in Creek. Black aggregates are manganese and iron oxide. Plane polarized light (X 36); O-48-99A.
5. Photomicrograph of jasperoid from Shady dolomite found on east bank of French Broad River, opposite Hot Springs. Bands of brown iron oxide and black manganese oxide are imbedded in quartz. Plane polarized light (X 50); O-48-347.

Figure

2. Folds in the Rome formation exposed in road cut along Dry Branch near Shut-in Creek. Dark band beginning at bottom center is folded to left and then sharply and isoclinally around lighter layer on which package of cigarettes rests (left center).
4. Same field as figure 3, but with crossed nicols to show the spherulitic silica.
6. Same field as 2, but with crossed nicols to show the mosaic outlines of quartz.

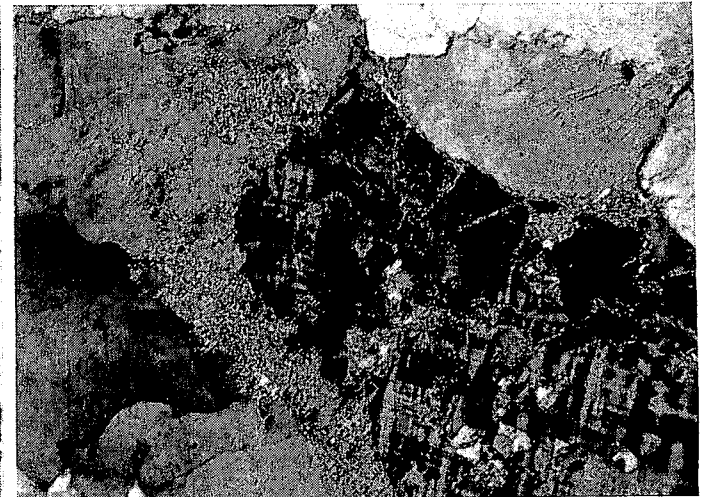
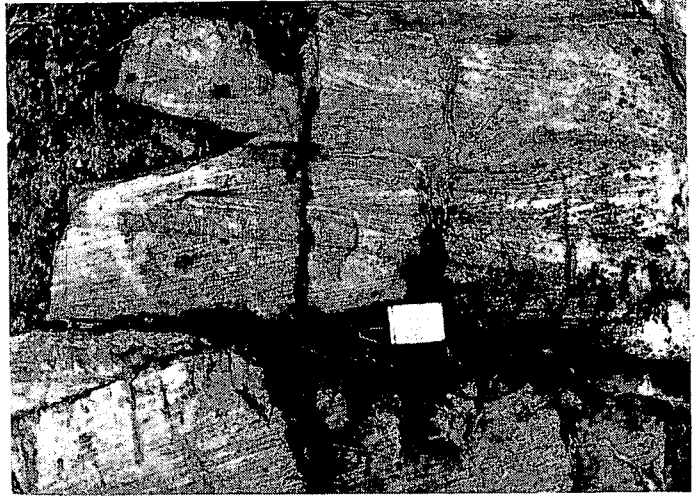
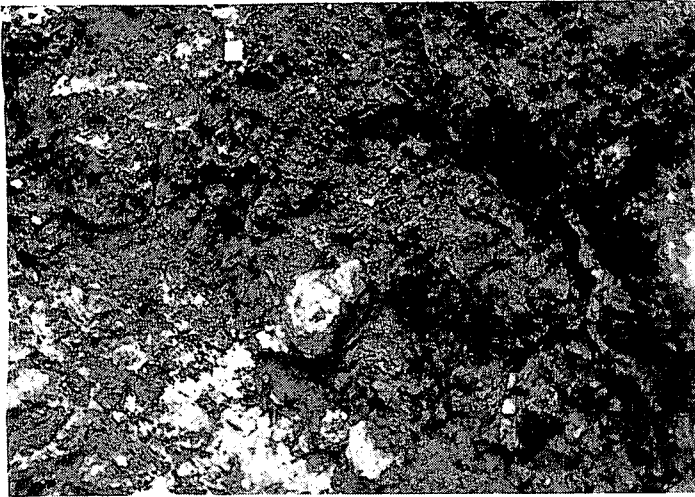


PLATE V. PHOTOGRAPHS OF ERWIN, HAMPTON, UNICOI, AND SANDSUCK ROCKS.

Figure

1. Fault breccia along Camp Ground road about 1200 feet from U. S. Highway 25-70. Fragments of Erwin quartzite, ranging from thin silvers to large blocks, some of which have been rounded, are imbedded in a ferruginous matrix. Cigarette pack near top indicates relative scale.
3. Spheroidal weathering of siltstone in the Hampton formation near house above the first Spring Creek bridge south of Hot Springs. Bedding is parallel to outcrop plane and straight fractures seen in rocks are joints.
5. Basal Unicoi conglomerate showing pebbles and slate inclusion (dark band at right). Hammer is resting in pothole found near the mouth of Big Laurel Creek.

Figure

2. Crossbedding in feldspathic quartzite of the Hampton middle quartzite member along Shut-In Creek.
4. Siltstone in the Sandsuck formation exposed in road cut along N. C. Highway 209. Concentric shells formed by active weathering along bedding (about parallel to plane of photograph) and joints.
6. Photomicrograph of arkose near the top of the Unicoi formation along Spring Creek. Both quartz and microcline are replaced by sericite. Crossed nicols (X 36); O-48-2A.

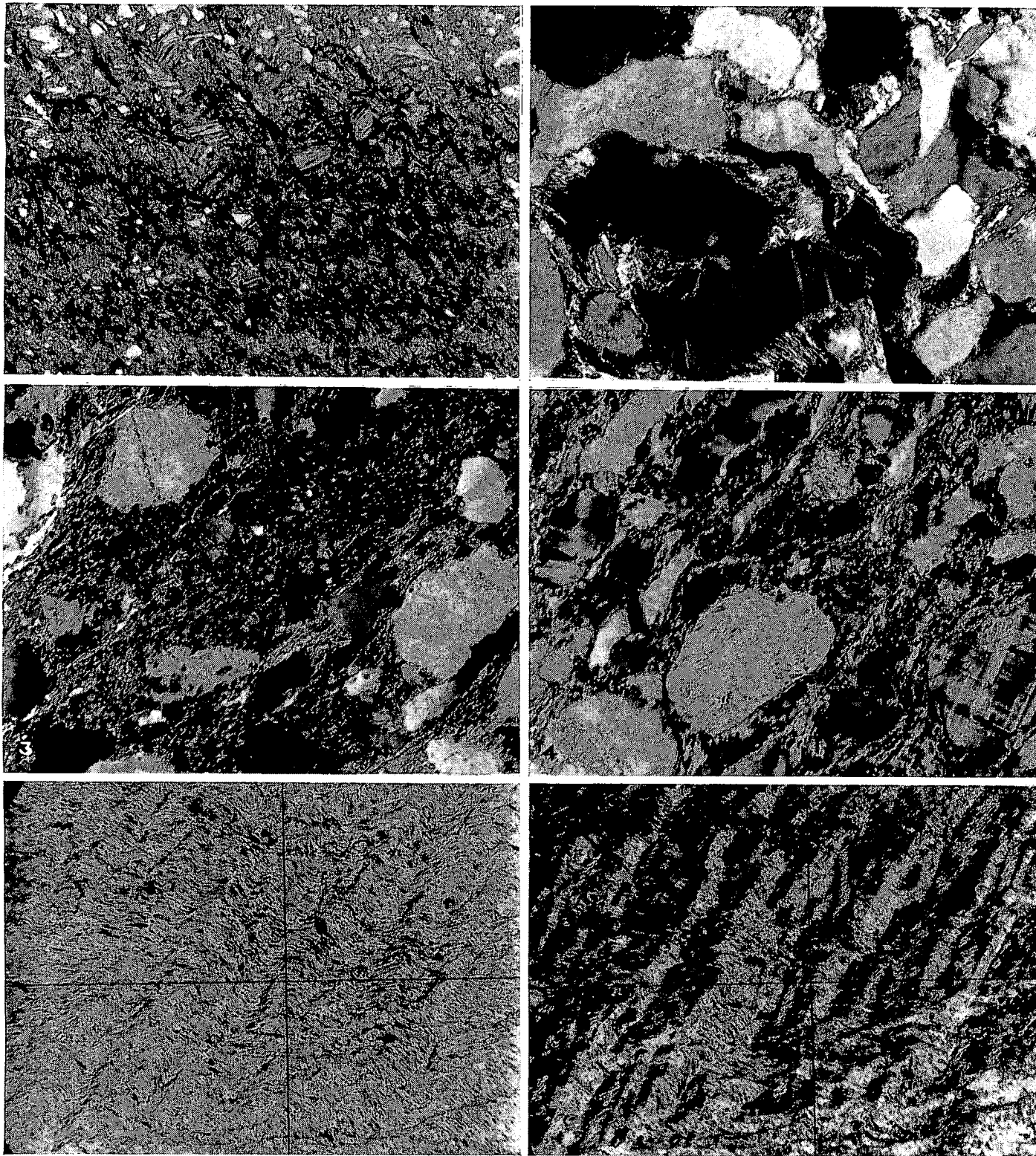


PLATE VI. PHOTOMICROGRAPHS OF SNOWBIRD ROCKS.

Figure

1. Photomicrograph of banded siltstone near the top of the Snowbird formation along East Fork Shut-in Creek. Bedding is horizontal; cleavage cuts across it diagonally. Chlorite lamellae are truncated by cleavage planes. Plane polarized light (X 50); O-48-391.
3. Photomicrograph of somewhat mylonitized Snowbird feldspathic quartzite. Sericite lamellae are parallel to bedding and shear planes. Crossed nicols (X 50); O-48-506.
5. Photomicrograph of sericite phyllite found along thrust fault near Rector Butt. Plane polarized light (X 50); O-48-535.

Figure

2. Photomicrograph of Snowbird quartzite showing growth of sericite plates perpendicular to surfaces of quartz and feldspar grains. Crossed nicols (X 90); O-48-159.
4. Photomicrograph of mylonitized Snowbird feldspathic quartzite. Quartz porphyroclasts show strain shadows and granulated quartz forms fluxion structure around feldspar grains. Crossed nicols (X 50); O-48-973.
6. Same field as figure 5, but with crossed nicols to emphasize microscopic crinkles.

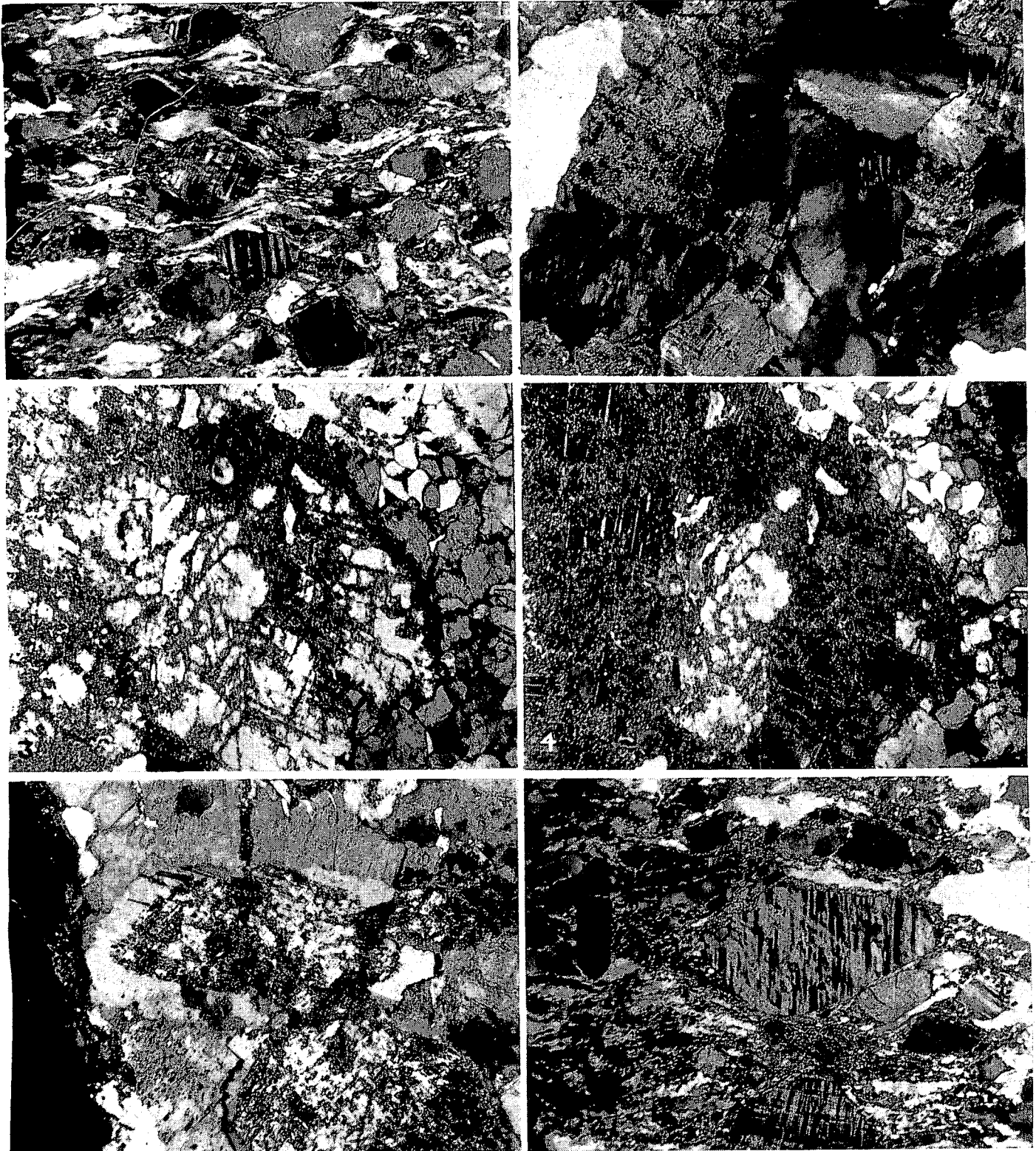


PLATE VII. PHOTOMICROGRAPHS OF SNOWBIRD AND PRE-CAMBRIAN CRYSTALLINE ROCKS.

- Figure
1. Photomicrograph of mylonite in Snowbird formation showing exceptionally well developed fluxion structure formed by quartz and a little sericite around microcline porphyroclasts. Crossed nicols (X 36); O-48-BMP-16.
 3. Sericite replacement of quartz and feldspar in pre-Cambrian crystalline rock. Dark gray mineral on right is hornblende. Plane polarized light (X 31); O-48-529A.
 5. Albite-rimmed saussurite (center) in sericitized and epidotized "Max Patch granite" of Kelth. Crossed nicols (X 90); O-48-MPL.

- Figure
2. Slightly deformed pre-Cambrian crystalline rock found in road cut along N. C. Highway 209. Quartz (with strain shadows), microcline, and saussurite are present. Crossed nicols (X 36); O-48-282.
 4. Same field as figure 3 but with crossed nicols to show plagioclase twinning.
 6. Mylonitized pre-Cambrian crystalline rock. Microcline porphyroclasts are enveloped by thin layers of sericite and by smeared out quartz lenses. Crossed nicols (X 36).

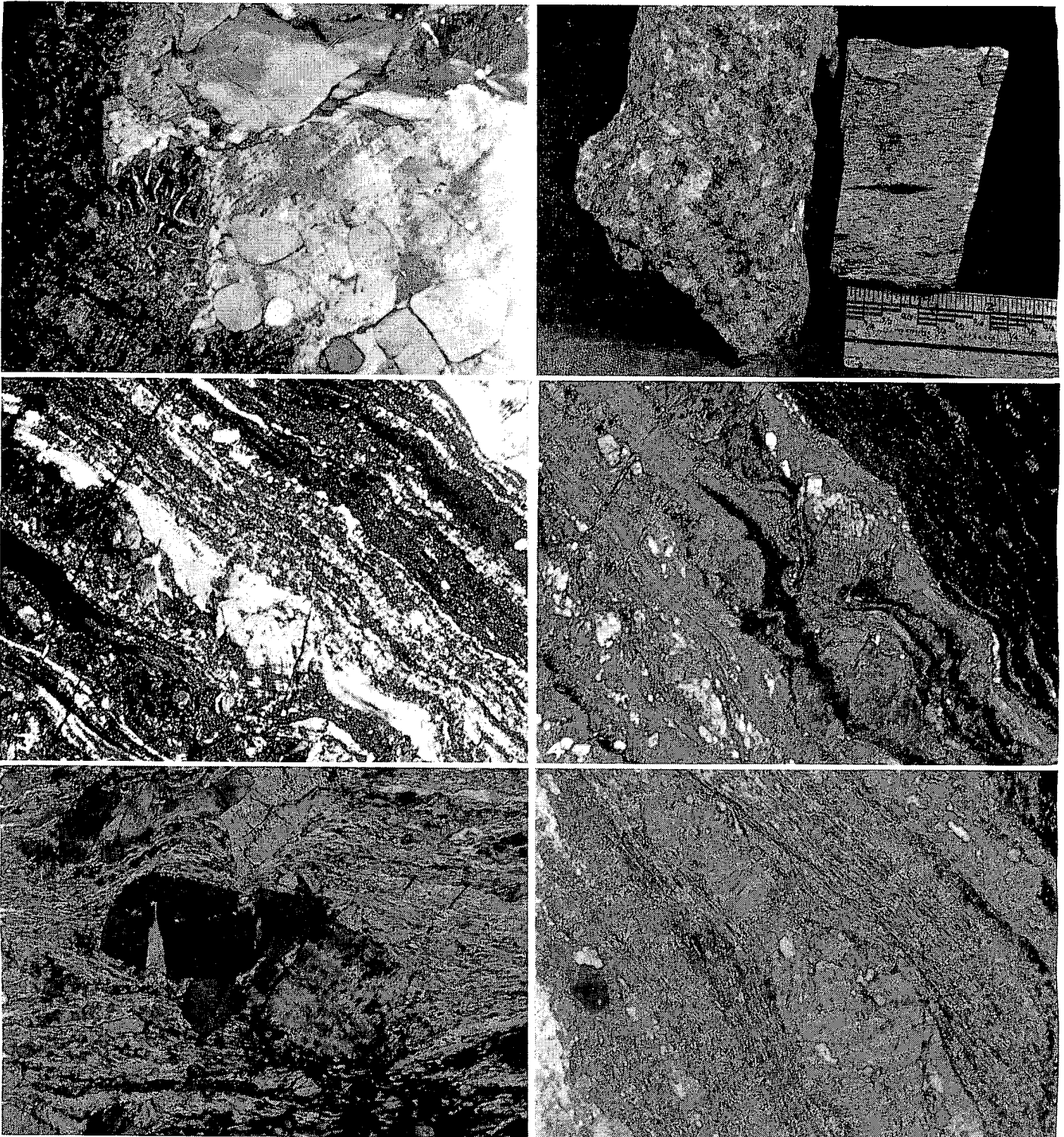


PLATE VIII. PRE-CAMBRIAN CRYSTALLINE ROCKS BEFORE AND AFTER MYLONITIZATION.

Figure

1. Photomicrograph of relatively undeformed "Max Patch granite". Quartz inclusions in microcline do not show strain shadows as do quartz grains not enveloped by feldspar. Albite of myrmekite has been saussuritized. Crossed nicols (X 27); O-48-MPCB.
3. Photomicrograph of mylonite derived from "Max Patch granite". Almost all the quartz is fine comminuted; biotite (in black bands at upper left) is finely shredded; sole survivors are feldspar porphyroclasts. Dark bands at lower left consist of deformed quartz at extinction. Crossed nicols (X 45); O-48-263.
5. Well developed fluxion structure around somewhat fractured feldspar porphyroclasts. Fracture in potash feldspar (left of center) is filled with quartz. Crossed nicols (X 31); O-48-1025.

Figure

2. Hand specimens of "Max Patch granite" and of mylonite derived from it. Divisions on ruler are in inches.
4. Almost same field as in figure 3, but with gypsum plate to show preferred orientation of lattices of granulated quartz in bands.
6. Porphyroclasts of feldspar and sutured quartz surrounded by granulated quartz and sericite. Crossed nicols with gypsum plate (X 36); O-48-753.

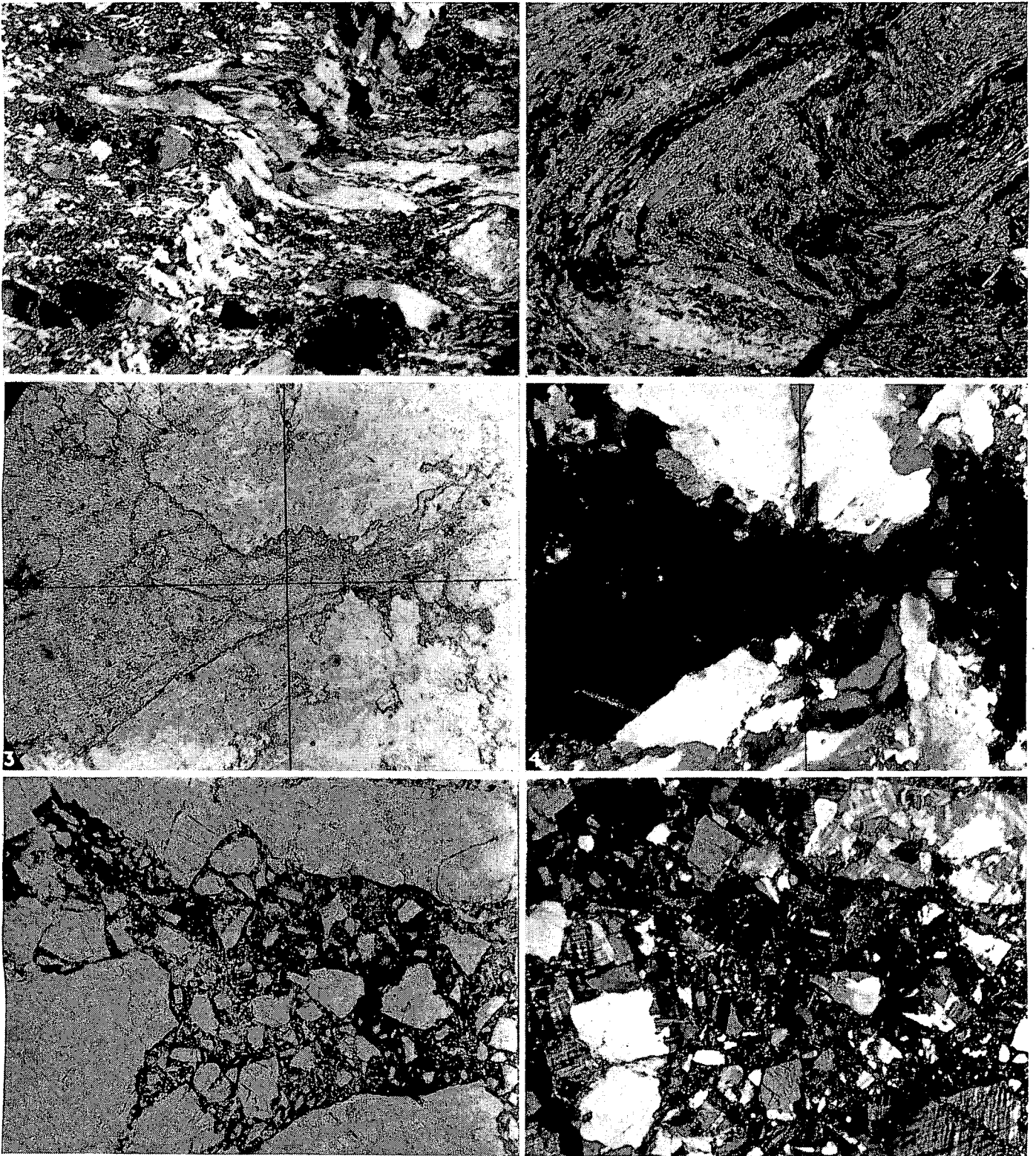


PLATE IX. PHOTOMICROGRAPHS OF PRE-CAMBRIAN CRYSTALLINE ROCKS SHOWING MYLONITIZATION AND MINERALIZATION.

Figure

1. Minor offset developed across shear planes in mylonite. Individual bands are not broken but bent and some of the quartz is recrystallized. Crossed nicols (X 36); O-48-474.
3. Fluorite replacement of country (pre-Cambrian crystalline) rock. Plane polarized light (X 50); O-48-893.
5. Fine-grained spectacular hematite filling voids in brecciated pre-Cambrian crystalline rock. Specimen collected at prospect pit 900 feet southwest of Doe Branch school. Plane polarized light (X 27); O-48-941.

Figure

2. Fan fold developed in ultramylonitized sericite-rich rock. These folds are superimposed on larger ones which measure one to two inches from crest to crest. Crossed nicols (X 36); O-48-789.
4. Same field as figure 3, but with crossed nicols.
6. Same field as figure 5, but with crossed nicols.

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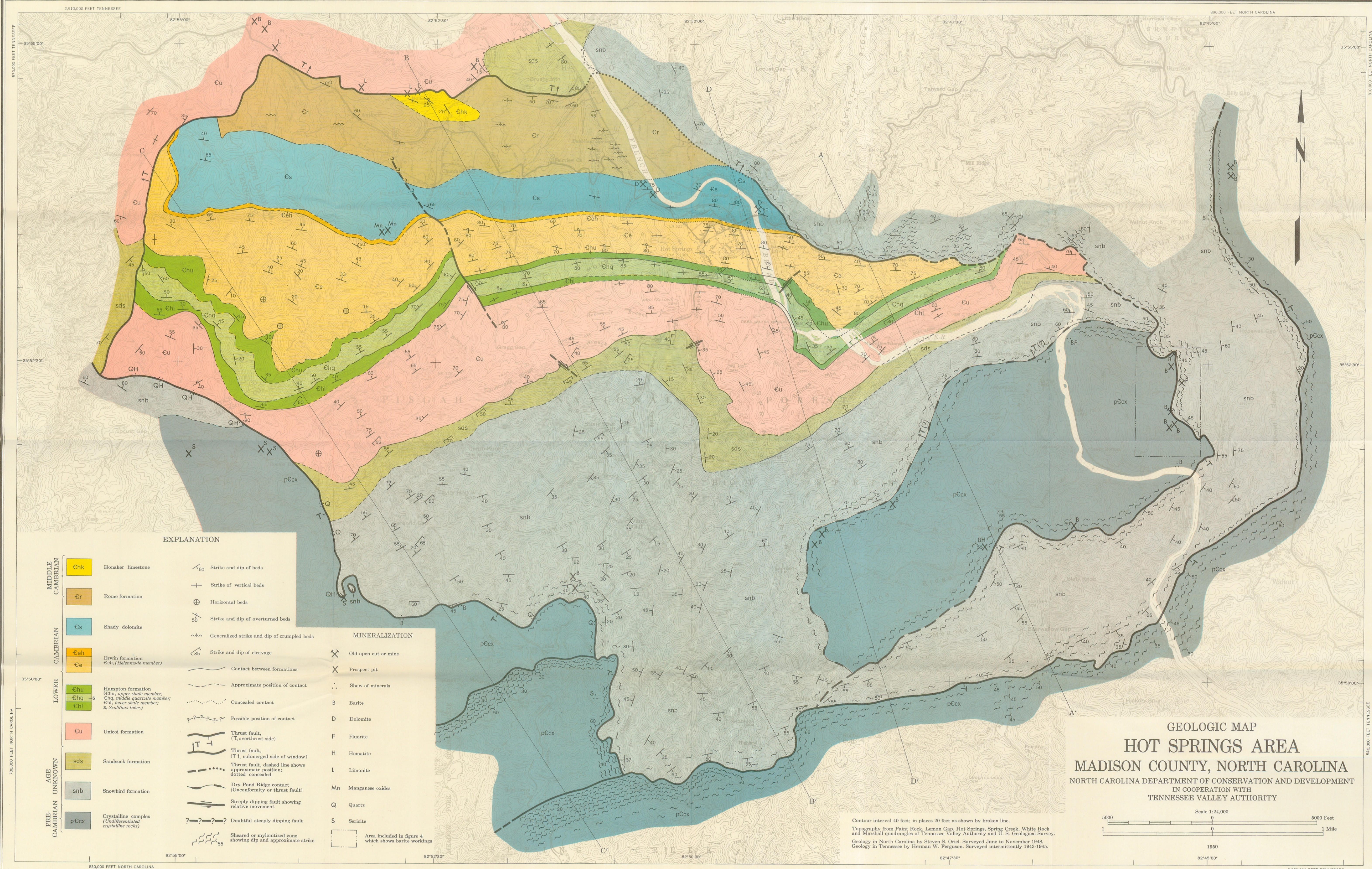
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EXPLANATION

- | | | | | |
|-----------------|------|---|-----------------|--|
| MIDDLE CAMBRIAN | Chk | Honaker limestone | \swarrow_{60} | Strike and dip of beds |
| | Cr | Rome formation | + | Strike of vertical beds |
| | Cs | Shady dolomite | ⊕ | Horizontal beds |
| LOWER CAMBRIAN | Ceh | Erwin formation | \swarrow_{50} | Strike and dip of overturned beds |
| | Ce | Ceh, (Helanade member) | ~ | Generalized strike and dip of crumpled beds |
| LOWER CAMBRIAN | Chu | Hampton formation | \swarrow_{35} | Strike and dip of cleavage |
| | Chq | Chu, upper shale member; Chq, middle quartzite member; Chi, lower shale member; S, Scallithus tubes | — | Contact between formations |
| | Chi | | - - - | Approximate position of contact |
| LOWER CAMBRIAN | Cu | Unicoi formation | · · · | Concealed contact |
| | sds | Sanduck formation | ~ | Possible position of contact |
| AGE UNKNOWN | snb | Snowbird formation | — — | Thrust fault, (T, overthrust side) |
| PRE-CAMBRIAN | pCcx | Crystalline complex (Undifferentiated crystalline rocks) | — — — | Thrust fault, (T1, submerged side of window) |
| | | | - - - | Thrust fault, dashed line shows approximate position; dotted concealed |
| | | | — — | Dry Pond Ridge contact (Unconformity or thrust fault) |
| | | | — — | Steeply dipping fault showing relative movement |
| | | | ~ | Doubtful steeply dipping fault |

MINERALIZATION

- | | |
|-------|---|
| X | Old open cut or mine |
| X | Prospect pit |
| · · · | Show of minerals |
| B | Berite |
| D | Dolomite |
| F | Fluorite |
| H | Hematite |
| L | Limonite |
| Mn | Manganese oxides |
| Q | Quartz |
| S | Sericite |
| □ | Area included in figure 4 which shows barite workings |

GEOLOGIC MAP
HOT SPRINGS AREA
MADISON COUNTY, NORTH CAROLINA
 NORTH CAROLINA DEPARTMENT OF CONSERVATION AND DEVELOPMENT
 IN COOPERATION WITH
 TENNESSEE VALLEY AUTHORITY

Contour interval 40 feet; in places 20 feet as shown by broken line.
 Topography from Paint Rock, Lemon Gap, Hot Springs, Spring Creek, White Rock and Marshall quadrangles of Tennessee Valley Authority and U. S. Geological Survey. Geology in North Carolina by Steven S. Oriol. Surveyed June to November 1948. Geology in Tennessee by Herman W. Ferguson. Surveyed intermittently 1943-1945.

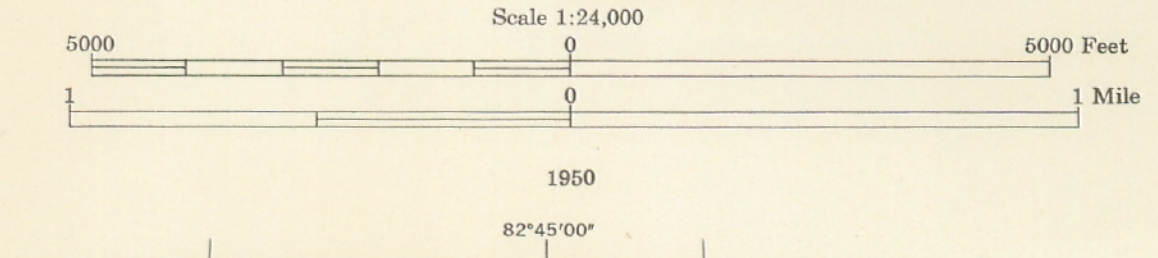


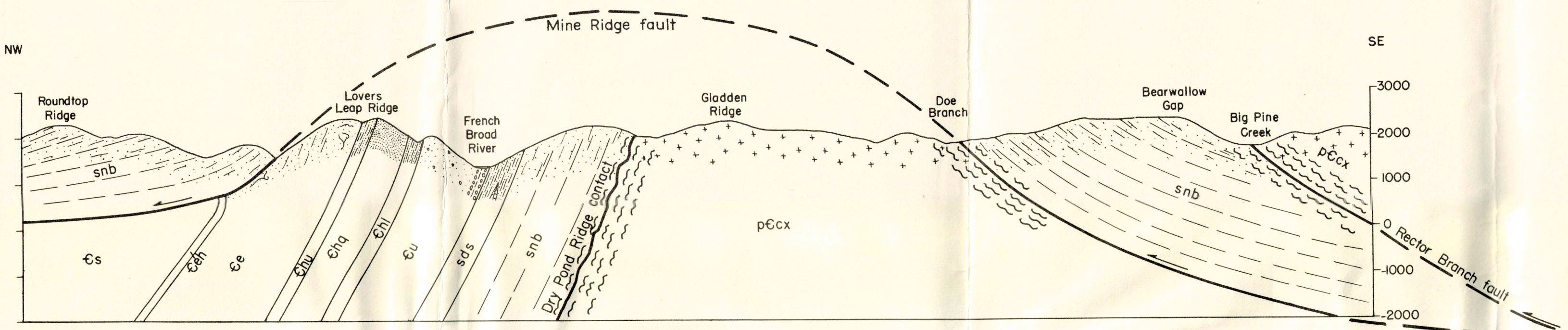
PLATE II
GEOLOGIC STRUCTURE SECTIONS ACROSS THE HOT SPRINGS AREA, MADISON COUNTY, NORTH CAROLINA

(Accompanying Geologic Map, Plate I)

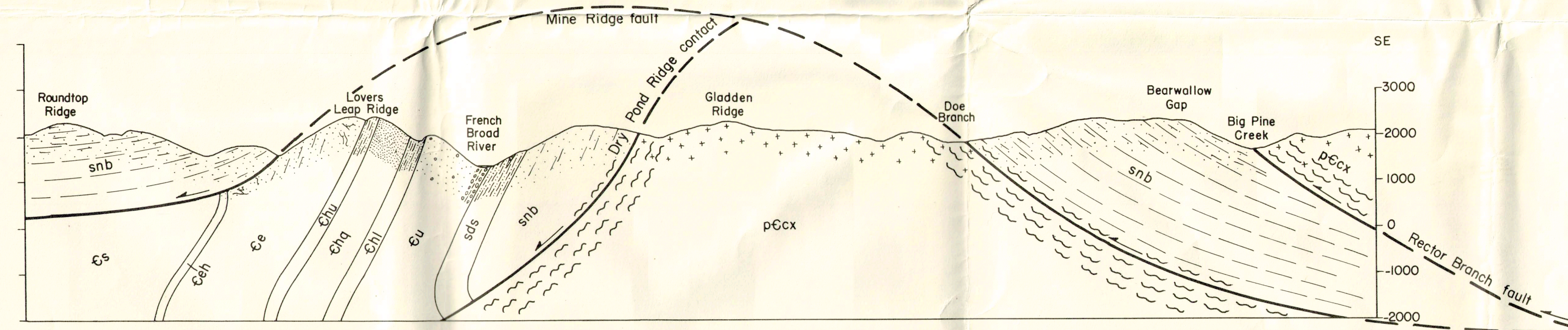
By Steven S. Oriel

EXPLANATION

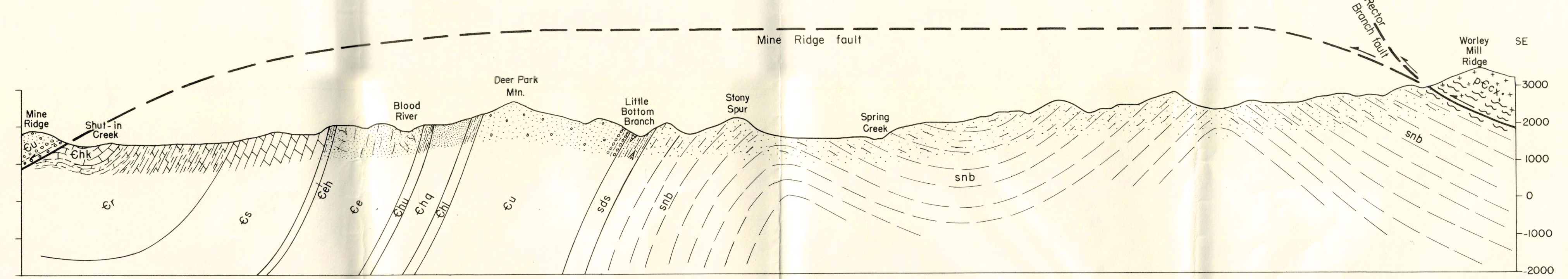
- MIDDLE CAMBRIAN
 - Chk, Honaker limestone
 - Cr, Rome formation
 - Cs, Shady dolomite (with solution cavities)
 - CAMBRIAN
 - Ge, Erwin formation (Ceh, Helenmode member)
 - LOWER CAMBRIAN
 - Hampton formation (Chu, upper shale member; Chq, middle quartzite member; Chl, lower shale member)
 - Eu, Unicoi formation
 - AGE UNKNOWN
 - sds, Sandsuck formation
 - snb, Snowbird formation
 - PRE-CAMBRIAN
 - pCcx, Crystalline complex
- Contact between formations
 ——— Thrust fault (arrows show relative movement)
 -?-?-? Doubtful strike fault
 - - - Trace of bedding on plane of section
 ~~~~~ Sheared or mylonitized zone showing trace of dip on plane of section.



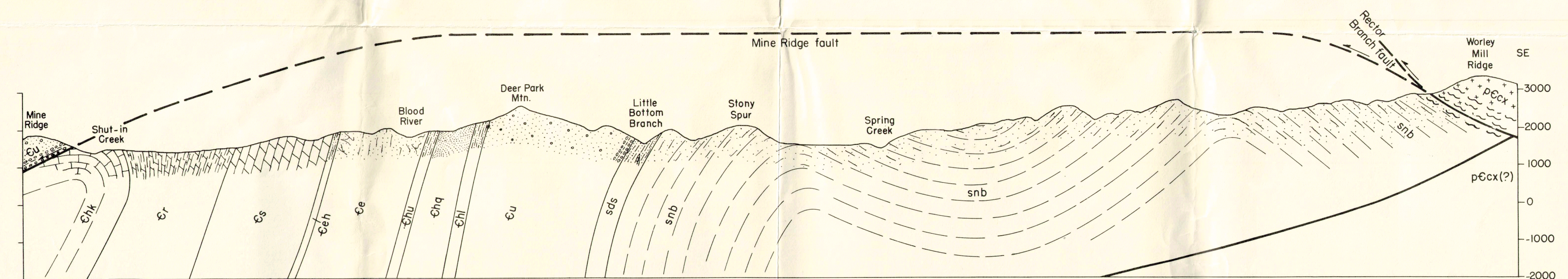
Section along line A-A'. Interpretation 1



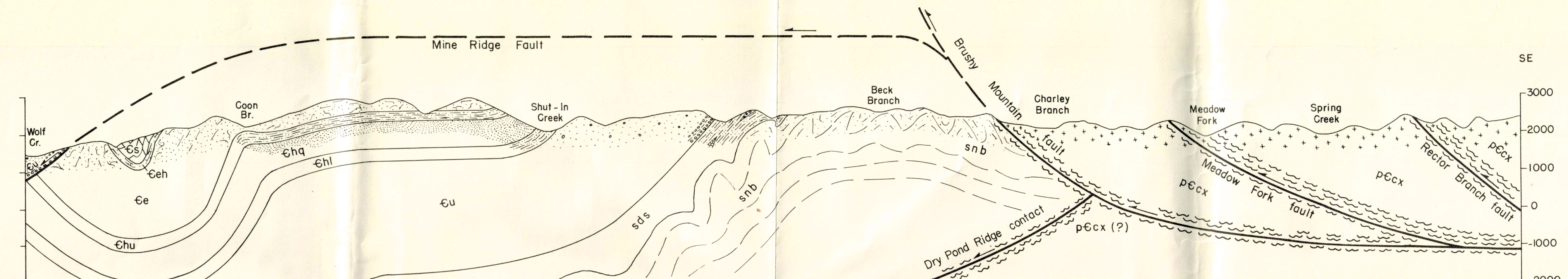
Section along line A-A'. Interpretation 2



Section along line B-B'. Interpretation 1

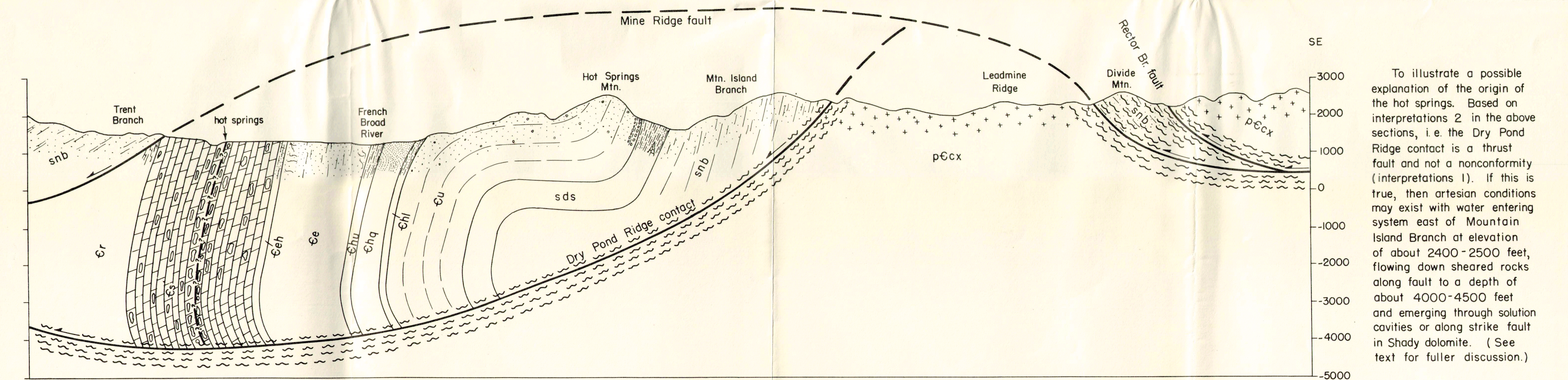


Section along line B-B'. Interpretation 2



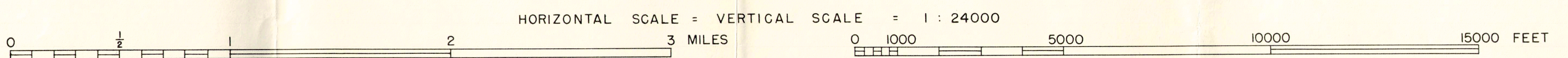
Section along line C-C'. Interpretation 2

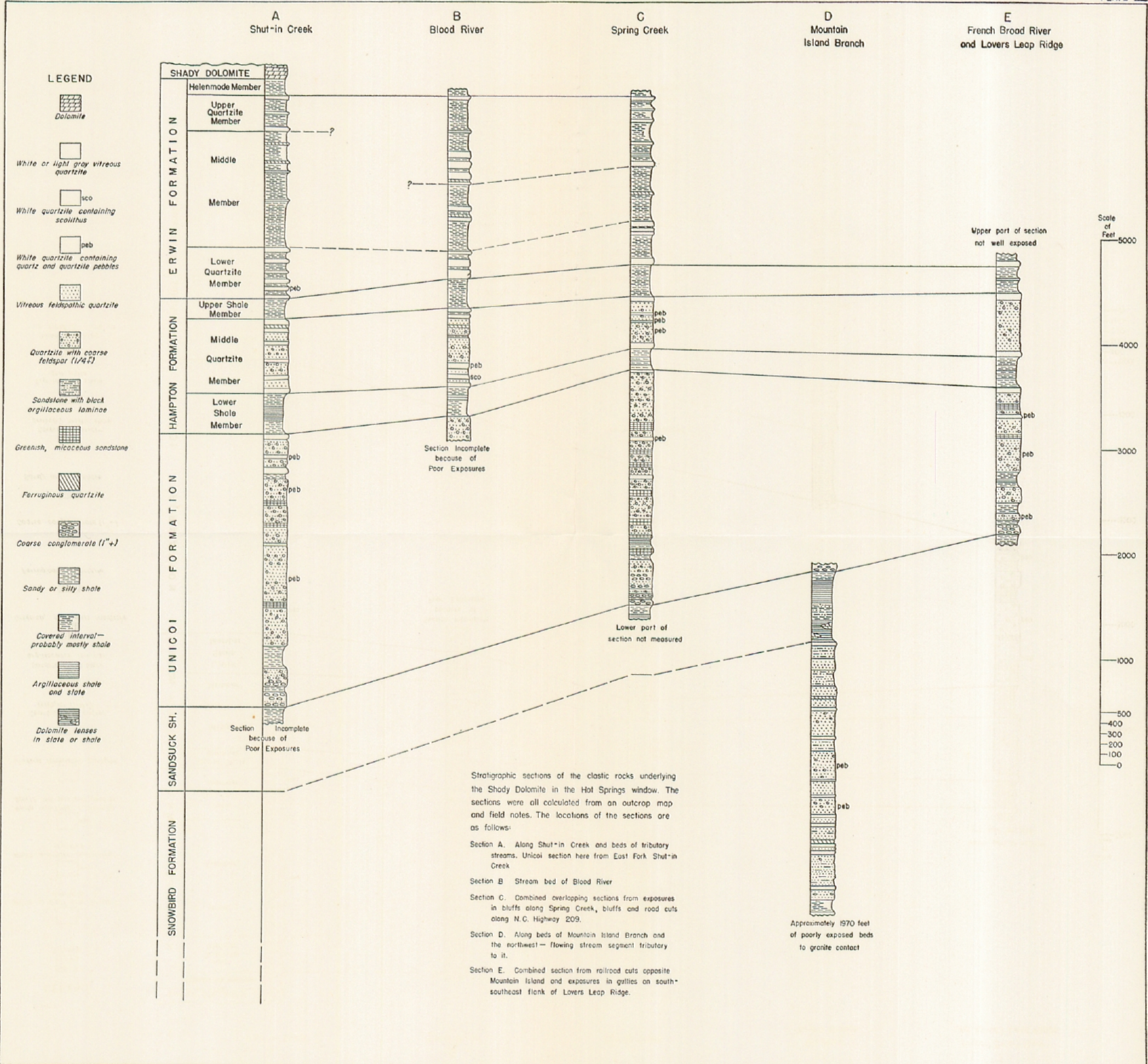
[Almost along line of Section D-D' of Ferguson and Jewell (unpublished, plate I)]



Section along line D-D'

To illustrate a possible explanation of the origin of the hot springs. Based on interpretations 2 in the above sections, i.e. the Dry Pond Ridge contact is a thrust fault and not a nonconformity (interpretations 1). If this is true, then artesian conditions may exist with water entering system east of Mountain Island Branch at elevation of about 2400-2500 feet, flowing down sheared rocks along fault to a depth of about 4000-4500 feet and emerging through solution cavities or along strike fault in Shady dolomite. (See text for fuller discussion.)





Stratigraphic sections of the clastic rocks underlying the Shady Dolomite in the Hot Springs window. The sections were all calculated from an outcrop map and field notes. The locations of the sections are as follows:

Section A. Along Shut-in Creek and beds of tributary streams. Unicoi section here from East Fork Shut-in Creek

Section B. Stream bed of Blood River

Section C. Combined overlapping sections from exposures in bluffs along Spring Creek, bluffs and road cuts along N.C. Highway 209.

Section D. Along beds of Mountain Island Branch and the northwest-flowing stream segment tributary to it.

Section E. Combined section from railroad cuts opposite Mountain Island and exposures in gullies on south-southeast flank of Lovers Leap Ridge.

Approximately 1970 feet of poorly exposed beds to granite contact