Geology of the Central Great Smoky Mountains Tennessee

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By PHILIP B. KING

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GEOLOGY OF THE CENTRAL GREAT SMOKY MOUNTAINS, TENNESSEE

By PHILIP B. KING

ABSTRACT

This report describes the geology of an area about 300 square miles in the central segment of the Great Smoky Mountains, extending 20 miles northward in Tennessee, from the mountain crest at the North Carolina line, across the foothills, into the Appalachian Valley. The south half of the area lies in Great Smoky Mountains National Park. Adjacent areas in the Great Smoky Mountains are dealt with in companion geologic reports by other authors.

Except for a small intrusive body, rocks of the report area are all of sedimentary origin. They consist of varieties of limestone, dolomite, shale, sandstone, siltstone, and conglomerate, which were laid down in later Precambrian and early Paleozoic time, and which have since been much deformed, and in part lightly to heavily meamorphosed. The younger sedimentary rocks, of Ordovician and Cambrian ages, are exposed toward the north, in the Appalachian Valley, on Chilhowee Mountain, and in coves in the foothills; those of later Precambrian age, termed the Ocoee series, are exposed in the south, in the foothills and main mass of the Great Smoky Mountains. Total thickness of sedimentary rocks in the area is certainly more than 5 miles, but because of missing intervals produced by deformation, and uncertainties as to succession, the total is undetermined.

The Ocoee series of the foothills and mountain area is a body of terrigeneous clastic rocks, which has minor intercalations of limestone and dolomite but no volcanic components or known fossils. Many of the clastic rocks are coarse grained, most are poorly sorted texturally and mineralogically, and few are cleanly washed. Many parts are monotonous sequences, changes from one rock type to another being gradational both vertically and laterally. The rocks of the Ocoee series are divisible into broad lithologic units—the Snowbird group, Great Smoky group, and Walden Creek group—which are, in turn, divided into intertonguing and intergrading formations of local extent.

Within the report area the Snowbird group occurs in the southern part of the mountain foothills and is as much as 17,000 feet thick. It consists of relatively fine-grained rocks, mainly siltstone, but includes some interbedded argillaceous rocks and many sandstone layers in the lower part. The base of the Snowbird group is not exposed in the area, but elsewhere it lies unconformably on basement rocks. At one locality the Snowbird is overlain conformably by the Rich Butt sandstone which is also part of the Ocoee series, but is not assigned to any of the groups.

The Great Smoky group lies mainly south of the Snowbird group and forms the main mass of the Great Smoky Mountains, where it is as much as 25,000 feet thick. The Great Smoky group consists mainly of rocks coarser grained than the Snowbird group; they include fine conglomerate and coarse to fine sandstone interbedded with layers of silty or argillaceous slates and phyllites. Nearly all the coarse rocks are graded, in layers a few feet to ten feet thick, and have wide textural range in each layer. The middle part of the Great Smoky group is dominantly coarse sandstone and fine conglomerate, and the lower part is finer grained sandstone; in the upper part are thick intertonguing units of dark slate and phyllite. Within the report area, neither the base nor the top of the Great Smoky group are exposed; farther southeast it overlies the Snowbird group, and farther south it is overlain by rocks of the Murphy marble belt.

The Walden Creek group lies north of the Snowbird group, forming the northern part of the mountain foothills, and is as much as 8,500 feet thick. It is more heterogeneous than the other groups of the Ocoee series, consisting of argillaceous and silty rocks, discontinuous masses of conglomerate and sandstone, and minor layers of quartzite, limestone, and dolomite. Within the report area the base of the group is not exposed, but farther northeast rocks lithologically like the Walden Creek group overlie rocks lithologically like the Snowbird group. On Chilhowee Mountain the uppermost beds of the Walden Creek group are overlain, probably disconformably, by the Chilhowee group.

Within the report area the Ocoee series is broken into fault blocks as a result of the great deformations to which it has been subjected, and the three groups occur in different blocks so that their mutual relations are not apparent. The intergrading and intertonguing which has been proved between the different formations suggests that similar relations existed between the groups also. Observations in the broader Great Smoky Mountain region indicate that the Snowbird group is the lowest unit and the Walden Creek the highest; the stratigraphic position of the Great Smoky group is less clear, but it may be at least partly equivalent to the Walden Creek group.

The Chilhowee group, which overlies the Walden Creek group on Chilhowee Mountain, contains diagnostic Lower Cambrain fossils in its upper beds, and trace fossils extend downward to about its middle; it is classed as of Cambrian(?) and Cambrian ages. The group is as much as 3,200 feet thick, and consists of sandstone, feldspathic below and quartz-

ose above, and several well-differentiated interbedded shale formations. It is overlain by the Shady dolomite of Early Cambrian age, small remnants of which are preserved in the report area.

The remaining sedimentary rocks are of Ordovician age and as much as 7,500 feet thick. The upper part of the Knox group, of Early Ordovician age, is largely limestone and dolomite, but the succeeding rocks of Middle Ordovician age are mostly shale, siltstone, and fine-grained sandstone; many of these are calcareous, but limestone layers are subordinate.

No strata higher than those of the Middle Ordovician series are preserved in the report area, although a short distance to the west these are succeeded by others of Devonian and Mississippian ages. Within the Great Smoky group of the mountain area is a small body of intrusive metadiorite, which is interpreted also to be of Paleozoic age.

The Great Smoky Mountains lie within the strongly deformed region of the southern Appalachians. The report area includes parts of two tectonic provinces of different structural habit, the mountains and foothills lying in one and the Appalachian Valley in another. South of the boundary between them a wide zone of thrust faulting extends across the central part of the area.

Two major low-angle faults dominate the zone. The northwestern, or Great Smoky, has moved the rocks of the mountains and foothills at least 10 miles over the rocks of the Appalachian Valley; it is a late feature of the deformation, little disturbed since its emplacement and younger than the regional metamorphism. Some miles to the southeast is another major low-angle fault, the Greenbrier, which has moved the rocks of the main Great Smoky Mountains northwestward over those of the foothills; it is older than the Great Smoky fault, was folded and faulted after its emplacement, and is earlier than much of the regional metmorphism. In the same area as the Greenbrier fault are the major high-angle faults of the Gatlinburg family, which are late features of the deformation like the Great Smoky fault, but which have been displaced not only by dip-slip but by strike-slip movements. Besides these major faults the zone includes a host of others of various magnitudes, which form a complex network in the foothill area in which some faults offset others. Some of these faults probably moved as early as the Greenbrier fault, others as late as the Great Smoky fault.

The rocks between the faults have been variably deformed, depending partly on their competency, partly on their structural situation. The Chilhowee group and upper part of the Walden Creek group on Chilhowee Mountain are openly folded, but the rest of the Walden Creek group is greatly disordered, showing complex small-scale folds and faults in nearly every exposure. The Snowbird group in the eastern part of the report area is again openly folded, but to the west its rocks are more foliated, contorted, and sheared. The Great Smoky group of the mountain area forms a broad homocline, little disrupted by faulting, in which the rocks dip moderately to steeply southeastward.

Rocks of the Appalachian Valley are virtually unaltered, but those of the foothills and mountain area are regionally metamorphosed, the strength of the metamorphism increasing southeastward. Physical effects of the metamorphism increase variably, the mineralogic effects regularly and progressively. The northern part of the metamorphosed rocks is characterized by the mineral chlorite and the part to the south by the mineral biotite; in the extreme south, however, garnet occurs in small amounts with the biotite. The foliation produced by the regional metamarphism has been widely deformed by later slip cleavage, and locally by various shear structures. The chronologic sequence of these small-scale structures is obviously related to that of the major structures, but details of the relation have not been determined.

After deformation of the rocks of the Great Smoky Mountains had been completed, presumably in late Paleozoic time, the region was subjected to subaerial erosion, under conditions of increasing crustal stability. This regime has continued to the present, with variations and modifications, and the region has been degraded, from levels high above any rocks or topographic forms now preserved, to its present configuration. Most of the record of these events has been lost, but the later events are indicated by partially preserved landforms, residuum, and deposits.

Oldest well defined landforms are remnants of a Valley Floor surface, which extended widely across the mountain foothills and into the Appalachian Valley during part of Tertiary time. When it was formed, saprolite and other residual materials accumulated widely, not only on the valley floor, but on the mountain areas.

No certain record remains of early Pleistocene time, but later Pleistocene events are indicated by various alluvial and colluvial deposits. In places, several sets of deposits can be differentiated, the earlier of which were eroded before the accumulation of the later; the deposits probably formed during glacial substages of Wisconsin time, and their erosion during interglacial substages. During glacial substages no glaciation occurred in the area; but the climate was colder than now, imposing a harsh erosional regime in the mountains, part of which projected above timberline. Earlier formed saprolite was shifted downslope as colluvium, to which fragments were also contributed by mass wasting of the underlying bedrock. These processes resulted in block fields on the mountain slopes and bouldery alluvium near the mountain bases; they also made available material that was deposited along the streams farther out, which is now preserved in places as terraces.

The Recent epoch is represented mainly by stream alluvium, but grass balds and other vegetational features in the mountains preserve the record of minor climatic fluctuations.

Mineral deposits of economic interest are meager in the area. Small deposits of iron ore were worked by the early settlers, and stone has been quarried in places for local construction. Largest present mineral production is of limestone of the Knox group, which is quarried in places for use in highway construction and other purposes.

INTRODUCTION

PLAN AND PURPOSE OF REPORT

The boundary between Tennessee and North Carolina is delimited for about 50 miles in midlength by the crests of the Great Smoky Mountains, which include some of the highest summits in the southeastern United States, and culminate in Clingmans Dome, which has an altitude of 6,642 feet. Ramifying spurs and foothills descend northwestward from the State-line divide toward the Appalachian Valley in Tennessee, as well as southeastward toward the less regularly disposed mountains of the main part of the Blue Ridge in North Carolina. All the Great Smoky Mountains are heavily forested, the higher summits being covered by spruce and fir and the lower slopes by a great variety of hardwoods. Much of this forested mountain wilderness has been set aside for the American people as Great Smoky Mountains National Park.

To the geologist, as well as to the naturalist and vacationist, the Great Smoky Mountains are of prime interest, as they display a transition from the deformed, but fossiliferous and unaltered Paleozoic rocks of the Appalachian Valley on the northwest, into the crystalline metamorphic and plutonic rocks of the main part of the Blue Ridge on the southeast. The mountains are formed of a great mass of clastic, unfossiliferous sedimentary rocks, the Ocoee series of later Precambrian age, which have been transported many miles northwestward over the Paleozoic rocks along low-angle faults. On the northwest these clastic rocks are little altered, if at all, but southeastward they pass gradually into rocks almost as thoroughly crystalline and metamorphosed as the adjacent ones in the Blue Ridge.

Between 1946 and 1954 Great Smoky Mountains National Park and its surroundings were investigated geologically by a field party of the U.S. Geological Survey, and the greater part of the region was mapped in detail. The present report describes part of the results of this investigation—a segment in the center of the mountains—covering an area of about 300 square miles. The segment is 14 miles broad, and extends 20 miles southward, from the southeastern part of the Appalachian Valley to the mountain crest on the Tennessee-North Carolina boundary. It lies in Sevier and Blount Counties, Tenn., and embraces the Walden Creek, Pigeon Forge, Wear Cove, and Gatlinburg 7½-minute topographic quadrangles, as well as the northern parts of the Thunderhead and Silers Bald 7½-minute quadrangles (fig. 1).

The part of the results of the U.S. Geological Survey investigation east of the present report area is being described in other reports by Jarvis B. Hadley, Richard Goldsmith, and Warren Hamilton. The part west of the present report area is being described in a report by Robert B. Neuman and Willis H. Nelson. These reports form companion pieces to the present work.

PRESENT WORK

The central Great Smoky Mountains, and the Great Smoky Mountains in general, are, geologically speaking, a region of great difficulty and complexity which, up to the time of the present investigation (1946), were little known or understood. Within the present report area the only comprehensive work which had been done previously was that of Arthur Keith, published in the Knoxville folio of 1895, which was in effect a preliminary reconnaissance. During the 9 years of the present investigation many geologists worked in the report area and, as understanding developed slowly, it was necessary to review and revise the work done earlier as the investigation progressed.

Initial work on the Great Smoky Mountains project was a study of three quadrangles lying centrally on the north flank of the range, the Wear Cove, Gatlinburg, and Cartertown (fig. 1), which were mapped, respectively, by Herman W. Ferguson, Philip B. King, and Jarvis B. Hadley. Two of these quadrangles, the Wear Cove and Gatlinburg, lie in the present report area, and the Cartertown in one of the report areas to the east. At the conclusion of the initial work in 1948, much information on the geology had been obtained, but it was realized that no certain interpretation of the stratigraphy, structure, or other features was yet possible. Results on the three quadrangles were accordingly laid aside until a wider area of the mountains could be studied. Observations and conclusions on the Wear Cove and Gatlinburg quadrangles as here presented are considerably modified from those available at the close of the initial work.

As a part of the initial work, the Gatlinburg quadrangle was mapped by King between September 1946 and March 1948.

The Wear Cove quadrangle was similarly mapped by Ferguson with the assistance of George D. Swingle, between November 1946 and December 1948. These geologists were at that time on the staff of the Tennessee Division of Geology, and their work was done under cooperative arrangement between the Division and the U.S. Geological Survey. In addition, during the same period, they extended their mapping southward to the Tennessee-North Carolina boundary and northward to the Appalachian Valley, to include parts of the Thunderhead, Silers Bald, and Walden Creek quadrangles. Other duties prevented these geologists from continuing with the project beyond its initial phase, and they were unable to take part in the later review and revision.

After completion of mapping in the Gatlinburg quadrangle, King likewise extended his mapping to the south and north:

Mapping was done in the Silers Bald quadrangle on the south between February and April 1949, with the assistance of Robert B. Neuman, connecting on the west with the part of the quadrangle mapped by Ferguson and Swingle. Because of the inaccessibility of the area, traverses were spaced widely, and the

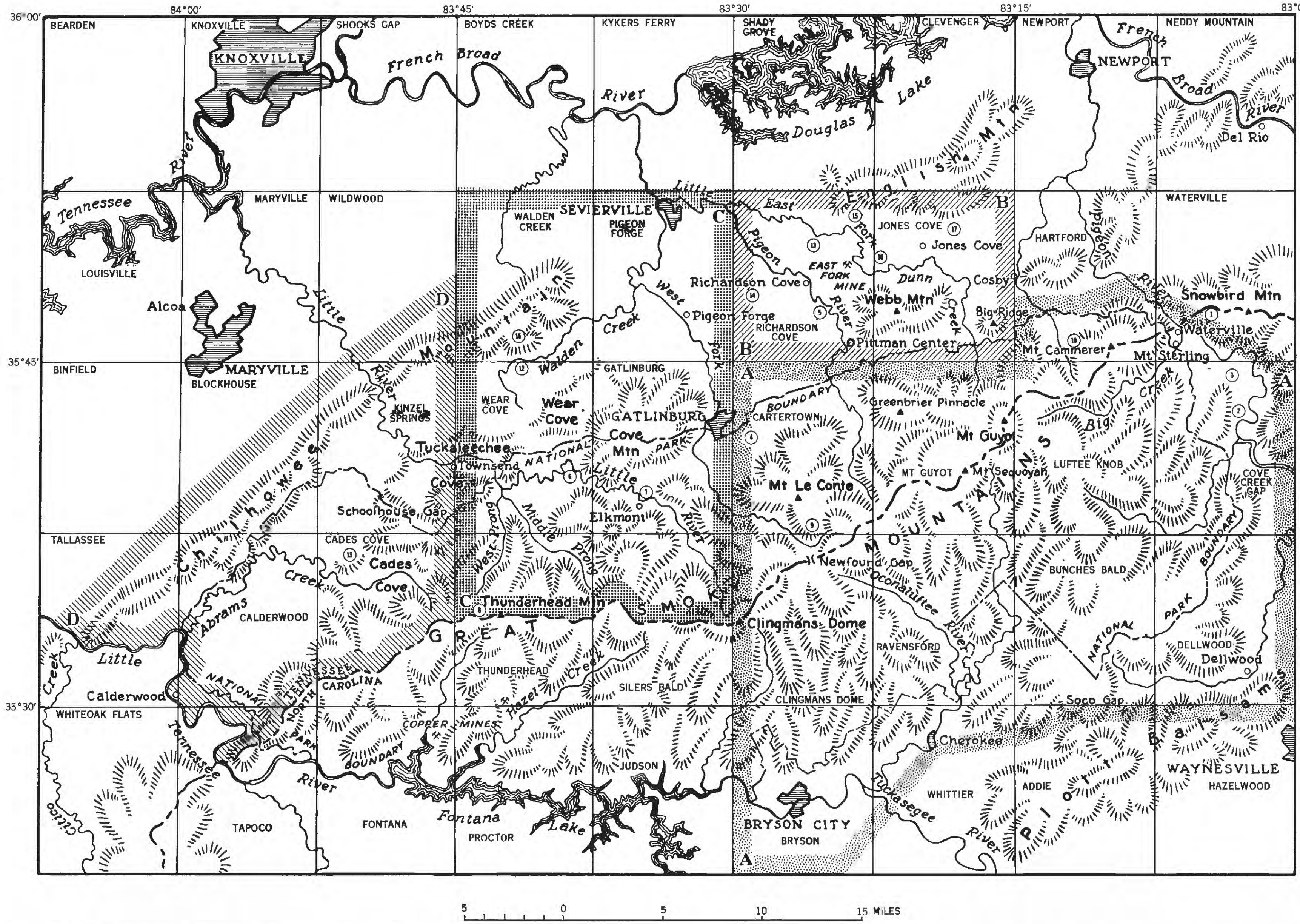

FIGURE 1.—Index map of Great Smoky Mountains and vicinity, showing named 7½-minute quadrangles, areas covered by reports on Great Smoky Mountains, and type localities of stratigraphic units of Ocoee series. Areas covered by reports: *A*, Eastern Great Smoky Mountains, by J. B. Hadley and Richard Goldsmith. *B*, Richardson Cove and Jones Cove quadrangles, by Warren Hamilton. *C*, Central Great Smoky Mountains, by P. B. King. *D*, Western Great Smoky Mountains, by R. B. Neuman and W. H. Nelson. Type localities of formations: 1, Snowbird Mountain. 2, Wading Branch Ridge. 3, Longarm Mountain. 4, Roaring Fork. 5, Little Pigeon River. 6, Metcalf Bottoms. 7, Elkmount. 8, Thunderhead Moutain. 9, Anakeesta Ridge. 10, Rich Butt Moutain. 11, Cades Cove. 12, Walden Creek. 13, Licklog Hollow. 14, Shields Mountain. 15, Wilhite Creek. 16, Dixon Mountain. 17, Yellow Breeches Creek. 18, Sandsuck Branch.

resulting coverage is less complete than that in any of the other quadrangles.

Mapping in the Pigeon Forge quadrangle on the north was carried on at intervals between June 1948 and April 1954, incorporating an earlier preliminary study of part of the area by John K. Lydecker in July and August 1947. The rest of the mapping of the Pigeon Forge quadrangle south of the Appalachian Valley was completed by Warren Hamilton in April and May 1954, as an extension of his work on the Richardson Cove quadrangle to the east.

In 1949, Neuman began a study of the Ordovician rocks in the Great Smoky Mountains project area, and between March 1950 and June 1951 he mapped these rocks in the part of the Appalachian Valley in the Walden Creek and Pigeon Forge quadrangles. During the same period Neuman also revised previous mapping by King, Ferguson, and Swingle of the Ordovician rocks exposed in Wear and Tuckaleechee Coves in the Gatlinburg and Wear Cove quadrangles.

Between September 1951 and April 1954 King revised the rest of the initial mapping in the Wear Cove, Walden Creek, and Thunderhead quadrangles, giving principal attention to the problems of the Walden Creek group. Previous observations were reviewed, and an extensive net of additional traverses was run between the earlier ones. As a result of revisions by King and Neuman in these quadrangles, mapping by Ferguson and Swingle was much altered, except in the Chilhowee Mountain area of the Walden Creek quadrangle and the mountain area of the Thunderhead quadrangle.

Rock specimens collected by King, Ferguson, and Swingle during the initial phase of the investigation were studied in thin section under the microscope by Hadley. At the close of the investigation, a suite of rock types which had not been included in Hadley's work was similarly studied by Hamilton.

On completion of fieldwork, those varied results were assembled by King, who prepared the manuscript, maps, sections, and other illustrative material, and worked out conclusions and interpretations. He is therefore credited with authorship of the report. In the text, significant contributions by the other geologists are indicated by footnotes, but it should be understood that in many places these contributions are so complexly interwoven that they cannot always be appropriately credited.

ACKNOWLEDGMENTS

The Great Smoky Mountains project of the U.S. Geological Survey was undertaken at the request of the National Park Service, primarily to provide additional scientific data as an aid to its naturalist program in Great Smoky Mountains National Park, and incidentally as an aid to construction of engineering works in the park. The field party is indebted to the park superintendents of the period, Blair A. Ross, John C. Preston, and Edward A. Hummel, and to other members of the National Park Service staff in Gatlinburg, for many courtesies and much assistance, including use of working quarters and equipment. Work on the project was carried on in close cooperation with Arthur Stupka, park naturalist, with whom information was freely exchanged, and who has checked many of the nongeologic data during preparation of the manuscript for the present report. Similar close cooperation was had with Frederick W. Cron and others of the staff of the U.S. Bureau of Public Roads in Gatlinburg, who were engaged in surveys and construction work in the national park and its vicinity.

The field party is also indebted to the State Geologists of Tennessee of the period, H. B. Burwell, Herman W. Ferguson, and William D. Hardeman, for making possible the arrangement during the initial phase of the project by which the fieldwork of Ferguson and Swingle could be carried out, and for subsequent loan of field maps, notebooks, and specimens resulting from this work.

During the investigation, Robert A. Laurence, of the U.S. Geological Survey, was an unfailing source of aid and counsel, and provided the facilities of his Knoxville office.

Treatment of Cenozoic deposits and landforms in the present report was greatly aided by field conferences with Charles S. Denny, Gerald M. Richmond, and Harold E. Malde, of the U.S. Geological Survey, who are engaged in research in Pleistocene geology.

In July 1950, K. J. Neuvonen, now of Helsinki, Finland, collected a suite of rocks from the Great Smoky Mountains and made petrofabric analyses of many specimens, including four from the present report area, results of which are noted in this report.

In May 1951, the U.S. Bureau of Mines drilled a hole to a depth of 70 feet in Big Spring Cove to verify a deduction that this area is a window in the Great Smoky thrust sheet, underlain by limestone. The field party is indebted to Victor J. Lynch, chief of the Mining Branch, Southeastern Region, for making this test possible.

A master's thesis of the University of Tennessee by J. G. Bumgarner contains data on the Fair Garden anticline of the Pigeon Forge quadrangle which usefully supplements the work of the party and which was made available through the courtesy of its author.

The field party is further indebted to many local residents of the central Great Smoky Mountains during the extended period of the investigation, for their interest in the work being done, for their encouragement, and for providing access to areas not otherwise accessible. Among the many, specific mention should be made of Mr. A. G. Heinsohn, who permitted a survey of his Norton Creek Ranch, which covers an extensive district in the northern part of the Gatlinburg quadrangle.

PREVIOUS WORK

Although brief mention has been made of the central part of the Great Smoky Mountains in various geologic publications, beginning with one by the first State Geologist of Tennessee, Gerard Troost (1841, p. 27–44), the only previous works bearing significantly on the area are those of James M. Safford, second State Geologist, in the period just before and after the Civil War (1856; 1869, p. 21–30, 49–52, 188–191, and others), and of Arthur Keith (1895a) for the Knoxville folio between 1889 and 1894.

All later geologists are indebted to Safford for laying the groundwork of much of the geographic and geologic knowledge of the "Unaka Chain," or mountain area of east Tennessee. He divided its rocks into an "Ocoee conglomerate and slate" and an overlying "Chilhowee sandstone," both assigned to a Potsdam or Lower Silurian age (Safford, 1869, p. 158). The first, the modern Ocoee series, was named for the gorge of the Ocoee River south of the Great Smoky Mountains; the second, the modern Chilhowee group, was named for Chilhowee Mountain in the northern foothills of the Great Smoky Mountains. Various traverses across the Ocoee series were described, including one from Sevierville up the West Prong of the Little Pigeon River to Alum Cave, across the present report area (Safford, 1869, p. 191–192). Rocks underlying the Appalachian or "Great" Valley just northwest of the mountains were classed as "Knox group," and "Trenton" or "Nash series." These were believed to be younger than the Ocoee and Chilhowee, but like them, were assigned to a Lower Silurian age. The fault which raised the older rocks of the mountains against the younger rocks of the valley was recognized along the northwest slope of Chilhowee Mountain. It was shown further that Wear, Tuckaleechee, and Cades Coves to the southeast are also underlain by dolomites of the Knox, but the only explanation that could be offered for their presence was that "they are patches of the great calcareous formations which became entangled, by the folding and faulting to which all the strata in common were subjected, in the mountain masses of Ocoee and Potsdam formations" (Safford, 1869, p. 219).

Keith's work was an early phase of a comprehensive program of mapping in the Southern Appalachians, under the direction of Bailey Willis, for the folio series of the U.S. Geological Survey. One may suppose that the Knoxville 30-minute quadrangle, of which the present report area is a part, was selected for study near the beginning of the program because it contained many important formations and structures, and because it was a key area from which work could be extended into surrounding regions. So far as the present report area goes, this selection was a misfortune, as many problems of the region were not understood at the time of this early fieldwork.

Keith divided Safford's "Ocoee conglomerate and slate" (Ocoee series) and "Chilhowee sandstone" (Chilhowee group) into many formations, which were traced through the mountain part of the Knoxville quadrangle. His formations of the Chilhowee group and their order of succession have stood the test of time, although he erroneously supposed that the overlying Shady dolomite, mainly exposed in Miller Cove west of the report area, was Knox dolomite which lay with hiatus and unconformity on the Chilhowee group (Keith, 1892). His formations of the Ocoee series were less firmly based, and their order of succession has been proved by later work to be very differnet from what was then supposed. The Ocoee formations were, moreover, classed in the folio as of "age unknown," because Keith and Willis at the time believed that they were a series of Silurian or later age that lay unconformably on the Chilhowee group of Chilhowee Mountain and the Knox dolomite of the coves to the southeast (Walcott, 1891, p. 299–300).

Misapprehension as to the stratigraphic succession arose largely from failure to realize the structural complexities of the area. The great low-angle faults of the Southern Appalachians were unknown at the time of mapping, and many higher angled faults associated with them were not detected. It is true that both Keith and Safford recognized thrust faults in the Appalachian Valley. They also mapped a thrust fault along the entire northwest edge of Chilhowee Mountain, which separated the rocks of the mountain from those of the Appalachian Valley; but Keith supposed that this one died out northeastward. The Knox in the cove areas was correctly shown to be arched in a series of anticlines and to underlie the surrounding rocks of the Ocoee series, but the Ocoee was supposed to be younger than the Knox and to succeed it in stratigraphic order (Walcott, 1891, p. 300).

As Keith extended his mapping in more detail into surrounding regions, he came to realize the geologic incongruities published in the Knoxville folio. During a field conference in the Mount Guyot quadrangle in 1898, attended also by C. R. Van Hise, Cooper Curtice, and G. W. Stose, it was concluded that the Ocoee did not lie unconformably on the adjacent Ordovician rocks, but that it had been carried over them on low-angle faults (U.S. Geol. Survey, 1899, p. 39–40; Stose, G. W., and Stose, A. J., 1944, p. 375). By 1901 Keith (U.S. Geol. Survey, 1902, p. 49) had "determined the Cambrian age of the Ocoee formations and their correlation with the previously known Cambrian series". At about this time he prepared "a general review of all information concerning the age of the Ocoee strata" (U.S. Geol. Survey, 1901, p. 68); but this was not published, and it is no longer available. He also subdivided the Ocoee into a new set of formations with a revised order of succession that much resembles the succession as interpreted by the present field party. These revisions were first set forth in his Asheville folio (Keith, 1904).

Although Keith thus made great progress in interpretation of the rocks of the east Tennessee mountain area in his later work, no published revision of his earlier map and text on the Knoxville quadrangle was ever presented, except a brief report on the "Great Smoky overthrust" (1927), which indicated that Wear, Tuckaleechee, and Cades Coves were windows in the thrust sheet. Application of Keith's later views to the present area, or elsewhere in the mountain part of the Knoxville quadrangle, is thus not apparent without much field study, and it is doubtful whether Keith himself ever reveiwed the area again to determine such application in detail.

GEOGRAPHY

PHYSICAL GEOGRAPHY

REGIONAL RELATIONS

The Great Smoky Mountains are part of the Unaka province, a subdivision of the Blue Ridge province that develops southwestward from Virginia. On the northwest, the mountains of the Unaka province front the Appalachian Valley, or lowland part of the Valley and Ridge province, and they separate the valley from the main part of the Blue Ridge in North Carolina. Like the Valley and Ridge province, the Unaka province is made up of sedimentary rocks, but these differ from those of the former in being generally older, more largely clastic, and without thick carbonate components. Instead of being cut into low ground with well-defined strike ridges like the rocks of the Valley and Ridge province, those of the Unaka province have been shaped into high massive mountains that less perfectly express their rock structure. Like the rocks of the main part of the Blue Ridge province, those of the Unaka province have been metamorphosed, but they lack the thorough recrystallization and partial granitization of the latter. Weathering and erosion have consequently modeled them more harshly than the rocks of the main Blue Ridge, so that fewer areas have been cleared for cultivation and much of the range remains in forest.

Although the Unaka province forms one of the most imposing mountain chains of the Southern Appalachian highlands and determines the Tennessee-North Carolina State line through much of its course, it is not a main drainage divide. The water parting between streams draining to the Atlantic coast and the Tennessee River lies instead to the southeast, at the farther edge of the Blue Ridge province, and master streams flow thence northwestward toward the Tennessee River, passing through the mountains of the Unaka province in deep and rocky gorges. Two such master streams, the Pigeon and Little Tennessee Rivers, cross these mountains not far east and west of the report area and serve to define the Great Smoky Mountains geographically as a segment of the Unaka province about 50 miles long; the term "Great Smoky" has, however, been given far wider scope in popular legend.

FEATURES IN REPORT AREA

RELIEF AND DRAINAGE

The present report area displays a representative cross section of the north flank of the Great Smoky Mountains, from the Appalachian Valley on the north to the crest of the State-line divide on the south, which is divisible into a number of physical units, described below. This flank is drained entirely by streams flowing north off the mountains—the West Prong of the Little Pigeon River, the Little River, and their tributaries.

Lowest point in the area, where the Little Pigeon River leaves it on the north in the Appalachian Valley, stands at an altitude of about 880 feet. Highest points are on the mountain crest on the south and include from west to east Thunderhead Mountain, Silers Bald, and Mount Buckley, which rise to altitudes of 5,530, 5,620, and 6,582 feet, respectively; Clingmans Dome, the highest point in the mountains at an altitude of 6,642 feet, lies a little east of the southeast corner of the area. Total relief in the report area is thus about 5,700 feet.

Local relief increases progressively southward. On the north, Chilhowee Mountain projects 1,500 to 2,000 feet above the Appalachian Valley at its base; farther south, Cove, Blanket, and Sugarland Mountains rise more than 2,500 feet above their surroundings; Clingmans Dome near the southeast corner stands 3,500 feet above the head valley of the Little River.

APPALACHIAN VALLEY

A strip as much as 5 miles broad on the north edge of the report area is part of the Appalachian Valley, a region of lowlands widely cleared for cultivation and more heavily populated than any other dealt with herein. The greater part of the valley within the area is formed by shales which are carved into hilly surfaces. Where the shales are sandy and most resistant to erosion, these hills project as a maze of steep-sided knobs several hundred feet high, the most extensive being the Slate Knobs west of Sevierville. A lesser part of the valley within the area is formed of limestone and dolomite which has been cut into rolling ground, heavily mantled by deep reddish residual soil and colluvium.

CHILHOWEE MOUNTAIN

In the west half of the report area the Appalachian Valley is bordered southeastward by Chilhowee Mountain, one of the "great outliers of the Unaka Chain" (Safford, 1869, p. 29), a narrow steep-sided ridge 31 miles long, which extends 24 miles southwestward from the report area to the Little Tennessee River. Chilhowee Mountain differs from all the other eminences in the area in being marked by persistent and distinctive lines of cliffs and ledges (fig. 2); these are formed of successive sandstone and quartzite formations, separated by slope-making shales, all dipping at low angles southeastward.

Chilhowee Mountain ends abruptly northeastward about 6 miles southwest of Sevierville, its quartzite ledges bending about in a synclinal hook. Farther east the boundary between the Appalachian Valley and the main foothills is less sharply marked, and has been deeply indented by erosion.

FOOTHILL BELT

A belt of diverse foothill country about 8 miles wide borders Chilhowee Mountain and the Appalachian Valley on the southeast. Most of its rocks are argillaceous and stand in steep-sided ridges and knobs of formless pattern, not unlike those of the shale areas of the Appalachian Valley, although relief is greater because the rocks which form them are more metamorphosed and resistant than those of the valley. Adjacent crests stand at nearly the same heights, but rise gradually southward to the foot of the main Great Smoky Mountains. These accordant summits may represent remnants of an ancient valley-floor surface from which the foothills have been carved (fig. 5). Projecting above their neighbors are scattered higher ridges of short length, but more regular trend, formed of interbedded conglomerate, sandstone, and quartzite.

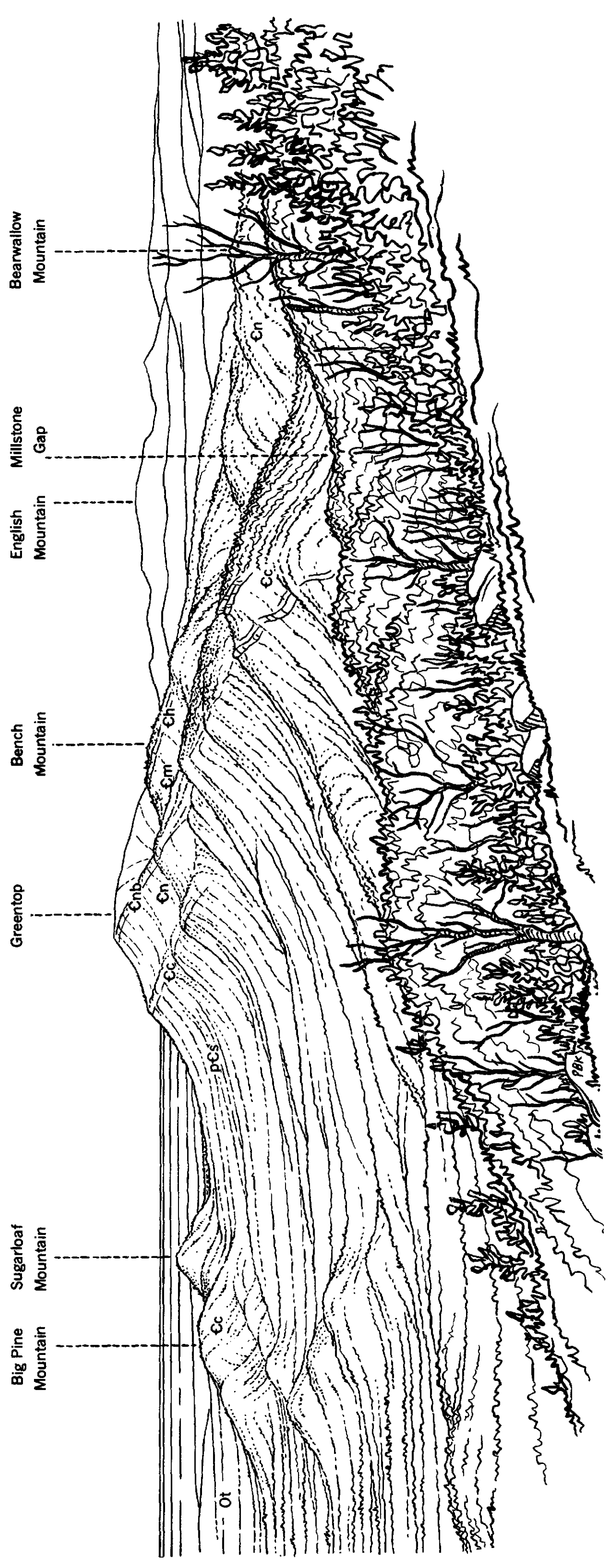

FIGURE 2.—View northeast along crest of Chilhowee Mountain from Millstone Gap fire tower, near west edge of report area, showing outcrops of Chilhowee group and associated formations. Trace of Great Smoky fault lies near base of foothills on left; Sugarloaf and Big Pine Mountains are Cochran formation in a slice overlying the fault. pꞒs, Sandsuck formation; Ꞓc, Cochran formation; Ꞓn, Nichols shale; Ꞓnb, Nebo sandstone; Ꞓm, Murray shale; Ꞓh, Hesse sandstone; Ot, Tellico formation.

Most of the foothills are timbered, but they have been so extensively cut and burned that only second- or third-growth forest remains; part has been cleared for pasture.

Lower courses of some of the larger valleys of the foothills, as that of the West Prong of the Little Pigeon River and of Walden Creek, a tributary from the west, are broad and alluviated, or flanked by stream terraces, so that they support prosperous farms. Most of the other valleys, and upper courses of even the larger streams, are narrow and gorgelike, with little bottom land, although in many places they support small farms. Near the base of the higher mountains to the south, however, many of the valleys widen into small coves that have been deeply filled by bouldery alluvium washed down from the mountains during an earlier time. One of these coves, The Sugarlands on the West Prong of the Little Pigeon River, was at one time extensively cleared and cultivated, but it is now abandoned and forms part of Great Smoky Mountains National Park. Another cove, a few miles below on the same stream, known to the early settlers as "White Oak Flats," is now occupied by the town of Gatlinburg.

COVE AREAS

Embedded in the foothill belt are Wear, Tuckaleechee, and Cades Coves, the first two in the report area, the last farther west. These are mountain valleys 2 to 6 miles across, floored by limestone and calcareous shales that have been worn down to rolling or terraced surfaces, and partly masked by wash from the foothills that surround them. Limestone outcrops and hills covered by limestone residuum are most extensive in Tuckaleechee Cove on the west, which is drained by the through-flowing Little River; Wear Cove on the east, which lies near the head of drainage, is more extensively mantled by wash. The coves are largely cleared for cultivation and constitute outliers of limestone farmland like that characteristic of the Appalachian Valley on the northwest (fig. 3).

Two smaller coves in the southwestern part of the report area, Whiteoak Sink and Big Spring Cove, duplicate features of the larger ones, as each is cut on limestone and rimmed by foothills. Limestone outcrops are abundant in Whiteoak Sink, which is notable in that all drainage leaves it by underground channels; in Big Spring Cove the limestones are buried by wash, although a few sinks betray the presence of limestone not far beneath the surface. Like the larger coves, the two smaller ones were once cleared and cultivated, but the clearings are now abandoned and overgrown.

GREAT SMOKY MOUNTAINS PROPER

The main Great Smoky Mountains, which rise steeply to great height southeast of the foothills, are formed largely of resistant coarse thick-bedded sandstones and interbedded slates and schists. Within the report area these rocks dip mainly southeast at low to steep angles; some of the ridges are cuestalike, but forms of the rest give little hint of the underlying rock structure (fig. 4). The sandstones in places, as on Mount Le Conte, Sugarland Mountain, and Blanket Mountain, project in massive cliffs and ledges; but because of their feldspar content they decay readily into soil, so that the ledges are rarely continuous. Parts of the mountain slopes are heavily mantled by coarse talus and blocks, some of which reach astonishing size. Talus and block fields are not actively in process of growth, for most are overgrown by forest. Large rounded sandstone boulders choke nearly every stream that drains the mountain area.

From Gatlinburg eastward, mountains rise behind foothills in massive bastions and the boundary between them is abrupt. In this eastern segment, a little east of the mapped area, the summit of Mount Le Conte projects to 6,593 feet, yet lies but a few miles behind the edge of the foothills, so that the mountain front is one of the longest steep declivites in the Eastern United States (fig. 5). West of Gatlinburg, the boundary between mountains and foothills is less definite. Long ridges and divides, such as Sugarland Mountain and Miry Ridge, lead north from the main crest on the State line to lower country; Cove Mountain, a high outlying spur formed of sandstones like those in the main mountain area, projects well into the foothills.

The main Great Smoky Mountains are entirely forested with a variety of vegetation which equals that in any other area in the United States north of Florida; about 1,300 species of flowering plants are known, including 131 native trees (Jennison, 1938, p. 269, 286). Practically all major forest groupings of the Eastern United States are present. Many species resemble those which were extensive throughout North America and Europe during the Tertiary, but elsewhere they have only partly survived the rigors of Pleistocene glaciation (Cain, 1943, p. 233; Whitaker, 1956, p. 3). Part of the original forest growth has been disturbed by lumbering (in the report area, especially in the Little River drainage basin) and locally by farm clearings of the mountaineers, but these areas have been reclaimed by second-growth forest since establishment of the national park. Patches of virgin timber remain elsewhere, and the visitor is astonished at the girth and height attained by familiar forest

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trees that have only modest dimensions elsewhere; some are more than 6 feet in diameter and more than 100 feet high (Jennison, 1938, p. 286–287).

Coves, valleys, and moist northern slopes at lower altitudes are dominated by the "cove hardwoods," whose canopy trees include buckeye, birch, basswood, silver bell, sugar maple, beech, tulip-popular, and various deciduous magnolias (Whitaker, 1956, p. 45–46). Dry exposed southern slopes at this altitude bear stands of oak, hickory, and formerly chestnut (now nearly exterminated by blight), and in the driest areas, groves of pines.

Floral assemblages change with increasing altitude, many species dropping out, and others having an altered flowering and growing season. Higher groves of cove hardwoods, near 4,000 feet, are less varied than below, but they have a highly developed herb carpet; mountain maple, red beech, black cherry, birch, and magnolia are characteristic. Hemlock also appears and dominates the nearby ridges as well.

Summits above 4,500 feet in the eastern part of the mountains are crowned by a dark, somber growth of spruce and fir. Red spruce and Fraser fir are mingled between 5,500 and 6,000 feet, but the former dominates below and the latter above, both being interspersed with patches of beech and fire cherry. The Fraser fir forests on the high mountain summits are close to the tree limit (Braun, 1951, p. 145). The flora of the spruce-fir zone resembles that which grows not far above sea level a thousand miles to the north, in northern Maine and southeastern Canada (Shanks, 1954, p. 360). A few miles west of Clingmans Dome the spruce and fir forest come to an end, and from there westward hardwoods extend over the summit of the range; this marks the farthest limit of the Canadian-type flora in the southern Appalachian (Whitaker, 1956, p. 60–61).

Although most of the mountain crests west of the spruce-fir forests are covered by hardwoods, some are "bald," or bare of trees, and support grasses and low shrubs (Camp, 1931). Along the ridge summits within the area, such grassy patches occur on Silers Bald, and nearly continuously from Thunderhead Mountain west to Spence Field. The balds do not express timberline conditions, as nearby forested mountains extend as high or higher. They are probably floral relics of an earlier and harsher climatic period, as will be shown in this report (p. 141–142). The balds have certainly been maintained by exposure to prevailing winds, and, to some extent in the last century, by the local inhabitants, who used them as summer pasturage for stock; at present they appear to be in process of encroachment by the surrounding forest.

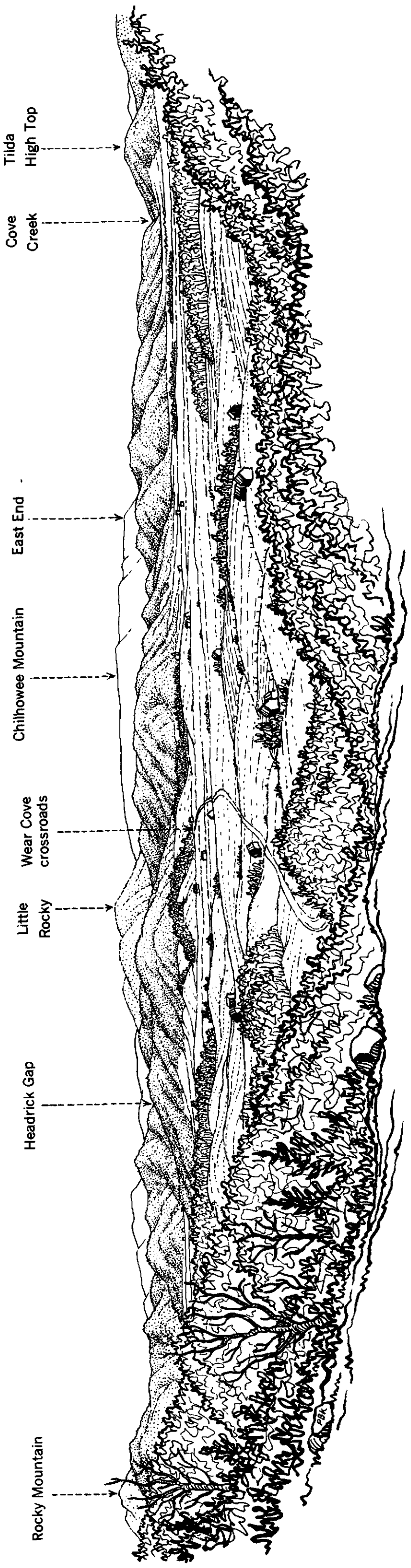

FIGURE 3.—View north across Wear Cove from a little east of Wear Cove Gap. Cultivated lowland in middle distance is underlain by Ordovician limestones and shales of Wear Cove window. Wooded hills of foreground and distance are formed of phyllites and sandstones of Ocoee series in Great Smoky thrust sheet. Main trace of Great Smoky fault is beyond Chilhowee Mountain, about 8 miles distant.

Considerably different from the grass balds are other open areas on the ridge crests, known locally as "laurel slicks," and technically as "heath balds" (Cain, 1930). From a distance they appear to be a smooth grassy carpet, but are in reality an almost impenetrable tangle of head-high rhododendron, mountain laurel, and other members of the heath family. Probably no individual laurel slick is very old, and they originated after removal of forest cover by fire, landslide, or lumbering. They cover wide areas on spurs near the heads of the various prongs of the Little River, from which timber was cut during the last 40 years. Laurel slicks seem to be in process of continuous reclamation by the adjoining forest.

CLIMATE

The Great Smoky Mountains share the general warm, humid climate of the Southeastern States, but individual features are created by their position well inland, within a mountainous region, and by their strong relief. There is, for example, marked differentiation in local climates with altitude (Shanks, 1954, p. 357–359).

Variations with altitude are illustrated by a study undertaken cooperatively between 1946 and 1950, by the U.S. Weather Bureau, the National Park Service, and the Tennessee Valley Authority (Smallshaw, 1953, p. 583). During this period, records were made at eight stations on or near the transmountain highway (U.S. Highway 441), whose range in altitude is between 1,460 and 6,300 feet. The period of observation is insufficient to indicate long-term trends, yet the records do include a wide range in precipitation and temperature from year to year.

Precipitation at the lowest station, at the National Park Service Headquarters near Gatlinburg on the north, resembles that elsewhere in the Appalachian Valley, and varies between 50 and 60 inches yearly. Above this station, a regular and rapid increase in precipitation occurs, amounting to 50 percent or more above 5,000 feet, in the spruce-fir zone. Here, the 5-year average is 90 inches and the long-term average is probably above 80 inches. At the station near Clingmans Dome, at 6,300 feet, 105 inches of precipitation was recorded in the exceptionally rainy year 1949. Precipitation near the mountain summits is thus the greatest in the United States outside the rain forests of the Northwest coast. Nevertheless, effects of altitude appear to be less pronounced above 3,500 feet, as mean differences between records of stations at higher altitudes are less than those between them and stations at lower altitudes.

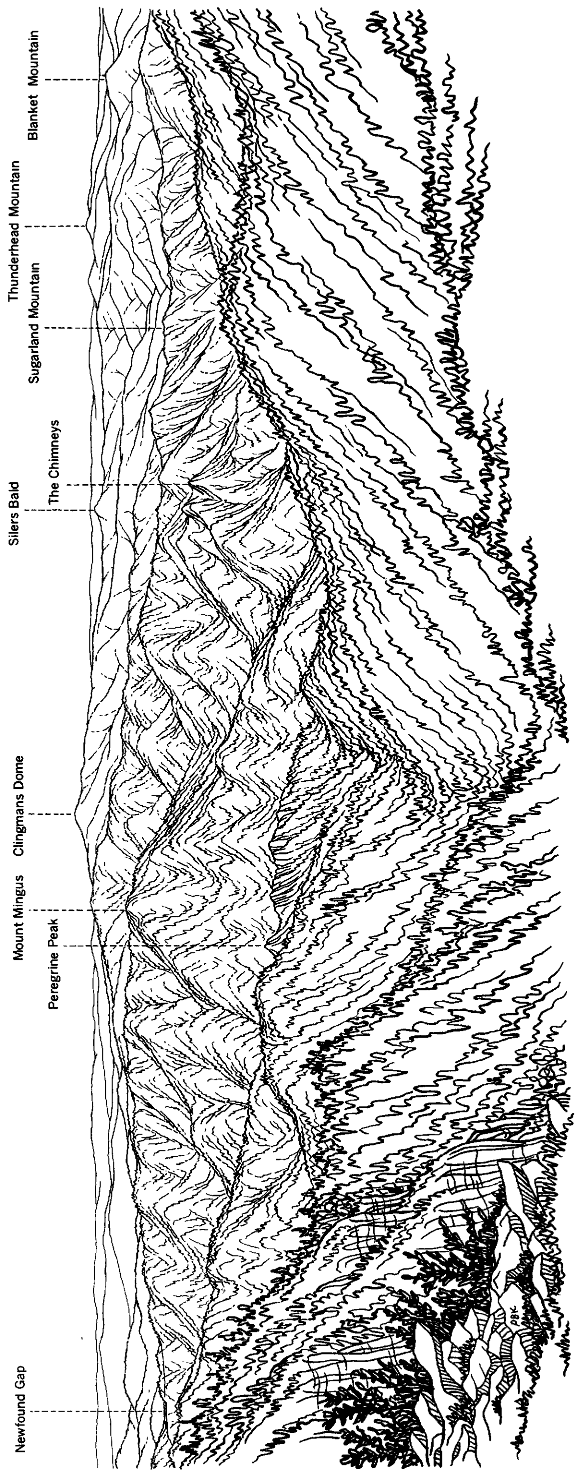

FIGURE 4.—View showing summit profiles of Great Smoky Mountains. From Cliff Top, on Mount Le Conte, looking southwest across central part of mountains. State-line divide is defined by Newfound Gap, Clingmans Dome, Silers Bald, and Thunderhead Mountain; valley of West Prong of Little Pigeon River in middle distance, that of main prong of Little River behind the ridge of Sugarland Mountain. Note vague accordance of spurs leading off the State-line divide, below summit peaks, suggesting a former high-level surface of moderate relief.

The Great Smoky Mountains share with the remainder of the southern Appalachian highlands a distinctive precipitation regime of two maxima—one in the winter and early spring, another in late summer. The autumn months, and to some extent the spring months, are comparatively dry, and are the "fire seasons" of the foresters.

Much of the winter precipitation is in the form of snow; but snowfall is erratic, and the snow cover rarely persists throughout the winter, except at sheltered places in the mountains. Heavy snowfall, from a few or many storms, occurred in some of the years of the survey, yet throughout the winters of 1944–45 and 1950–51 the mountains were nearly snowfree.

Summer precipitation is mainly derived from thunderstorms, whose banks of cloud, gathering along the mountain crests, are familiar sights during that season. Of special geologic interest are rare cloudbursts of very local extent, which produce exceedingly rapid runoff and destructive flash floods. One of these, on August 5, 1938, shed about 12 inches of rainfall in 4 hours on Webb Mountain (Moneymaker, 1939, p. 190), and another on September 1, 1951, shed 4 to 6 inches in 1 hour on Mount Le Conte (Smallshaw, 1951, p. 3). Runoff from these cloudbursts breaches the protective cover of vegetation and causes more erosion than the milder storms of scores or more of intervening years. During the storms of 1938 and 1951, residuum and slope wash on heavily forested mountain slopes was removed in large volume by gullying and landslides, and local cuts were even made to depths of 4 feet in bedrock (Moneymaker, 1939, p. 190–194). Great quantities of coarse channel debris were also shifted long distances downstream. After the 1951 flood, the present writer observed that boulders 5 feet in diameter in the bed of the West Prong of the Little Pigeon River were intermingled with, and overlay fragments of, paving that had been eroded from the adjacent highway.

Temperature, like precipitation, varies with altitude, the average rate of decrease per thousand feet of ascent being 2.23°F (Shanks, 1954, p. 355). The spruce-fir forests average 10° to 13°F cooler than the base of the mountains during the growing season, so that the arrival of spring is 1 month to 6 weeks behind that in the lowlands. Winter temperatures on the mountaintops are, however, much more variable than summer temperatures, as suggested by the erratic amount of snowfall already noted. The climate of the spruce-fir forests of the mountain summits is warmer

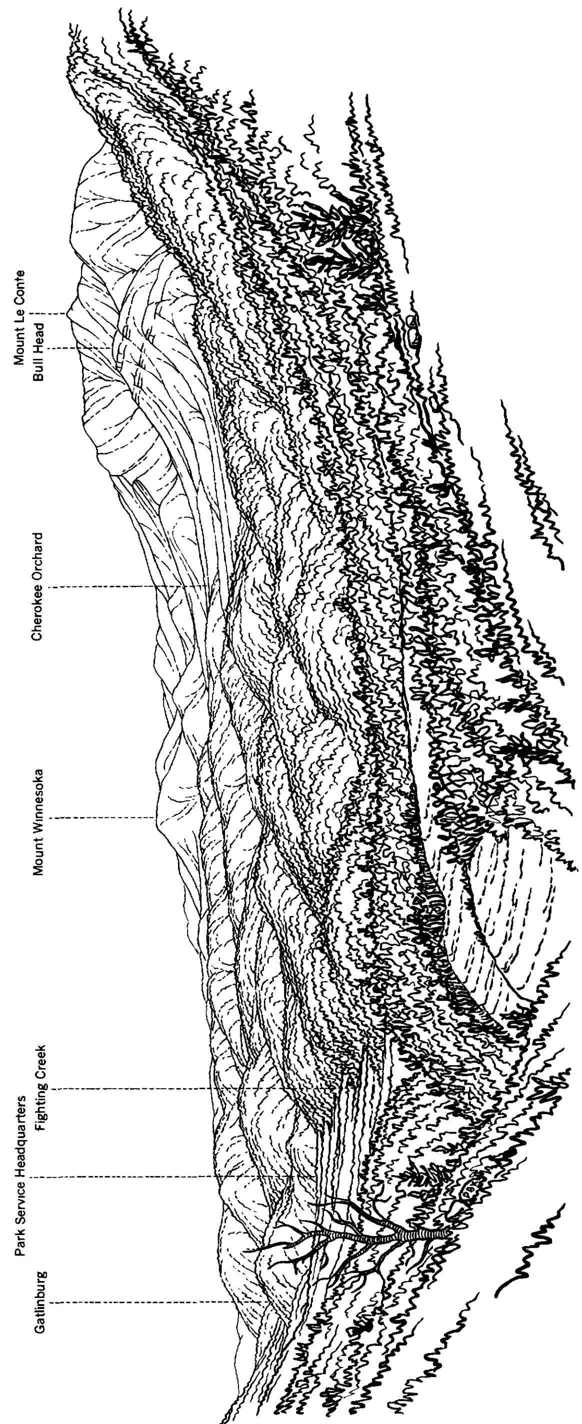

FIGURE 5.—View showing profiles of lower slopes of Great Smoky Mountains. From overlook on Tennessee Highway 73 a little east of Fighting Creek Gap, looking east. Topographic relief in view, from Gatlinburg to summit of Mount Le Conte, is more than a mile. Ridge crests below foot of Mount Le Conte seem to be remnants of a former valley-floor surface, now dissected to depths of hundreds of feet by modern drainage. Rocks of Great Smoky group form mountains to right, those of Snowbird group (Roaring Fork sandstone) the lower ground to the left; contact between them is the Greenbrier fault, whose trace lies near the base of the steep slopes, from Mount Winnesoka to the foreground. Gatlinburg fault follows valley of Fighting Creek on left.

and more moist than that of comparable low-altitude far-northern forests, its nearest climatic analogue being in northern New England, the Maritime Provinces of Canada, and the coastal region of Oregon and Washington (Shanks, 1954, p. 360).

HUMAN GEOGRAPHY

SETTLEMENT OF AREA

First European explorers who reached the East Tennessee country, of which the central Great Smoky Mountains are a part, found it occupied by "Overhill" tribes of the Cherokee Indians, a semicivilized people who lived in permanent villages on alluvial bottoms of the larger streams of the foothills, where they practiced primitive agriculture. They did not penetrate the higher mountains, except during occasional forays.

White settlers arrived in east Tennessee about 175 years ago, at the time of the Revolutionary War, and created farmsteads and settlements in the Appalachian Valley. The abortive "State of Franklin," set up shortly after, in 1784, included an extensive Sevier County. A county of that name was not officially recognized, however, until 1795, when it was established with about its present limits as part of the new State of Tennessee. Sevierville, the county seat, was laid out in the same year (Goodspeed, 1887, p. 834–837).

Settlement of the mountain area soon followed that of the Appalachian Valley, Wear Cove being occupied in 1795 and "White Oak Flats" shortly thereafter. Later, even more isolated communities, farmsteads, and cabins were established in valleys and little coves well back in the mountains. Many pioneers reached the area by ascending various forks of the Little Pigeon River from the Appalachian Valley, but some crossed over from North Carolina by a rough trail passing through Indian Gap, not far from the present highway summit (Foscue, 1945, p. 194–196). Most mountain settlers were of Scotch or Scotch-Irish ancestry, and included such families as Ogle (Oglesby), Whaley, Reagan, and Clabo (Clabaugh), whose decendants today occupy much of the country in the central Great Smoky Mountains north of the national park.

CIVIL WAR PERIOD

A post office was established at "White Oak Flats" in 1860, named "Gatlinburg" for Radford Gatlin, local storekeeper. Ironically, he left soon thereafter, never to return, as he was a Confederate sympathizer and the mountain country was a stronghold of Union sentiment.

Sevier County, in fact, furnished scores of volunteers to the Union armies, and people of the county were willing suppliers of provisions to General Burnside's army, beseiged in Knoxville by General Longstreet's Confederate army, in November and December 1863 (Rule, 1900, p. 167–168; Tennessee Valley Authority, 1937, p. 92). Local tradition tells of a "Battle of Burg Hill" at about the same time, when a small Confederate force, entrenched on the heights above Gatlinburg, was routed by Union troops, probably as part of the skirmishing of the Knoxville campaign.

THE MOUNTAINEER ECONOMY

Aside from the tumultuous Civil War years, the central Great Smoky Mountains remained isolated for generations. Until 1916 only a rough track down the West Prong of the Little Pigeon River joined Gatlinburg with the county seat and the outside world. Mountaineers practiced a self-sufficient economy of farming, hunting, and timber cutting (National Park Service, 1941, p. 11–12).

This economy early made use of the "banks" of residual brown iron ore which were discovered at many places in the foothills and Appalachian Valley, for all iron implements, such as ploughs, guns, and domestic utensils, had to be manufactured locally. A small furnace and iron works were operated for many years at Pigeon Forge, supplied by ore brought in from deposits nearby, in Wear Cove and elsewhere (Willis, 1886, p. 335–336). Although at one time sanguine expectations were held as to the mineral wealth of Sevier County (Killebrew, 1881, p. 32–34), little sign of the diggings at the old "ore banks" now remains; probably no single deposit was large, and each was soon mined out.

LUMBERING OPERATIONS

Aside from clearing land for farming, timber was cut by mountaineers only for cabin logs, cabinet wood, and other valuable lumber; much of the land remained virgin. Systematic cutting on a commercial scale did not begin in the central Great Smoky Mountains until 1903, when the drainage basin of the Little River began to be exploited. Operations continued for years, the last timber being taken out in the mid-1930's.

Commercial lumbering was by railroad, the trunkline extending into the basin from the headquarters village of Townsend at the west edge of the mapped area; branches led up the main west prong above Elkmont and the Middle Prong above Tremont. Grade of the line up the west prong is now followed by Tennessee Highway 73 between Townsend and Elkmont.

Grades of the network of feeder lines, penetrating southward nearly to the mountain crest, are still visible in this part of the mapped area. The Little River drainage basin has now largely been reclaimed by second-growth forest.

GROWTH OF TOURIST INDUSTRY

An incidental result of lumbering and railroad building was the opening up of a part of the mountains hitherto inaccessible to visitors. As a consequence, the community of Elkmont near the head of one of the railroads was developed as a vacation resort, where many Knoxville families built summer cottages.

Similar influences began to be felt in Gatlinburg with construction of a passable access road in 1926. The earlier self-sufficient mountaineer economy then passed into one largely dependent on visitors, tourists, and vacationists, a process accelerated by establishment of Great Smoky Mountains National Park in 1926 and by completion of the transmountain highway (U.S. Highway 441) in 1938.

MODERN TOWNS AND VILLAGES

Today the central Great Smoky Mountains contain the towns of Sevierville (the county seat) with 1,600 people and Gatlinburg with 1,200 people, as well as the villages of Pigeon Forge and Townsend and the cottage community of Elkmont. Sevierville is business center of a large agricultural area and supports a cannery, textile mill, and other light industries. Gatlinburg is principal focus for visitors to this part of the Great Smoky Mountains and headquarters of the national park.

ACCESS

Except for the Smoky Mountain Railroad, whose line from Knoxville ends at Sevierville, access to the area is by highway, road, and trail. U.S. Highway 411, one of the main routes along the Appalachian Valley, extends across the northern part of the area, passing through Sevierville. From Sevierville, U.S. Highway 441 leads south to Gatlinburg along the route of the old road up the West Prong of the Little Pigeon River, and thence ascends to the mountain crest at Newfound Gap, where it crosses into North Carolina. Tennessee Highway 73 forks west from the latter beyond Gatlinburg and descends the Little River to Townsend, staying largely in the national park. County roads north of the national park provide access to many parts of the mountain foothills.

Within the park itself, aside from the two highways noted, access is mainly by a system of one-way truck roads and by trails, from which few areas in the mountains are more than a mile distant. The Appalachian Trail, in its course from Maine to Georgia, follows the State-line divide at the south edge of the area.

DESCRIPTION OF ROCK FORMATIONS

BROADER RELATIONS

Rocks of the central segment of the Great Smoky Mountains are all of sedimentary origin (with one insignificant exception), and consist of varieties of limestone, dolomite, shale, siltstone, sandstone, and conglomerate, parts of which have been lightly to heavily metamorphosed. The sediments were laid down in early Paleozoic and in latest Precambrian time. The younger sedimentary rocks, of Ordovician and Cambrian ages, are exposed toward the north, in the Appalachian Valley, on Chilhowee Mountain, and in the cove areas; those of earlier age, assigned to the later Precambrian and termed the Ocoee series, are exposed in the south, and form the foothill belt and main mass of the Great Smoky Mountains.

Within the area, the sequence is broken into blocks as a result of the great deformations to which the rocks have been subjected, so that successive fault blocks contain groups of formations, not all the relations between these groups being apparent within the report area.

Relative ages between different sequences of Paleozoic formations on the north can be deduced from their contained fossils, and missing intervals between these parts of the section can be filled in the surrounding areas. The Ocoee series on the south, on the other hand, contains no known fossils. Some of its groups have clearly been deposited in very different realms from those adjacent, and attained their present proximity as a result of many miles of movement along low-angle faults. It is thus not always possible to determine their relative ages, and whether they formed far apart in time or at the same time.

Total thickness of sedimentary rocks in the area is probably many thousands of feet, or even many miles, but because of the missing intervals, uncertainties as to succession, and possibility that some units are contemporaneous with others, it seems idle to mention any total figure.

MAP RELATIONS

Distribution of the different rock formations in the central Great Smoky Mountains is shown in a generalized manner on plate 1, and in detail on a larger scale on plates 2-7. Representation on these maps requires explanation.

In the central Great Smoky Mountains, as in much of the southeastern United States, surface of the bedrock has been much weathered, has been covered by soil and slope wash, and has been overgrown by vegetation. Natural outcrops of the bedrock are scattered, the best being along the streams and in ledges along the steeper slopes, especially in the more quartzose formations. Limestones and dolomites are extensively masked by residuum and colluvium, argillaceous rocks by chips of weathered debris, and feldspathic sandstones by sandy soil. Contacts between units, whether sedimentary or structural, are exposed only by fortunate accident. Much aid is afforded, however, by artificial exposures, especially roadcuts where the bedrock has been penetrated beneath the surficial cover.

These conditions present obstacles to geologic mapping and interpretation which, in the report area, are compounded by the complex structure and stratigraphy. Formations of the Ocoee series are monotonous through great thicknesses and contain few or no traceable horizons, one unit being gradational into another and abrupt contacts being generally the result of faulting. In mapping, the geologist is presented with an equation, one part being the stratigraphy, the other the structure. If one were known the other could be interpreted, yet neither is evident, and both must be worked out by inference as the work proceeds. Conclusions can be arrived at only from cumulative facts and inferences gathered over a wide area; in the present study these were derived from areas well beyond the limits of the central Great Smoky Mountains.

On the maps which accompany this report, representation is based, first of all, on contacts which have been located in natural and artificial exposures; these contacts have been extended on the basis of outcrops of adjacent and contrasting rocks or of float and residuum that was weathered from the bedrock. The representation adopted in these intervening areas is what appears geometrically plausible. Such representation is that which is preferred by the author and is not necessarily the single unique solution. Geologic maps such as these, in which observation is interwoven with much inference, tempt a geologist to indulge in circular reasoning; map relations, themselves based on inference, are likely to be cited as evidence for the correctness of the inference itself (cf. B. L. Miller, 1944, p. 217). The present text was prepared with awareness of this fallacy, and much effort has been made to avoid it.

In a few parts of the area, available evidence does not lead to a logical interpretation and no certain answer appears possible. In such places it seemed best to keep the mapping as nearly as possible within the range of field facts, rather than force it into some logical but fanciful interpretation, which might have little relation to eventual reality.

STRATIGRAPHIC UNITS

Stratigraphic units in the central Great Smoky Mountains are partly those which have been established as a result of previous geologic work, but part have been emended, revised, or renamed as a result of the present investigation. Rocks of the Middle Ordovician series have thus been revised by Neuman (1956), and those of the Ocoee series through the joint work of the geologists of the party (King and others, 1958). Table 1, below, sets forth the rock units exposed in the central Great Smoky Mountains and their known and inferred relations to each other.

OCOEE SERIES (LATER PRECAMBRIAN)

GENERAL CHARACTER

The greater part of the rocks of the central Great Smoky Mountains belong to the Ocoee series (Stose, G. W., and Stose, A. J., 1944, p. 401; 1949, p. 270; King, 1949, p. 662; Rodgers, 1953, p. 24; King and others, 1958), a body of terrigenous clastic sedimentary rocks, which has minor intercalations of limestone and dolomite but no volcanic components or known fossils. Many of the clastic rocks are coarse grained, most are poorly sorted texturally and mineralogically, and few are cleanly washed. Many parts are monotonous sequences—changes from one rock type to another commonly being gradational both vertically and laterally—with few or no mappable key beds. Aggregate thickness of the series is comparable to that of all the Paleozoic rocks in the adjacent Appalachian Valley.

Throughout most of the outcrop area of the Ocoee series, no base or top is visible. On the southeast side of the Great Smoky Mountains, however, the basal beds of the Ocoee lie unconformably on older granites and gneisses. In the northwestern part of the mountains its upper beds are apparently succeeded by the Cochran formation at the base of the succeeding Chilhowee group. To the south, also, it is succeeded by formations of the Murphy marble belt. Here, it appears reasonable to place the top of the Ocoee series at the base of the Nantahala slate (Furcron, 1953, p. 34–38; Hurst, 1955, p. 8), although some geologists in

TABLE 1.—*Rock formations exposed in central Great Smoky Mountains*

System	Series	Group	Formation	Formation thicknesses (feet)	Cumulative thicknesses (feet)	Relations between units
Paleozoic(?)			Metadiorite			Intrusive into rocks of Ocoee series.
						Top of sequence in report area; overlain to west by Bays formation (Middle Ordovician), Chattanooga shale (Devonian and Mississippian), and Grainger and Greasy Cove formations (Mississippian).
Ordovician	Middle Ordovician		Sevier formation	[1] 200–400	[1] 5,725–7,590	
						Conformity.
			Chota formation	700		
						Conformity.
			Tellico formation	4,000		
						Conformity.
			Blockhouse shale (with Whitesburg limestone member at base, and Toqua sandstone member in lower part)	400		
						Hiatus and minor unconformity.
			Lenoir limestone (with Douglas Lake member locally at base, and Mosheim limestone member)	25–90		
						Erosional unconformity.
	Lower Ordovician	Knox group (upper part)	Newala limestone Longview dolomite Chepultepec dolomite (merging into Jonesboro limestone in south)	[1] 400–2,000		
						Sequence broken; in adjoining areas missing sequence consists of Copper Ridge dolomite or Conococheague limestone (Upper Cambrian), Conasauga group (Upper and Middle Cambrian), and Rome formation (Lower Cambrian).
Cambrian	Lower Cambrian	Chilhowee group	Shady dolomite	[1] 100	[1] 2,850–3,200	
						Conformity.
			Helenmode formation	200		
						Conformity.
Cambrian(?)	Lower Cambrian(?)		Hesse sandstone	100–200		
						Conformity.
			Murray shale	500		
						Conformity.
			Nebo sandstone	250		
						Conformity.
			Nichols shale	700		
						Conformity.
			Cochran formation	1,000–		
						Probable slight unconformity.
Later Precambrian	Ocoee series	Walden Creek group	Sandsuck formation	[1] 2,000	[2] 8,500	
						Sequence broken.
			Wilhite formation: Upper division	[2] 1,000		
			Wilhite formation: Lower division	[2] 2,500		
						Conformity.
			Shields formation	[3] 1,500		
						Conformity.
			Licklog(?) formation	[3] 1,500		
						Sequence broken; Walden Creek group probably overlies Snowbird group, but may be lateral equivalent of Great Smoky and Snowbird groups, at least in part.
		Unclassified	Rich Butt sandstone (in east) and Cades sandstone (in west)	[1] 1,500		
						Rich Butt sandstone lies conformably on Snowbird group; relations of Cades sandstone uncertain; these units may be lateral equivalents of Great Smoky group, at least in part.

[1] Exposed. [2] Approximate exposed. [3] Approximate.

TABLE 1.—*Rock formations exposed in central Great Smoky Mountains*—Continued

System	Series	Group	Formation	Formation thicknesses (feet)	Cumulative thicknesses (feet)	Relations between units
Later Precambrian	Ocoee series	Great Smoky group	Unnamed sandstone (southwestern part of area only)	[1] 4,500		
						Conformity.
			Anakeesta formation	3,000–4,500		
						Gradational vertically and laterally.
			Thunderhead sandstone	5,500–6,300		
					[1] 14,000–23,300	Gradational vertically and laterally.
			Elkmont sandstone	[1] 1,000–8,000		
						Sequence broken in report area; conformable in southeastern part of mountains.
			Pigeon siltstone	[1] 10,000		
						Gradational vertically and laterally.
			Roaring Fork sandstone	[1] 7,000		
		Snowbird group	Metcalf phyllite (western part of area).	Not determined.	[1] 17,000	Relations uncertain; Metcalf is a metamorphic facies of Snowbird group and probably equivalent to parts of Pigeon and Roaring Fork formations.
						Base of Snowbird group concealed in area; in southeastern part of mountains lies unconformably on earlier Precambrian.

the past have included in the Ocoee the Nantahala and even higher formations of the Murphy marble belt (Wilmarth, 1938, p. 1528).

The Ocoee series is classed by the U.S. Geological Survey as a provincial series comparable to other series of the Precambrian, such as the Keweenawan, Belt, and Grand Canyon.

HISTORY OF TERMINOLOGY

The Ocoee series corresponds to the "Ocoee conglomerate and slate" which Safford (1856, p. 151–152; 1869, p. 183–198) named for exposures in the gorge of the Ocoee River, Polk County, Tenn., southwest of the Great Smoky Mountains, and recognized as constituting much of the Unaka province from there to northeastern Tennessee. In the same region, Safford also recognized an overlying unit, the "Chilhowee sandstone," now termed the Chilhowee group.

Keith, in his series of geologic folios on the southern Appalachians, divided the rocks of the Unaka province into formations that he attempted to trace over the whole region, but he did not formally use Safford's names Ocoee and Chilhowee. Keith's interpretations evolved as mapping of widening areas brought increasing understanding, so that in the later folios the stratigraphic terminology and conclusions as to age, sequence, and structure of the rocks differ greatly from those of the earlier folios. This evolution is difficult to follow in the publications, because Keith made no general summary and did not explain fully in the folios the reasons for changes made in terminology and interpretation.

Keith's initial interpretation of the rocks of the Ocoee series was set forth in his Knoxville folio (1895a); formations there established were extended southwestward into the Loudon quadrangle by Keith (1896) and into the Cleveland quadrangle by Hayes (1895). In the Knoxville quadrangle, which includes the present report area, the following classification was used (table 2):

TABLE 2.—*Classification of rocks now placed in Ocoee series, as used by Keith in Knoxville folio (1895a)*

Chilhowee Mountain	*Mountain and foothill area*
Cochran conglomerate at top	Top not preserved
Cambrian:	Age unknown:
Sandsuck shale	Clingman conglomerate
	Hazel slate
Base not exposed	
	Thunderhead conglomerate
	Cades conglomerate
	Pigeon slate
	Citico conglomerate
	Wilhite slate
	Lies unconformably on various Cambrian and "Silurian" (that is, Ordovician) formations.

As folio mapping was extended into surrounding areas, Keith discovered that the units of the Knoxville quadrange were not only inapplicable regionally, but that the rocks had a different sequence, structure, and regional pattern from that first supposed. About 1901 he therefore developed a new classification and interpretation (U.S. Geological Survey, 1901, p. 69; 1902, p. 49), which he used in the Asheville and subsequent folios (table 3).

Keith transferred these units from an "unknown" to a Cambrian age because he concluded that the Nantahala slate and Great Smoky conglomerate were the southeastern equivalents of the Nichols shale and Cochran conglomerate of the Chilhowee group, and because the other units lay conformably beneath them.

Keith's revised terminology and interpretation were remarkably perceptive for their time. His formations have proved to be useful geologic entities, recognizable over wide areas in much the manner originally shown, and were mostly placed in the correct sequence. Later work has indicated the need for revision and amplification, because of more detailed mapping, and further understanding of the structure, sedimentation, and metamorphism; Keith's stratigraphy, however, forms the basis on which such revisions of the Ocoee can be made.

TABLE 3.—*Classification, as revised by Keith, of Ocoee series and related formations in Asheville and Nantahala folios (1904, 1907a), and Mount Guyot, Cowee, and Murphy quadrangles (1952)*

Revised sequence	*Approximate equivalents of Knoxville folio* [As interpreted by present author]
Overlying formations of Murphy marble belt	Not present
Nantahala slate: Type, Nantahala Gorge, Nantahala quadrangle	Not present
Great Smoky conglomerate: Type, Great Smoky Mountains, Knoxville and Mount Guyot quadrangles	Clingman conglomerate, Hazel slate (part), Thunderhead conglomerate, Cades conglomerate
Hiwassee slate: Type, gorge of Hiwassee River, Murphy quadrangle	Pigeon slate (part), Citico conglomerate, Wilhite slate, Sandsuck shale
Snowbird formation Type, Snowbird Mountain, Mount Guyot quadrangle	Pigeon slate (part); rest mostly not present in Knoxville quadrangle
Unconformity	
Carolina and Roan gneisses and associated granites	Not present

GROUPS AND FORMATIONS OF OCOEE SERIES

On the basis of the work of the present field party, such a revised classification has been set up (King and others, 1958).

The rocks of the Ocoee series are divisible into broad lithologic units, which were recognized as formations by Keith. As each of these can be divided into different component units, it is more convenient to rank them as groups, which we have termed the Snowbird, the Great Smoky, and the Walden Creek groups. Two of the groups, the Snowbird and Great Smoky, are adapted from Keith's formations of those names; they were sufficiently defined in the original descriptions, and their type localities are in the Great Smoky Mountains, where they were restudied during our investigation. The third group, the Walden Creek, corresponds approximately to Keith's Hiwassee slate. Because the type locality of the Hiwassee is outside the Great Smoky Mountains, where it was never adequately defined, and because of other ambiguities, this name is abandoned and a new name substituted.

The groups into which the Ocoee series is divided are of regional extent (fig. 6), but formations within the groups are local; they interfinger and intergrade with each other along the strike, and some do not persist beyond a quadrangle or two. Those used in the central Great Smoky Mountains are presented in table 1; the complete classification is set forth elsewhere (King and others, 1958). Many of the formations are newly named, but for some of them formation names used by Keith (1895a) in the Knoxville folio can be adapted, although these names are redefined and the formations do not lie in the straitgraphic order originally assumed. Four of them, the Wilhite, Pigeon, Cades, and Thunderhead, are thus adapted and redefined. Three others, the Citico, Hazel, and Clingman, as used by Keith, are for various reasons unsuitable for further use and are therefore abandoned.

LITHOLOGIC TERMINOLOGY

The clastic rocks of the Ocoee series were given the general designation of "slates" and "conglomerates" by Safford and Keith, but they exhibit much greater variety than implied thereby. For the most part they were originally argillaceous shales, sandstones, and conglomerates, but in parts of the series the intermediate class of siltstones is present. Nearly every formation or group contains most of the rocks of these textural ranges; in some of them, where the sediments are graded, the whole textural range of a formation may occur within a few feet of thickness. All the rocks have now been slightly to greatly metamorphosed, although in even the most altered parts their original sedimentary nature is still evident.

The argillaceous rocks, being most susceptible to physical effects of metamorphism, assume from place

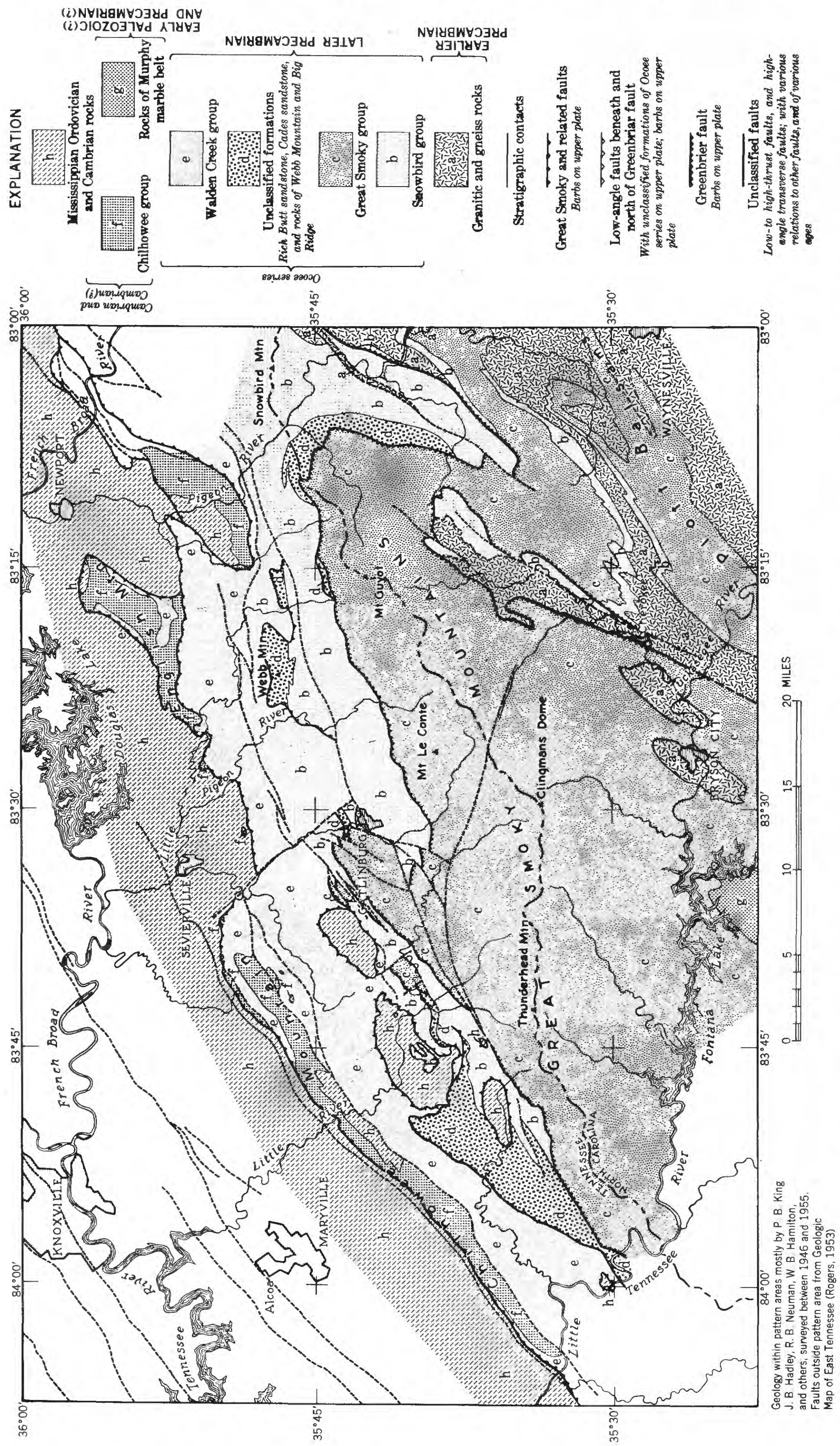

FIGURE 6.—Geologic map of Great Smoky Mountains and vicinity showing Ocoee series and adjacent formations and the groups into which the Ocoee is divided.

to place in the area the guise of "shales," "slates," "phyllites," and "schists." In the descriptions which follow, some general term is needed for these argillaceous components regardless of their present degree of alteration, but none seems to be available. The term "argillite," for example, which would seem to have general connotations, has unfortunately been preempted for a variety with special structural character, and the terms "lutite" and "pelite," proposed for them, have not gained wide currency. These rocks will therefore be referred to herein as the "argillaceous rocks," although it is recognized that their original argillaceous minerals have been for the most part recrystallized into various metamorphic minerals.

The coarser clastic rocks will be referred to herein as "siltstones," "sandstones," and "conglomerates," depending on the coarseness of the detrital grains. Some units, such as the Great Smoky and its subdivisions, have previously been termed "conglomerates," whereas they include every variety of texture in their graded layers; the sand textures dominate and the pebbly layers are relatively fine-grained and subordinate. These units will accordingly be referred to as "sandstones," although the presence of subordinate finely conglomeratic fractions is recognized. On the other hand, true "conglomerates," some of considerable coarseness, form many beds in the Walden Creek group and will be so termed.

In the descriptions, use of special compositional terms for the coarser clastic rocks appears needless. The sandstones are certainly not "quartzites," although some have been so called (Stose and Stose, 1949, p. 278); many possess the same degree of induration and cementation as that class, but they contain as many or more detrital grains of feldspar than of quartz,—quartz is not a conspicuous cementing material,—and they are quite unlike the true quartzites of the Chilhowee group. Many of the sandstones do correspond to "arkose" or to "graywacke" as these terms have been defined by different petrographers; usage of these terms, however, has been so varied and has implied so many conflicting compositional, textural, or even genetic characters that discussion of them had best be reserved for the interpretative section on page 66.

Metamorphism of the coarser clastic rocks has more lightly affected their gross physical appearance and structure than that of the argillaceous rocks. Even where strongly altered in the southern part of the report area, they retain their original layering and coarse varied texture; alteration is, at most, expressed by growth of small porphyroblasts of low- to middle-grade metamorphic minerals and by internal deformation resulting in crushing or elongation of the detrital grains, which produces a crude linear or foliate structure.

The metamorphosed coarser rocks of the Ocoee series might be termed "gneisses," in the sense that they are made up of relatively thick layers of varied texture, rather than being evenly textured and thinly foliate. This structure, as in many gneisses, is the result of original sedimentary layering, but in the report area it has not been modified by recrystallization and flowage to the degree that one would expect in a truly gneissic rock; use of the term, in the report area at least, would be inappropriate and misleading.

Metamorphism of the coarser rocks of the Ocoee series might be indicated by the prefix "meta" to produce "metasiltstone," "metasandstone," and "metaconglomerate." This connotes the essentially sedimentary character of the altered rocks; but the prefix does not seem to add precision, as all the rocks of the Ocoee series are metamorphosed to a lesser or greater degree. Therefore, regardless of the metamorphic condition of the rocks, it seems best in this report to use their sedimentary names "siltstone," "sandstone," and "conglomerate." Some degree of alteration and metamorphism can be assumed for all; its nature in a particular rock or locality is explained in the qualifying descriptions in the text.

SNOWBIRD GROUP[1]

The oldest rocks of the report area occur in the southern foothills of the Great Smoky Mountains and are part of the Snowbird group, which is the lowest and oldest unit of the Ocoee series.

The Snowbird group corresponds to the Snowbird formation of Keith (1904, p. 5), named for Snowbird Mountain, northeast of the Great Smoky Mountains across the Pigeon River. The type area of the unit was restudied during the present investigation (Hadley and Goldsmith, 1963), and there it has been divided into 4 intertonguing formations that have a gross thickness of about 13,000 feet; the lowest of these formations rests unconformably on earlier Precambrian basement rocks.

The upper two of the formations in the type area, the Roaring Fork sandstone and Pigeon siltstone, extend into the eastern part of the report area (Gatlinburg and Pigeon Forge quadrangles), but their base is not exposed, their top is faulted, and they crop out in separated areas, so that their sequence can only be established by comparison with the sections farther east. In the western part of the report area, as near the Little River (Wear Cove quadrangle), the Snow-

[1] Description of the Roaring Fork sandstone and Pigeon siltstone is based on observations by King; description of the Metcalf phyllite includes observations by H. W. Ferguson and G. D. Swingle.

bird is represented by strongly foliated argillaceous and silty rocks termed the Metcalf phyllite. Relations of the Metcalf to the other two formations is uncertain, but it is probably an altered phase of one or both of them. The Metcalf is complexly faulted between formations of other groups of the Ocoee series, and pinches out among them south of Cades Cove, a short distance west of the report area.

ROARING FORK SANDSTONE

GENERAL FEATURES

Definition

The Roaring Fork sandstone is named for the upper course of Roaring Fork in the Cartertown quadrangle (King and others, 1958), a little east of the report area, where a representative section is well exposed. On the Knoxville map, outcrops of the Roaring Fork within the report area were apportioned by Keith (1895a) between the "Citico conglomerate" and "Pigeon slate." Such differentiation was based on vague and inconstant lithologic distinctions, and the units so designated have no relation to formations of those names at their type localities.

Occurrence in report area

From Roaring Fork, the Roaring Fork sandstone extends westward into the report area south of Gatlinburg (Gatlinburg quadrangle), where it crops out in a triangular area about 3 miles across, bounded by the Great Smoky group on the northwest and southeast, in Cove Mountain and the main Great Smoky Mountains, with each of which it is in fault contact. Within the area the Roaring Fork sandstone dips gently to the southeast, and about 1,000 feet is exposed. Lowest beds on the northwest are cut off by the Gatlinburg fault; highest beds on the southeast are cut off, in turn, by the Greenbrier fault, although east of the report area higher beds wedge in beneath the latter and grade up into the Pigeon siltstone.

Within the report area, exposures that embrace large thicknesses of the formation occur along Le Conte Creek between Gatlinburg and Twin Creeks Government Headquarters, and along the West Prong of the Little Pigeon River between the National Park Service Headquarters and The Sugarlands. Some of the best outcrops are in the old State highway quarry just east of the headquarters, and in the National Park Service quarry on Sugarland Branch a mile to the south.

Topographic features

In the area south of Gatlinburg the Roaring Fork sandstone forms a series of foothill ridges that slope northwest from the higher Great Smoky Mountains (fig. 5). Ridgetop profiles show a succession of knobs and saddles, the knobs being formed by sandstone beds and the saddles by silty and argillaceous beds. Intervening stream valleys consist of a succession of graded meadows carved on the silty and argillaceous rocks, separated by narrows and cascades formed on the sandstones. At the foot of the Great Smoky Mountains, below the contact between the Roaring Fork sandstone and Great Smoky group, the valleys widen into alluvium-filled basins, such as the Sugarlands and Little Sugarlands; these basins have no relation to the nature of the bedrock, but are depositional features resulting from filling of the valleys by mountain-derived detritus.

LITHOLOGY

The Roaring Fork sandstone of the report area consists of fine-grained sandstone, siltstone, and phyllitic argillaceous rocks, about 30 percent of the total thickness being sandstone, 50 percent siltstone, and 20 percent argillaceous rocks; these form interbedded units 50 to 200 feet thick. On the geologic map (pl. 5), the approximate extent of the thicker and more persistent sandstone beds is shown.

Sandstone

The sandstone beds of the Roaring Fork are 10 to more than 100 feet thick and are locally very massive. Even the most conspicuous sandstone beds can be traced along the strike only with difficulty, as their feldspathic nature causes them to break down readily into soil; such beds, besides, may lens out laterally or be cut off by unrecognizable faults. At the National Park Service quarry on Sugarland Branch a bed, 120 feet thick, that is underlain and overlain by phyllitic siltstone, has been worked.

In this quarry and elsewhere the sandstone is gray or blue gray, tough, compact, and fine grained, and has no trace of granules or pebbles. Although hard and firm where fresh, the sandstone is not quartzite, for it contains nearly as much feldspar as quartz—the cause of its ready decomposition on weathering. Bedding in the sandstone is indicated by dark laminae, most of which lie parallel, although scattered layers 1 or 2 feet thick are crossbedded. The sandstone shows few megascopic effects of metamorphism, but many beds contain small biotite porphyroblasts, indicating that mineralogically at least it is a medium-grade metamorphic rock.

Siltstone

The siltstone of the Roaring Fork closely resembles that of the overlying Pigeon, described below, differing mainly in that it does not form continuous units of great thickness, but is interrupted at frequent intervals by beds of sandstone and argillaceous rocks. It is dull greenish, fine grained, and marked by bedding planes 6 inches to 1 foot apart, with intervening faint, narrow, light and dark laminae. Some beds, by an increase in granularity, approach fine-grained sandstone; others are more argillaceous and grade into phyllite. In the siltstone which immediately underlies the sandstone bed at Sugarland Branch quarry, bedding surfaces are covered by detrital mica flakes as much as a millimeter across. Although not so strongly foliated as the argillaceous rocks, all the siltstone has a well-marked cleavage.

Argillaceous rocks

The argillaceous rocks, like the siltstone, are dull green and marked by light and dark laminae. They exhibit greater megascopic effects of metamorphism than the other components of the Roaring Fork, and are converted into lustrous thoroughly foliated phyllites. In Spring Branch, a mile southwest of the National Park Service Headquarters, one phyllite bed is bright green and probably contains more chlorite than the remainder.

Vein quartz has been introduced into the phyllites in large volume, principally along the foliation, and is a important constituent of the phyllite residuum. One of the most striking areas of residual quartz is in the valley of Thirst Branch on the east side of the West Prong of the Little Pigeon River 1½ miles south of the National Park Service Headquarters, where many acres of hillside are strewn with quartz blocks, some more than 5 feet in diameter.

PETROGRAPHY

Typical specimens of sandstone from the Roaring Fork were examined in thin section by Hadley and have the mineral composition given in table 4; chemical composition of one of the specimens is given in table 5.

TABLE 4.—*Estimated modes, in percent, of Roaring Fork sandstone*

[Estimated by J. B. Hadley]

	GB-16	GB-305
Detrital minerals		
Quartz	60	41
Microcline and orthoclase	25	16
Plagioclase (albite)	11	23
Epidote	1.5	1
Sphene and leucoxene	Trace	.5
Apatite	--------	.3
Metamorphic and secondary minerals		
Biotite	1.5	5
Muscovite and sericite	1.0	9
Iron oxides and pyrite	--------	2
Calcite	--------	2

Both specimens from 120-ft bed exposed in National Park Service quarry on Sugarland Branch 1 mile south of National Park Service Headquarters. Percentages in GB-305 adjusted to composition calculated from chemical analysis.

TABLE 5.—*Chemical analysis, in percent, of Roaring Fork sandstone*

[Lois D. Trumbull, analyst. Specimen GB-305; 52-1499 CD]

SiO_2	74.19
Al_2O_3	12.52
Fe_2O_3	1.27
FeO	1.67
MgO	.74
CaO	1.10
Na_2O	2.57
K_2O	4.17
H_2O-	.01
H_2O+	.89
TiO_2	.42
ZrO_2	.00
CO_2	.09
P_2O_5	.12
MnO	.05
C	.00
	99.81

The sandstone consists largely of detrital grains 0.1 to 0.3 mm in diameter, of which about half are quartz and much of the remainder plagioclase and potash feldspar. In one of the specimens plagioclase is dominant, and this appears to be true for most of the sandstones east of the report area that were studied by Hadley. The muscovite includes a few detrital flakes as much as 0.2 mm in diameter, but most of it and the sericite are in recrystallized flakes. The presence of biotite is significant in suggesting the metamorphic grade of the rock.

STRATIGRAPHIC RELATIONS

The Roaring Fork sandstone is the lowest unit of the Snowbird group in the report area and its base is not exposed. East of the report area it overlies coarser clastic formations of the Snowbird group, which, in turn, lie unconformably on earlier Precambrian basement rocks.

Within the report area the Roaring Fork sandstone south of Gatlinburg is not in contact with the Pigeon siltstone north of Gatlinburg, the two being separated by fault blocks of other rocks. The formations of the two areas extend eastward where their contact is well exposed (Cartertown quadrangle); here, the top of the Roaring Fork is placed at the highest continuously traceable sandstone bed in the silty and argillaceous rocks. Nevertheless, the two units are made up of the same sorts of sandstone, siltstone, and argillaceous rocks, although in different proportions, and the contact is conformable and gradational.

The highest beds placed in the Roaring Fork in the area to the east lie more than a mile north of the lowest beds in the report area which are placed in the Pigeon, which suggests a considerable intergradation westward of beds of Roaring Fork lithology with those of Pigeon lithology. The extent of such intergradation cannot be proved, because of the existence of high-angle transverse faults in the intervening area.

PIGEON SILTSTONE

GENERAL FEATURES

Definition

The Pigeon siltstone (King, 1949, p. 639–640) is adapted from the Pigeon slate of Keith (1895a), and named for exposures along the Little Pigeon River and its West Prong, the type locality being along the main prong of the Little Pigeon River between Pittman Center and Richardson Cove (Richardson Cove quadrangle). The original Pigeon slate included these same rocks, but also siltstones farther north which are now placed in the Wilhite formation of the Walden Creek group. In Keith's later mapping near Snowbird Mountain (1904 and Mount Guyot map) he placed lithologically and stratigraphically similar siltstones in the upper part of his Snowbird formation. The unit is now classed as the upper formation of the Snowbird group.

Occurrence in report area

Within the report area the Pigeon siltstone is exposed near the West Prong of the Little Pigeon River for about 4 miles northward from Gatlinburg (Gatlinburg and Pigeon Forge quadrangles). In the type area to the east the Pigeon is 10,000 to 15,000 feet thick, depending on the magnitude ascribed to known and inferred structures (Hamilton 1961). An equally great thickness is probably exposed in the report area, but the sequence is less certain and is probably disrupted by transverse faults.

Along the river the lowest beds of the formation occur in the south, where they lie in probable fault contact with the sandstones of Dudley Bluff, referred to the Rich Butt sandstone. Farther east, Roaring Fork sandstone occurs beneath the Pigeon, but in another fault block. Northward down the river for 2 miles the siltstone forms a great homoclinal sequence, standing nearly vertical and with tops of beds to the north. Beyond, near McCookville, it is thrown into numerous minor folds. These folded beds, probably in the upper part of the formation, differ somewhat from the siltstones below, and are described below as a carbonate-bearing unit. Siltstones similar to the latter also occur in a separate fault block in the northern part of the town of Gatlinburg, where they are overlain by the Rich Butt sandstone of Dudley Bluffs.

A mass of siltstone of uncertain affinities is exposed in a series of roadcuts on Tennessee Highway 73 where it descends eastward from Fighting Creek Gap to the valley of Fighting Creek (Gatlinburg quadrangle). The beds dip steeply southward, away from Roaring Fork sandstone on the lower slopes, and beneath massive sandstones of the upper part of the Elkmont higher on the ridges. They are on strike with thinner bedded sandstones of the lower part of the Elkmont, well exposed west of Fighting Creek Gap, but are of very different character. A possible interpretation, tentatively adopted on the geologic map (pl. 5), is that the siltstones are a part of the Pigeon which has been isolated in a slice along the Greenbrier fault.

Topographic features

The Pigeon siltstone forms steep-sided round-topped hills and ridges, some with slopes of 35° or steeper, which are partly timbered and partly cleared for cultivation or pasture. Along streams the siltstones form strong massive outcrops in which bedding partings are more conspicuous than cleavage. The cleavage planes are susceptible to weathering, however, and split the rock into slabby fragments which cover the nearby slopes. On hilltops and near stream heads, close to a former high-level valley-floor surface, weathering has proceeded longer, decay is more complete, and the siltstone has been changed to saprolite—a weathered rock which still preserves much of its original structure; this rock is overlain by red residual soil in which the only remaining hard fragments are vein quartz.

MAIN BODY OF FORMATION

Most of the Pigeon is a uniform body of laminated siltstone, made up of quartz and feldspar grains too fine to class as sandstone, yet with a perceptible granularity that distinguishes it from an argillaceous rock. The matrix of finer grained constituents is largely altered to sericite and chlorite, the latter imparting a characteristic greenish or dull blue-green color to the rock.

The siltstone beds are laminated throughout by light and dark layers a few millimeters to a centimeter thick, the light layers being somewhat thicker and coarser textured than the darker. Because of textural variations the light layers are in places coarse silts or fine sands, in others merely fine silts, but in all of them the dark layers are more argillaceous than the lighter. Many of the laminae are smooth and straight, but some of the coarser light-colored layers an inch or so thick show minute crossbedding and crenulations like "current-ripple bedding" (Kuenen, 1953, fig. 3, p. 1052).

Bedding surfaces of the siltstone layers can seldom be observed, but where exposed, in places they contain ripple marks that are probably related to the crossbedding described above. In a roadcut on Norton Creek 2,000 feet southwest of its mouth, bedding surfaces contain a great variety of ripples, trending in diverse directions, some closely spaced, others with amplitudes of 3 to 6 inches. At some other localities, however, rippled surfaces are probably of tectonic origin, like those in the siltstones of the Wilhite formation, described on page 52.

Interbedded in the siltstone at intervals of several hundred feet are layers of fine-grained sandstone a few feet to more than 50 feet thick. The sandstone layers are difficult to trace from one outcrop to the next, and may be very lenticular; a few layers in the lower part, however, are separately shown on the map. They are thickest and most abundant in the lower few thousand feet of section north of Dudley Bluff, although thinner layers are fairly numerous in the siltstone near the upper end of the homocline south of McCookville. The sandstone consists of grains of quartz and feldspar somewhat coarser than those in the siltstone, but nowhere attaining coarse sizes. Bedding laminae are generally few and faint, and in many places a coarse fracture cleavage is more conspicuous. The sandstone weathers into large float blocks.

In the southwestern part of the Richardson Cove quadrangle, just east of the report area, layers of coarse grit and fine conglomerate 25 feet thick are interbedded in the siltstone (Hamilton 1961). These layers contain grains and small pebbles of quartz, feldspar, and rock fragments, and are interbedded with thinner layers of black slate. No similar coarse beds have been observed in the Pigeon in the report area, but possible counterparts occur in the Metcalf, as noted below.

CARBONATE-BEARING UNIT

Along the West Prong of the Little Pigeon River, from McCookville for three-quarters of a mile northwestward to the lower end of the river gorge, the siltstone is of somewhat different character and forms an upper unit of the Pigeon. Where the sequence is better exposed farther east (Richardson Cove quadrangle), rocks of this sort grade indefinitely downward into the siltstones of the main body so that no precise stratigraphic contact can be drawn. Rocks of the unit are typically exposed in the "Rock Fold" quarry on U.S. Highway 441, a short distance south of the mouth of Caney Creek.

The siltstone of the unit is generally dull gray, but part of it is as strongly greenish as the main body. Some of it contains laminae, layers, and lenses, ¼ to 1 inch thick, of iron-bearing carbonate, spaced a few inches apart, and interbedded layers of carbonate-cemented sandstone 1 or 2 feet thick. On the northeast side of the river opposite the mouth of Caney Creek, slate of fair commercial quality is present where bedding and cleavage coincide; this slate has been quarried on a small scale for local use.

Most of the original fine-grained constituents in the siltstone have been altered to sericite and chlorite, but clastic grains of quartz and feldspar as much as 0.1 mm in diameter remain, some of the quartz being perceptibly blue. Successive laminae vary from argillaceous material to fine sandstone. The carbonate-bearing layers are a mixture of calcite and ankerite, the presence of iron being attested by their brown color on weathering; some of the carbonate layers are current bedded, suggesting that the carbonate grains are of clastic origin. The sandstone layers contain quartz grains as much as 0.5 mm in diameter; their carbonate cement is also iron-bearing as they weather brown and punky, and in places have a limonite crust. Some of the bedding surfaces of the sandstone layers are ripple marked, and some are coated with detrital mica.

Probable equivalents of the upper unit are exposed in a small area, bounded on the east and west by faults, in the northern part of the town of Gatlinburg between the mouth of Roaring Fork and Dudley Bluff. Beds dip steeply, and form a northward succession about 3,500 feet thick, overlain by the Rich Butt sandstone of Dudley Bluff. The main part is siltstone with dark-pigmented laminae, interbedded with lighter laminae containing iron-bearing carbonates; but this siltstone is underlain to the south by greenish laminated siltstone, probably equivalent to the main body of the formation.

PETROGRAPHY

Two specimens of siltstone typical of the main body of the Pigeon and specimens of siltstone and sandstone from the carbonate-bearing unit were examined in thin section by Hadley; their mineral composition is given in table 6.

Two of the specimens (GB–10 and 11) are from the main body of the formation in the homoclinal sequence north of Dudley Bluff, the first being silty and perceptibly granular, the second more argillaceous and finer grained. The two differ mainly in the amount of metamorphic micaceous minerals (chlorite and sericite), probably derived from original argillaceous components. Quartz and plagioclase grains are rounded to subangular and very small (0.02 to 0.10 mm), the sphene and other detrital grains being still smaller. Bedding is indicated by differences in size and amount of quartz and plagioclase grains from layer to layer, by thin seams of sphene, magnetite, and other detrital grains, and by greater amounts of chlorite in the darkér layers. Cleavage is indicated mainly by orientation of the sericite at an angle to the bedding.

TABLE 6.—*Estimated modes, in percent, of siltstone and sandstone from Pigeon siltstone*

[Estimated by J. B. Hadley]

	GB-10	GB-11	GB-7	PF-6
Detrital or primary minerals				
Quartz	44	24	33	45
Plagioclase	10	(1)	2	45
Apatite	Trace	-----	-----	Trace
Zircon	-----	-----	Trace	Trace
Tourmaline	-----	-----	-----	Trace
Sphene	1	Trace	Trace	0.1
Ilmenite	-----	Trace	-----	Trace
Magnetite	Trace	Trace	Trace	-----
Muscovite	2	-----	-----	Trace
Carbonate	-----	-----	5	9
Opaque dust	-----	-----	Trace	-----
Metamorphic and secondary minerals				
Chlorite	32	25	30	-----
Sericite	10	50	30	-----
Pyrite	-----	-----	Trace	-----

[1] Included with quartz.

NOTE.—Description of sample and locality as follows:

GB-10. Siltstone, greenish-gray. East side of West Prong of Little Pigeon River three-quarters of a mile north of Dudley Bluff, south of old site of Banner Church.

GB-11. Silty slate, greenish-gray, finer grained than GB-10, but from a nearby outcrop.

GB-7. Siltstone, dark-gray, carbonate-bearing. Cut on U.S. Highway 441 south of Dudley Bluff, in northern part of town of Gatlinburg.

PF-6. Sandstone, calcareous. "Rock Fold" quarry south of mouth of Caney Creek on west side of West Prong of Little Pigeon River, from base of exposure.

The specimen of carbonate-bearing siltstone from the upper unit (GB-7) is similar to the rocks just described, except that coarser lighter layers 1 to 3 mm thick contain much carbonate in the matrix as anhedral grains and aggregates, and the darker intervening layers are pigmented by a small amount of opaque dust.

The sandstone from the carbonate-bearing phase (PF-6) consists principally of detrital grains of quartz and plagioclase (albite) 0.06 to 0.20 mm in diameter. Carbonate mostly forms small rhombohedral grains scattered through the rock, in part replacing feldspar, and in part concentrated along bedding laminae; some coarser carbonate forms veins.

STRATIGRAPHIC RELATIONS

In the main area of the Pigeon siltstone along the West Prong of the Little Pigeon River, its upper part, north of McCookville (Pigeon Forge quadrangle), is in fault contact with the Walden Creek group; the relations of the Pigeon siltstone with this group have not been established. In the area in the northern part of the town of Gatlinburg, the upper beds are overlain conformably by the Rich Butt sandstone.

METCALF PHYLLITE

GENERAL FEATURES

Definition

The Metcalf phyllite is named for Metcalf Bottoms on the Little River south of Wear Cove (King and others, 1958), and is typically exposed along Tennessee Highway 73 in that vicinity. The Metcalf shares many of the lithologic characters of the Pigeon siltstone and Roaring Fork sandstone farther east in the report area and is probably equivalent to one or both of them, but it is thoroughly foliated, much contorted, and over wide areas pervasively sheared (figs. 18, 19); it is differentiated because of its uncertain stratigraphic relations and greater physical metamorphism.

Occurrence in report area

The Metcalf crops out between the high ridges of the Great Smoky Mountains and the cove areas on the northwest, in a belt extending from near the meridian of Gatlinburg southwestward to Cades Cove. Within the report area it forms a belt 1 to 3 miles wide which, to the northeast, lies on the slope of Cove Mountain (Gatlinburg quadrangle) and farther southwest forms a belt of foothills that has been deeply dissected by the Little River and its tributaries (Wear Cove quadrangle).

The Metcalf is mostly faulted against other rocks with which it is in contact. Through part of its course it overlies the Ordovician rocks of the coves along the Great Smoky fault; elsewhere it lies on the Walden Creek group along the Dunn Creek and Line Springs faults. Through much of its course it is overlain on the southeast by the Great Smoky group along the Greenbrier fault. Isolated bodies of the Great Smoky group and related formations are also tectonically intercalated in the Metcalf near Raven Den and near the Little River from The Sinks westward. At its northeast end, near Caney Creek, the Metcalf phyllite joins the Pigeon siltstone, but their stratigraphio relations are uncertain.

The Metcalf is a homogeneous body of thoroughly foliated argillaceous and silty rocks that are interbedded with layers of fine-grained sandstone. Because of small-scale folding of the formation, obliteration of bedding by cleavage over wide areas, and local shearing, its larger structure and original thickness cannot be determined; it is certainly many thousands of feet thick.

Topographic features

The Metcalf is well exposed in roadcuts and bold natural ledges along the various prongs of the Little River; outcrops are also abundant along the steeper side streams. Even away from the main streams and along the ridges where outcrops are sparse, presence of the formation is clearly indicated by its float of micaceous lustrous chips and slabs, with intermingled blocks of white vein quartz, which differs from float of the formations with which it is in contact.

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LITHOLOGY

Argillaceous rocks

The argillaceous rocks of the Metcalf have been altered to fine-grained, lustrous or silky, pale-green, gray-green, or light-gray phyllite, made foliate by such micaceous minerals as chlorite and muscovite. Foliation produces a thinly fissile cleavage along which the rock splits. Bedding is shown in places by thin light and dark laminae, bedding is everywhere subordinate to the foliation and in many outcrops is not discernible.

Siltstone

Siltstone is interbedded with the phyllite in most areas, and comprises a third to half the volume of the formation. The siltstone is more perceptibly granular than the phyllite and contains a greater proportion of fine detrital grains. Foliation is nearly as strongly developed and as pervasive as in the phyllite, but because of the granular texture the cleavage surfaces are dull. Bedding is much more evident in the siltstone; it is indicated not only by the usual light and dark laminae, but by partings a few inches to several feet apart. Most of the bedding laminae are rigorously parallel, but a few thin layers of current-ripple bedding similar to those in the Pigeon occur in places. At a few localities in the northwestern part of the outcrop belt the siltstone contains thin closely spaced brown-weathering carbonate layers, similar to those in the carbonate-bearing unit of the Pigeon. They are best developed in highly sheared siltstone not far beneath the Greenbrier fault along the Little River about a mile east of Tremont Junction, where associated thin sandstone layers also have a carbonate cement and weather brown.

Sandstone

Sandstone forms widely spaced beds, mostly only a few feet thick, although a few as much as 50 feet thick occur locally. These beds are most extensive north and northwest of Schoolhouse Gap at the west edge of the area (Wear Cove quadrangle), where they comprise a large part of the exposed section. The sandstone is gray, fine grained, of uniform texture, and consists largely of grains of quartz and feldspar. The sandstone beds lie mainly in the siltstone, of which they appear to be textural variants. They are somewhat sheared and crushed, and many are traversed by gash veins of quartz, but they are less foliated than the associated fine-grained rocks.

An aberrant set of sandstone beds, about a hundred feet thick, overlain and underlain by siltstone and phyllite, is exposed on the Little River about half a mile east of Tremont Junction (just north of elevation point 1,176, Wear Cove quadrangle). They are coarser grained and thicker bedded than the rest, and in some layers contain quartz grains as much as an eighth of an inch in diameter. They are separated by partings of blue-black pyritic slate. Similar thin coarse layers interbedded in the Metcalf are reported by Ferguson in ravines south of Tuckaleechee Cove west of the Little River. These aberrant coarse sandstones resemble the coarse sandstones interbedded in the otherwise fine-grained Pigeon in the southwestern part of the Richardson Cove quadrangle.

PETROGRAPHY

Mineral and chemical composition

Ten specimens of rocks from the Metcalf phyllite were examined in thin section by Hadley; their mineral composition is given in table 8. A chemical analysis of one of these rocks is given in table 7 and is compared with an analysis of a specimen of Pigeon siltstone.

TABLE 7.—*Chemical analysis, in percent, of Metcalf phyllite and Pigeon siltstone*

[Lois D. Trumbull, analyst]

	WC-300 (*52-1494 CD*)	*RC-299* (*52-1493 CD*)
SiO_2	55.52	56.28
Al_2O_3	21.43	21.36
Fe_2O_3	.65	.94
FeO	6.76	6.04
MgO	2.62	2.21
CaO	1.31	1.16
Na_2O	1.62	1.52
K_2O	3.60	4.92
H_2O-	.07	.07
H_2O+	4.36	4.12
TiO_2	1.06	.81
ZrO_2	.00	.00
CO_2	.38	.03
P_2O_5	.22	.24
S	.00	.00
MnO	.12	.11
C	.00	.00
	99.72	99.81

NOTE.—Description of sample and locality as follows:
WC-300. Metcalf phyllite, sandy, pale-green. Laurel Creek a quarter of a mile southwest of junction with West Prong of Little River.
RC-299. Pigeon siltstone, laminated, greenish, without conspicuous cleavage. Little Pigeon River a quarter of a mile north of bridge at Laurel (Richardson Cove quadrangle).

Phyllite

In the six specimens of phyllite (table 8), metamorphic micaceous minerals dominate, largely mixtures of chlorite and muscovite or sericite. All, however, contain detrital grains, less than 0.3 mm in diameter, of quartz and plagioclase feldspar. Bedding, where visible, is indicated by varying proportions of the detrital quartz and feldspar grains on the one hand, and the micaceous metamorphic minerals on the other, the laminae being

TABLE 8.—*Mineral composition of rocks from Metcalf phyllite*

[From examination in this section by J. B. Hadley. Percentages in specimen WC-300 adjusted to composition calculated from chemical analysis. In the other specimens mineral occurrences are indicated qualitatively, as follows: A, more than 50 percent; B, 10 to 50 percent; C, 1 to 10 percent; D, less than 1 percent]

	Phyllite						Siltstone		Sandstone	
	WC-1	WC-3	WC-4	WC-8	WC-300	WC-22	WC-24	WC-K18	WC-31A	WC-7A
Detrital minerals										
Quartz	B	C	C	B	25	A	B	B	A	A
Feldspar (mainly plagioclase)	C	C	C	C	14.7	C	C	C	B	B
Sphene and leucoxene	D	D	D	D	1.1	D	C	D	C	D
Rutile					Trace					
Apatite					.5					
Zircon				D	Trace			D	D	
Tourmaline				D	Trace				D	
Epidote					2.6			C	C	
Magnetite					.2			C	D	
Muscovite						D				
Metamorphic and secondary minerals										
Muscovite and sericite	A	A	A	A	30.5	B	B	B	C	D
Chlorite	C	D	B	B	20.6	B	B	B	B	
Biotite			D			C			D	
Pyrite	D				Trace	D	D		C	
Carbonate (mainly calcite)				D	.9		C	D		D

NOTE.—Description of sample and locality as follows:

WC-1. Phyllite, pale-green, crinkled. Little River about halfway between Metcalf Bottoms and The Sinks.
WC-3. Phyllite, crinkled, muscovitic. From near locality of WC-1.
WC-4. Phyllite, yellow-green, muscovitic, with strong slip cleavage. From near last locality.
WC-8. Phyllite with slip cleavage. Laurel Creek a quarter of a mile southwest of junction with West Prong of Little River.
WC-300. Phyllite, sandy, pale-green. From near locality of WC-8.
WC-22. Phyllite, sandy, muscovitic. Lower course of Strickler Branch west of Metcalf Bottoms.
WC-24. Siltstone, dark-gray. Wear Cove road a quarter of a mile south of Wear Cove Gap.
WC-K18. Siltstone, phyllitic, greenish, laminated. Road cut on west side of Middle Prong of Little River, south end of Walker Fields, 200 ft north of Fodderstack Branch.
WC-31A. Sandstone, greenish-gray. Laurel Creek, half a mile southwest of its junction with West Prong of Little River.
WC-7A. Sandstone, feldspathic. Laurel Creek a quarter of a mile north of mouth of Spence Branch.

0.5 to 2.0 mm thick. Bedding is best shown where the proportion of detrital grains is greatest.

The sections show a gradational series from rocks in which bedding is well preserved, but foliation is dominant (WC-22 and 300), into rocks in which a slip cleavage has been imposed (WC-1, 3, and 8). In the latter, many of the micaceous minerals are still parallel to the earlier foliation, but some have been brought into parallelism with the slip cleavage along thin laminae. In the more extreme phases (WC-4), slip cleavage penetrates all the rock along interlacing fractures followed by well-oriented micas, and earlier foliation has been confused or nearly destroyed. Some specimens contain grains of pyrite, partly anhedral, and others contain irregular quartz veinlets, in which the quartz has been strained and fractured.

Siltstone

The specimens of siltstone contain the same constituents as the phyllites, but they have a greater proportion of detrital grains of quartz, feldspar, and other minerals. Quartz grains are angular to subrounded, are partly recrystallized, and are from 0.01 to 0.10 mm in diameter. Bedding is shown by alternating light and dark laminae 0.2 to 4.0 mm thick, the lighter laminae containing more abundant and larger quartz grains. Foliation, less perfectly developed than in the phyllites, is expressed by orientation of micaceous minerals transverse to the bedding. Under the microscope, the specimens of silstone closely resemble those of the Pigeon.

Sandstone

The specimens of sandstone consist dominantly of detrital grains of quartz and feldspar from 0.3 to more than 1.0 mm in diameter; one specimen also contains a considerable variety of minor detrital minerals. The larger grains lie in a heterogeneous fine-grained groundmass, in part crushed, containing muscovite and chlorite that imparts a rude foliate structure.

Summary of petrography

In most respects, according to Hadley, the mineralogy of rocks of the Metcalf phyllite corresponds closely to that of the Pigeon siltstone and Roaring Fork sandstone farther east in the Great Smoky Mountains. The only exception is the minor tourmaline grains in three of the specimens, as this mineral is more characteristic of the Great Smoky group of that area. Resemblance of rocks of the Metcalf to those of the other formations of the Snowbird group is borne out by the chemical analyses of table 7, which indicate that the composition of the phyllite from the Metcalf and siltstone from the Pigeon are surprisingly alike, despite their different physical appearance and structure. These differences may result from the finer grain size and greater physical effects of metamorphism in the former.

STRATIGRAPHIC RELATIONS

The Metcalf phyllite closely resembles in general composition and textural range the Pigeon siltstone and Roaring Fork sandstone of the Snowbird group in the eastern part of the report area; it is most like the Pigeon in its homogeneity through great thicknesses and its lack (except near Schoolhouse Gap) of thick well-differentiated sandstone beds like those in the Roaring Fork. It differs from the Pigeon in containing a greater proportion of argillaceous rocks than siltstones and in its much greater metamorphism. The latter may result in part from its larger argillaceous content; it is also, at least in part, the result of its more complex structural relations; even the siltstones of the Metcalf are more foliated than those of the Pigeon.

Metcalf phyllite of typical aspect is traceable northeastward along the northwest slope of Cove Mountain to the valley of Caney Creek. Southeast of Caney Creek in John, Shanty, and Bearwallow Hollows it apparently dips beneath siltstones and sandstones of Pigeon aspect which extend thence eastward to the West Prong of the Little Pigeon River. This suggests either that the Pigeon is faulted over the Metcalf, or that the Metcalf is a phase of the lower part of the Pigeon, similar to more argillaceous units which occur in it farther east. Even if this relation is valid locally, it may not apply entirely to the larger mass of the Metcalf farther west, in parts of which the proportion of siltstone and sandstone is nearly as great as in the Pigeon and Roaring Fork.

RELATIONS OF SNOWBIRD GROUP TO HIGHER FORMATIONS

Within the report area the stratigraphic relations of the Snowbird group to rocks above it is largely undetermined. It is overlain on the southeast by the Great Smoky group along the Greenbrier fault and is faulted over the Walden Creek group on the northwest along the Dunn Creek and Line Springs faults. In the intervening area, in the northern part of the town of Gatlinburg, it is succeeded conformably by the Rich Butt sandstone. Relations of the Snowbird group to higher formations must be determined largely by observations outside the report area.

In the southeastern part of the Great Smoky Mountains, above the Greenbrier fault, a thinned representative of the Snowbird group is followed conformably by the Great Smoky group, proving that the latter is the younger unit (Hadley and Goldsmith, 1963). Just north of the Greenbrier fault, however, the Snowbird group is overlain conformably by the Rich Butt sandstone and related unclassified formations of the Ocoee series.

Relations with the Walden Creek group are less certain, but northeast of the Great Smoky Mountains near the French Broad River rocks lithologically like the Snowbird group are followed by rocks lithologically like the Walden Creek group, which have been variously termed Hiwassee slate or Sandsuck formation (Keith, 1904, p. 5; Oriel, 1950, p. 23–30; Ferguson and Jewell, 1951, p. 16–21), although both sets of beds are thinner here than in the Great Smoky Mountains. Whether the rocks of Snowbird and Walden Creek lithology in this northeastern area are the equivalents of those in the Great Smoky Mountains has not been determined, but an upward sequence from one rock type to the other is proved.

The Snowbird group is thus overlain by several different units of the Ocoee series of contrasting character from southeast to northwest. The significance of this relation will be discussed below (p. 68–70).

GREAT SMOKY GROUP[2]

GENERAL FEATURES

Definition

The Great Smoky conglomerate was named by Keith (1904, p. 6) for the Great Smoky Mountains, the term being used for the great mass of fine conglomerate, coarse sandstone, and argillaceous rock that forms much of the range. As the Great Smoky is divisible into several formations it is now termed the Great Smoky group (King and others, 1958).

Occurrence

The Great Smoky group forms the upper plate of the Greenbrier fault, terminating northwestward along the trace of the fault, and extending thence 20 to 25 miles southeastward. Through most of its extent the base of the group is cut off by the Greenbrier fault, but in the southwestern part of the Great Smoky Mountains it lies conformably on the Snowbird group. Throughout the mountains the Great Smoky group is the highest unit present, but farther south it passes beneath the Nantahala slate and higher formations of the Murphy marble belt (Keith, 1907a). Some parts of the group are strongly folded, but others dip more regularly; on the northern slopes of the mountains the group dips at moderate angles southeastward, forming a homoclinal sequence of great thickness. On the Middle Prong of the Little River the homocline involves as much as 25,000 feet of strata, but base and top are not exposed.

[2] Based on observations by King in the eastern part of the report area (Gatlinburg and Silers Bald quadrangles) and on observations by H. W. Ferguson and G. D. Swingle in the western part of the report area (Wear Cove and Thunderhead quadrangles).

In the report area, smaller bodies of the Great Smoky group, which are remnants of the Greenbrier thrust sheet, are downfaulted in the foothills northwest of the mountain area. As the rocks in this part of the Great Smoky group possess some special characters, they are separately treated in the descriptions of the formations which follow.

Subdivisions

The Great Smoky group is a mass of clastic rocks —fine conglomerate, coarse to fine sandstone, and silty or argillaceous slates and phyllites. The group is monotonous in character through great thicknesses, but is sufficiently different from one part to another to be divided into three formations.

Throughout much of the northern Great Smoky Mountains the middle part of the Great Smoky group is consistently a thick-bedded coarse sandstone and fine conglomerate, whereas the part beneath is thinner bedded, finer grained sandstone, and the part above contains prominent layers of dark argillaceous rocks. The middle part of the group is therefore set off as the Thunderhead sandstone; the part below is termed the Elkmont sandstone and the part above the Anakeesta formation. Coarse thick-bedded rocks of Thunderhead aspect are repeated, however, at various stratigraphically higher levels, and in the southeastern part of the report area such rocks form a consistent unit above the Anakeesta formation; for the present this unit is left unnamed.

The formations of the Great Smoky group distinguish gross lithologic contrasts between various parts of the sequence; the units intergrade vertically and intertongue laterally, so that they are rock-stratigraphic rather than time-stratigraphic units. Regionally, the Thunderhead sandstone is lower stratigraphically and older in the west than in the east, its bottom beds passing eastward into rocks of Elkmont lithology, and the lower part of the Anakeesta being replaced by the Thunderhead in the same direction. Within the report area, this relation is expressed by a tongue of the Thunderhead sandstone, which thins westward between a lower and an upper tongue of the Anakeesta formation, and by an apparent difference in stratigraphic position of the top of the Elkmont sandstone from place to place (pl. 8).

For the higher beds of the Great Smoky group, Keith (1895a) in the Knoxville report used the terms "Hazel slate" and "Clingman conglomerate," but these names are now abandoned.

The Hazel slate was named for outcrops on Hazel Creek, south of the report area in North Carolina; in the northern Great Smoky Mountains it was applied to beds now placed in the Anakeesta formation. The Hazel slate was subsequently (Keith, 1907a) considered to be synonymous with the Nantahala slate, and the name Hazel was adopted for another unit in Texas. It seems undesirable to revive the Hazel slate in the Great Smoky Mountains.

The Clingman conglomerate was named for Clingmans Dome southeast of the report area, but it was subsequently (Keith, 1907a) merged with the Great Smoky conglomerate. It is now known, however, that at Clingmans Dome and some other places coarse sandstone overlies argillaceous rocks of the Anakeesta formation and intertongues with it at various levels. Rather than use the term Clingman for these sandstones, it seems best to class them, depending on locality, as beds in the Anakeesta formation, as tongues of the Thunderhead sandstone, or as unnamed parts of the Great Smoky group.

ELKMONT SANDSTONE

GENERAL FEATURES

Definition

The Elkmont sandstone, or lowest unit of the Great Smoky group, is named for the community of Elkmont, 5 miles southwest of Gatlinburg (Gatlinburg quadrangle), in the midst of an outcrop area of the formation (King and others, 1958). Typical exposures occur along the Little River, from Tennessee Highway 73 southeastward past Elkmont, to the base of the Thunderhead sandstone.

The Elkmont in this vicinity, and in many places elsewhere, was mapped by Keith (1895a) as Cades conglomerate, but it now seems more appropriate to restrict the Cades to rocks exposed in the vicinity of Cades Cove, nearer its type locality.

Occurrence in report area

The Elkmont sandstone is exposed discontinuously across the report area. Many outcrops occur along the lower slopes and spur ends of the Great Smoky Mountains, the most extensive of which are those near Elkmont (Gatlinburg quadrangle). East of Elkmont the sandstone emerges above the Greenbrier fault along the bases of the Bull Head and Sugarland Mountain, but it is poorly exposed and much covered by talus. West of Elkmont it reappears near the Middle Prong of the Little River, its outcrop expanding westward to include the crest and all the north slope of the mountains (Thunderhead quadrangle). The Elkmont also forms an outlying area 5 miles long and 2 miles broad on the southeast flank of Cove Mountain west of Gatlinburg, which is drained by Norton Creek, and by Cliff, Buckberry, and Hickory Flats Branches (Gatlinburg quadrangle).

Near Elkmont about 6,000 feet of Elkmont sandstone is exposed below the Thunderhead sandstone, and in the mountains near the west edge of the report area as much as 8,000 feet is exposed. In the Cove Mountain area the formation is more folded and the exposed thickness less easy to determine, but it is probably little more than 2,000 feet. In none of these areas is the base of the formation visible.

MOUNTAIN AREA

Elkmont area

Near Elkmont, the type area, the Elkmont sandstone is exposed in a triangle between the Gatlinburg and Oconaluftee faults, which is split, in turn, by the Mids Gap and Huskey Gap faults that partly repeat the sequence; relations are further complicated by lateral changes in lithology across the area.

The upper few thousand feet of the formation is generally coarser grained than the lower part, and is also coarsest southwestward, where some of its beds are indistinguishable from those of the Thunderhead sandstone. (See unit 7, geologic section 2, below.) Northward and northeastward these coarse beds pass rapidly into finer grained sandstone, siltstone, and argillaceous rocks, and only a few thin gritty layers persist (units 2, 3, and 4, geologic section 1; unit 4, geologic section 3).

The beds beneath consist of fine-grained ledge-making gray sandstone, interbedded with silty sandstone and gray or greenish-gray silty and argillaceous rocks. A few of the sandstone beds contain granules and small pebbles of feldspar and glassy quartz. The sequences in each fault block contain a bed of coarser conglomerate made up of pebbles of the same minerals as much as an inch in diameter (unit 2, geologic section 2; unit 2, geologic section 3), but these lie at different depths below the top of the formation and are probably not correlative. The two conglomerate layers are underlain west of Elkmont by a great thickness of fine-grained sandstone, siltstone, and argillaceous rocks, whose base is not exposed, and whose outcrops are too scattered to give much indication of the nature of the sequence (unit 1, geologic section 3).

Blue quartz grains, a characteristic component of the Thunderhead sandstone above, decrease in abundance downward in the Elkmont. They are common in and upper coarse-grained beds, but are generally lacking in the finer grained beds below. None occur in the lower part, even in the two conglomerate layers.

The following three stratigraphic sections illustrate the sequence of the Elkmont sandstone in different parts of the two fault blocks.

Geologic section 1.—*Generalized section of Elkmont sandstone in block between Huskey Gap and Mids Gap faults, northeast of main east prong of Little River*

	Estimated thickness (feet)
Thunderhead sandstone at top of section.	
Upper coarse-grained division of Elkmont sandstone:	
4. Mainly silty and argillaceous rocks, at east end of exposure, in head drainage of Sugarland Branch; includes several layers of coarse sandstone and fine conglomerate a few feet thick in lower part. To southwest, toward Little River, whole unit changes into sandstone, some beds of which are as coarse and massive as those of the Thunderhead	1,250
3. Poorly exposed, mostly forming a sag in topography; on Mids Gap-Huskey Gap trail are outcrops of silty and argillaceous rocks	250
2. Sandstone, fine-grained, with rare gritty layers containing blue quartz and other grains as large as an eighth of an inch in diameter. Some fine-grained sandstone layers near east end of exposure contain chloritoid porphyroblasts. Forms high ridge east of Mids Gap	500
Lower fine-grained division of Elkmont sandstone:	
1. Mostly poorly exposed, on trail at Mids Gap consists of silty and argillaceous rocks. Thickness exposed here	200
Base of section cut off by Mids Gap fault.	

Geologic section 2.—*Generalized section of Elkmont sandstone in block between Huskey Gap and Mids Gap faults, southwest of main east prong of Little River*

	Estimated thickness (feet)
Thunderhead sandstone at top of section, on Burnt Mountain.	
Upper coarse-grained division of Elkmont sandstone:	
7. Sandstone, massive, gray; forms conspicuous ledges on north and west slopes of Burnt Mountain, some of which are 25 ft or more thick. Sandstone is about as coarse grained as most of Thunderhead sandstone, although conglomeratic layers are less common. Contact with Thunderhead is based on tracing of beds from northeast of river	1,200
6. Poorly exposed across Bearwallow Branch; probably many beds of silty and argillaceous rock	200
5. Sandstone, fine-grained, but includes some coarse-grained layers containing pebbles, as much as a quarter of an inch in diameter, of blue quartz, glassy quartz, and white feldspar	900
Lower fine-grained division of Elkmont sandstone:	
4. Argillaceous rocks and thin interbedded layers of fine-grained sandstone, and several beds of medium-grained sandstone 25 ft thick; latter contains seams of quartz 1 in. across, most quartz grains being glassy, a few blue. Well exposed on south side of Little River east of Jakes Creek	350
3. Mostly poorly exposed and deeply weathered; probably largely silty and argillaceous rocks	750

GEOLOGIC SECTION 2.—*Generalized section of Elkmont sandstone in block between Huskey Gap and Mids Gap faults, southwest of main east prong of Little River*—Con.

	Estimated thickness (feet)
Lower fine-grained division of Elkmont sandstone—Con.	
2. Conglomerate, mostly poorly exposed and indicated mainly by pebbly float. Contains glassy quartz pebbles as much as 1 in. across and smaller grains of quartz and feldspar, but no blue quartz; finer grained sandstone probably interbedded. Forms ridge west of Elkmont between Jakes Creek and Shields Branch	200
1. Mostly poor exposed, some outcrops of fine-grained sandstone near Shields Branch; thickness undetermined	?
Base of section cut off by Mids Gap fault.	

GEOLOGIC SECTION 3.—*Generalized section of Elkmont sandstone in block between Mids Gap and Gatlinburg faults*

	Estimated thickness (feet)
Top of section cut off by Mids Gap fault; section begins at least several hundred feet below base of Thunderhead sandstone.	
Upper coarse-grained division of Elkmont sandstone:	
4. Sandstone, medium- to fine-grained, with much interbedded silty and argillaceous rock especially near middle. Includes fewer coarse-grained or gritty beds than in sections to southeast, but a few are exposed on trail between Fighting Creek Gap and Mids Gap and one near base west of Little River at Camp Le Conte. Forms high ridge southeast of Fighting Creek Gap	1,800
Lower fine-grained division of Elkmont sandstone:	
3. Sandstone, fine-grained, ledge-making, gray; forms at least half the unit, the rest is silty sandstone and gray or greenish-gray silty and argillaceous rocks. A few sandstone beds contain grits and small pebbles of feldspar and glassy quartz; slightly coarser grains are present in one bed near middle. Well exposed along Elkmont road between Tennessee Highway 73 and Camp Le Conte	1,500
2. Sandstone, coarse; contains grains of feldspar and glassy quartz; blue quartz is absent. Forms ledge on Elkmont road just south of Tennessee Highway 73. Bed becomes coarser southwest of Little River, where it contains glass quartz pebbles as much as 1 in. across. In some outcrops of bed, grains are strongly flattened and elongated (specimen GB–N23)	25-50
1. Mainly poorly exposed; scattered outcrops along Blanket Creek and westward are mostly fine-grained sandstone, with interbedded silty and argillaceous rocks. Thickness undetermined; at least	2,000
Base of section cut off by Gatlinburg and Mannis Branch faults.	

Area west of Elkmont

The Elkmont sandstone also emerges across the Oconaluftee fault in the southwestern part of the report area, where it is exposed in the drainage basins of the Middle and West Prongs of the Little River. It is exposed, for example, along the Middle Prong between Tremont and the Oconaluftee fault and on the Bote Mountain road near the west edge of the report area.

A general correlation of these rocks with those in the Elkmont area is assured, as they underlie a full thickness of Thunderhead sandstone, but detailed correlation is uncertain. Matching of sections suggests that the top of the Elkmont in this area corresponds to the base of the upper coarse division of the Elkmont in the type area (pl. 8). The top of the Elkmont is placed at the base of the lowest thick coarse sandstone ledges on Meigs Mountain (unit 1, geologic section 5, p. 43) and at Tremont on the Middle Prong of the Little River. This contact extends southwestward to the State-line divided 2 miles west of Thunderhead Mountain, but it cannot be mapped definitely beyond the Middle Prong.

Where exposed along the Middle Prong of the Little River, the Elkmont sandstone resembles the Thunderhead sandstone; but the Elkmont is finer grained and thinner bedded, and does not form as conspicuous ledges. Scattered coarse beds contain quartz and feldspar grains as much as an eighth of an inch in diameter, but they contain blue quartz only rarely. Some of the sandstones have a "pepper and salt" texture, apparently caused by intermingling of fine light and dark grains. Most of the interbedded argillaceous rocks are gray to blue black, but some greenish chloritic beds were observed half a mile north of Tremont.

COVE MOUNTAIN AREA

In the area on the southeast flank of Cove Mountain west of Gatlinburg the Elkmont sandstone consists of alternating beds of sandstone and argillaceous rocks of about equal thickness. Some sandstone beds are as much as 5 to 25 feet thick, but most are much thinner. Beds of argillaceous rocks are as much as 10 feet thick, but many are mere partings between the sandstones. The Elkmont of this area differs from the Roaring Fork sandstone and Pigeon siltstone exposed nearby in its alternation of thin coarse and fine layers and in the consistently coarser grain of its sandstones.

Sandstone

The sandstone in this area is gray to light gray when fresh, and consists of grains of quartz and feldspar a few millimeters in diameter. Scattered through the sequence, but especially toward the top, are slightly coarser beds containing small pebbles of glassy quartz, white kaolonized feldspar, and small slate chips; no blue quartz is present. Graded bedding is well devel-

FIGURE 7.—Graded bedding in steeply dipping Elkmont sandstone in channel of Norton Creek half a mile above mouth of Roberts Branch, Gatlinburg quadrangle. Each graded bed ranges in texture from coarse sandstone at base (right) to siltstone at top (left).

oped in many layers, as on Norton Creek about 1½ miles above its mouth (fig. 7). Coarse sand at the bottom of a layer grades up into finer sand, which grades into an argillaceous parting at the top, individual graded units being a foot or two thick. The sandstone beds are best exposed in stream channels and roadcuts. On hillsides they have so disintegrated by weathering that there are few natural ledges; where ledges occur, they are strongly exfoliated, and their bedding can seldom be interpreted.

Argillaceous rocks

Argillaceous rocks are indurated, gray, blue gray, or black, and of fine uniform texture, in part laminated by light and dark seams a fraction of an inch thick. Bedding is evident in nearly every exposure, and foliation other than rough fracture cleavage is uncommon; the rocks are thus "argillites" as that term is strictly defined. The argillaceous rocks are more resistant to weathering than the sandstones, and persist as float on hillsides where the sandstones have been thoroughly decayed.

PETROGRAPHY

The petrographic character of the Elkmont sandstone is illustrated by five specimens of rocks which were collected in the Cove Mountain area and were examined in thin section by Hadley. These specimens have the mineral composition given in table 9. A chemical analysis of one of the sandstones is given in table 10.

Sandstone

The two specimens of sandstone (GB–12 and 5) are poorly sorted, for they have subangular grains 0.1 to as much as 4.0 mm in diameter and varying amounts of fine matrix. Over half the detrital grains are quartz, and many of the others are microcline, microperthite, and plagioclase; but minor grains of other minerals are present. Metamorphism has produced chlorite and

TABLE 9.—*Estimated modes, in percent, of rocks of Elkmont sandstone of Cove Mountain area*

[Estimated by J. B. Hadley]

	GB-12	GB-5	GB-13		GB-3	GB-4
			A	*B*		
Detrital minerals						
Quartz	60	60	Abundant	30	10	30
Microcline and microperthite	6	10	Common		Trace	Trace
Plagioclase (albite)	19	15	do	5	Trace	5
Muscovite and chlorite		Trace	Minor	Trace	2	10
Sphene and leucoxene		Trace				
Zircon	Trace		Rare		Trace	Trace
Apatite	Trace					Trace
Tourmaline			Rare			Trace
Magnetite and others	Trace					
Opaque dust			Sparse	1	1	2
Secondary and metamorphic minerals						
Chlorite	1	10		10	Trace	8
Sericite	4	5	Minor	54	86	45
Biotite	6			Trace		
Carbonate	3	Trace				
Iron sulfide		1				Trace

NOTE.—Description of sample and locality as follows:
GB-12. Sandstone, coarse, blue-gray, feldspathic. Buckberry Branch at altitude of 2,000 ft. Percentages from micrometric analysis and calculated mode of chemical analysis.
GB-5. Sandstone, coarse, feldspathic. Norton Creek half a mile southwest of its junction with Roberts Branch.
GB-13. Argillite, silty, dark-gray, with sandstone layer. Same locality as GB-12. *A*, coarse layer; *B*, fine layer.
GB-3. Argillite, silty, black. Norton Creek a quarter of a mile southwest of its junction with Roberts Branch.
GB-4. Argillite, silty, dark-gray. Same locality as GB-5.

TABLE 10.—*Chemical analysis, in percent, of Elkmont sandstone of Cove Mountain area*

[Lois D. Trumbull, analyst. Specimens GB-12 and 52-1490 CD]

SiO_2	82.06
Al_2O_3	7.87
Fe_2O_3	.20
FeO	2.17
MgO	.68
CaO	1.05
Na_2O	2.03
K_2O	2.03
H_2O-	.01
H_2O+	.87
TiO_2	.49
ZrO_2	.01
CO_2	.46
P_2O_5	.09
S	.03
MnO	.04
C	.00
	100.09
Less O for S	.02
	100.07

sericite, mainly in the matrix, and rare biotite. The metamorphic minerals are unoriented and do not produce a foliation in the rock.

Argillaceous rocks

In the three specimens of argillaceous rocks (GB–13, 3, and 4) the dark-and-light bedding laminae differ in the size of quartz and feldspar grains; grains in the finer layers are 0.01 to 0.10 mm in diameter and those of the coarser are 0.1 to 0.4 mm. The laminae also differ in the presence of sericite and opaque dust in the darker ones, and their absence in the lighter. In one specimen the laminae are graded, lighter layers fading into darker on one side, and with sharp contact on the other.

Detrital grains are quartz and feldspar and rare minor minerals. Scattered flakes of muscovite oriented parallel with the bedding are also detrital and impart a slight fissility to some of the specimens. Metamorphic sericite and some chlorite have developed in the finer grained layers, but these minerals are not oriented as to produce a foliation. One specimen contains rare biotite.

Altered sandstone

A single specimen (GB–N23) from the type area of the Elkmont was collected primarily to show metamorphic and structural features. It is from bed 2 of geologic section 3, about 3,500 feet below the top of the formation, from an outcrop on the Elkmont road just south of Tennessee Highway 73.

According to Hamilton, about 80 percent of this sandstone consists of quartz and feldspar grains, mostly less than 0.2 mm in diameter, but some as large as 2.0 mm. These minerals have been moderately crushed and recrystallized, as well as elongated in the plane of the foliation; they lie in a matrix of muscovite and biotite and finely crushed quartz and feldspar. Presence of biotite indicates that the locality from which the specimen was collected lies near the chlorite-biotite metamorphic isgrad. The general composition of the original detrital material closely resembles that of the Thunderhead sandstone.

STRATIGRAPHIC RELATIONS

The Elkmont sandstone in the report area, and elsewhere in the northern Great Smoky Mountains, lies on the Greenbrier fault and its base is cut off by this and other faults, so that the rocks on which it was originally laid are undetermined. In the southeastern part of the mountains, where the stratigraphic base of the Great Smoky group emerges, the Elkmont has not been identified and it is uncertain to what part of this sequence it is related.

Throughout the report area the Elkmont sandstone is succeeded by coarser rocks of similar character, which form the Thunderhead sandstone. In the Cove Mountain area, superposition of one over the other can be proved by graded bedding along Norton Creek and elsewhere, even though the rocks are steeply tilted. Throughout the report area the contact between the Elkmont and Thunderhead sandstones is exposed only for short distances in separate fault blocks, so that it cannot be determined whether these horizons are equivalent from place to place. Relations within the fault blocks of the Elkmont area and correlation of the section here with that near the Middle Prong of the Little River suggest that the top of the Elkmont, as drawn, descends toward the southwest, and that its upper part passes in this direction into Thunderhead sandstone (pl. 8).

THUNDERHEAD SANDSTONE

GENERAL FEATURES

Definition

The Thunderhead sandstone is named for Thunderhead Mountain, on the State-line divide in the southwestern part of the report area, where Keith (1895a) distinguished the Thunderhead conglomerate with about the same limits as the present unit. Thunderhead Mountain is in a remote part of the region; the formation is better exposed on Mount Le Conte a little east of the report area, where a full section is present. Excellent outcrops of the Thunderhead occur along U.S. Highway 441 along the southwestern base of Mount Le Conte.

Occurrence in report area

The Thunderhead sandstone forms most of the northern slopes and spurs of the Great Smoky Mountains, across the report area and eastward, where it dips at moderate to steep angles toward the southeast. Toward the east it forms the high massive ridges of Mount Le Conte, Bull Head, and Sugarland Mountain (Cartertown and Gatlinburg quadrangles) (fig. 8). Farther west, across an offset by the Ocanaluftee fault, it forms Blanket Mountain, Thunderhead Mountain, and other summits (Gatlinburg and Thunderhead quadrangles). To the south it is repeated by the Mingus fault and forms the northern slopes of Mount Buckley and Clingmans Dome (Silers Bald quadrangle).

North of its main outcrops, in the foothills of the Great Smoky Mountains, the Thunderhead sandstone is preserved in various outliers. It occurs in a wedge between the Mannis Branch and Gatlinburg faults near the Middle Prong of the Little River and forms much of Cove Mountain north of the Gatlinburg fault

(Wear Cove and Gatlinburg quadrangles). Beyond Cove Mountain smaller bodies of the Thunderhead are embedded tectonically in the Metcalf phyllite, along the main east prong of the Little River and near Raven Den east of Wear Cove.

Topographic features

The Thunderhead sandstone is the most prominently exposed unit of the Ocoee series (fig. 8). In the mountain area it forms great ledges and cliffs, which have been located and marked by hachures on the geologic maps (pls. 2-7). From a distance these ledges have the appearance of impassable ramparts, but because of their high feldspar content they are rarely continuous, and break down laterally into sandy soil. Ledges are 10 to 50 feet thick, and in many the bedding partings are few, faint, and obscured by low-dipping joints or curved spalls.

The sandstone breaks from the ledges in blocks or slabs, locally known as "graybacks," some "as large as good-sized cabins" (Safford, 1869, p. 189); the largest are 50 feet or more long and as much as 25 feet thick. On mountain slopes below the ledges these graybacks gather into block fields and waste streams, which are the source of the small to large rounded sandstone boulders that choke most of the streams draining the mountain area.

MOUNTAIN AREA

Stratigraphy

A complete section of the Thunderhead sandstone, between Elkmont sandstone and Anakeesta formation, occurs on Mount Le Conte just east of the report area, where it is about 6,000 feet thick. The Thunderhead, similarly delimited below and above, is about 6,300 feet thick on Thunderhead Mountain to the southwest; but the strata in the two areas are not wholly correlative, for in the intervening area the upper part of the Thunderhead intertongues southwestward with the Anakeesta formation. This relation is indicated by the stratigraphic sections (pl. 8) and on the geologic maps (pl. 6); details are given in geologic sections 4 and 5, below. The tongue of Thunderhead sandstone is 2,500 feet thick toward the northeast, where it is composed of sandstone layers as thick and prominent as the main body, from which it is separated by 1,000 feet of argillaceous rocks—the lower tongue of the Anakeesta formation (geologic section 5). Farther southwest it thins, and its sandstone layers are separated by greater thicknesses of argillaceous rocks (geologic section 4).

South of the Mingus fault, in the headwaters of the main east prong of the Little River, as much as 4,500

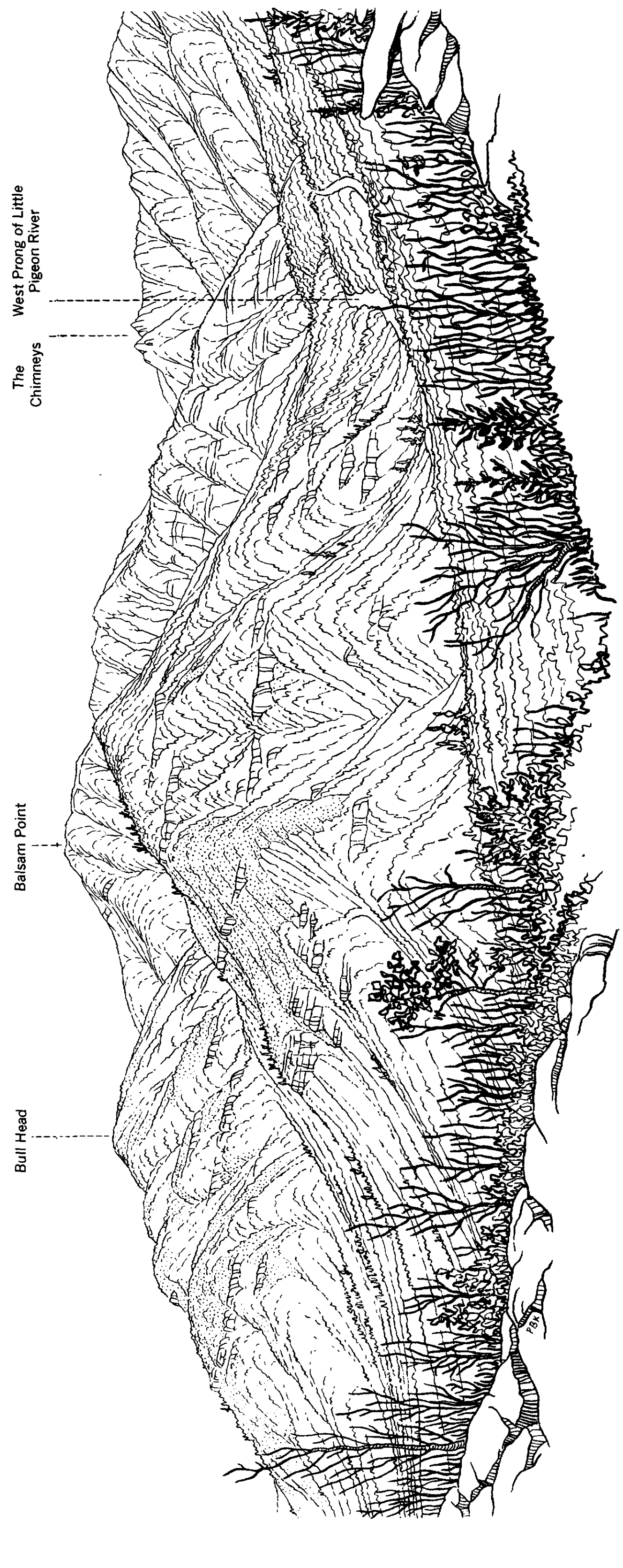

FIGURE 8.—Mount Le Conte massif viewed eastward across valley of West Prong of Little Pigeon River from near head of Road Turn Branch on Sugarland Mountain. Shows characteristic mountainside ledges and cliffs of Thunderhead sandstone. View encompasses the whole formation, here about 7,000 feet thick; Elkmont sandstone emerges at base of slope on left; Anakeesta formation caps mountain crest behind Balsam Point, and The Chimneys on the right.

feet of the main body of the Thunderhead sandstone is exposed, which is followed by 1,250 feet of argillaceous rocks that correspond to the lower tongue of the Anakeesta formation. Above the latter, on Mount Buckley and Clingmans Dome, is more than 3,000 feet of coarse sandstone, the original Clingman conglomerate of Keith (1895a), the lower part of which is equivalent to the tongue of the Thunderhead sandstone farther north.

Sandstone

The Thunderhead sandstone of the mountain area is strikingly uniform throughout, consisting of thick ledge-making coarse sandstone beds of somber aspect, separated by partings of slate. The only variation seems to be a slight coarsening in texture toward the east, where pebbly layers are more common and the pebbles larger.

The sandstone is gray to dark gray, dark hues being caused in part by metamorphic biotite but in part, especially near the top, by intermixing of dark-pigmented argillaceous material, which foreshadows the beginning of sedimentation of Anakeesta type.

Sandstone layers are a few feet to more than 10 feet thick, each being continuous rather than lenticular, at least across any single outcrop. Layers are graded. Most of the coarse bottom parts lie evenly on beds beneath, but a few of the contacts are channeled and scoured. Bottom parts mostly contain quartz and feldspar pebbles ⅛ to ½ inch in diameter, probably representing about the maximum crystal size in the granitic source rocks. Grain size decreases upward, where pebbles, if present, are more dispersed. The main part of each layer is coarse sandstone, but the upper part is relatively fine grained. Sandstone layers are generally succeeded by silty or argillaceous slate partings a few inches to a foot thick, which are followed by the next graded layer. This type of sequence is endlessly repeated through thousands of feet of section, no part differing greatly from any other. The maximum textural range of the formation is contained in each graded layer.

Quartz grains of the sandstone are in part clear and glassy, but these are mingled with varying amounts of quartz which is tinted a strong violet blue that is especially conspicuous when the rock is wet. This color was certainly inherited from the source rocks and did not result from any alteration in place, as both clear and blue quartz grains occur together, even within limits of single hand specimens.

Feldspar grains are white and are mostly abraded single crystals or cleavage fragments. Most are potassium feldspar (orthoclase and microcline); soda-lime feldspar (plagioclase) is subordinate. Pebbles of leucogranite, common in the Thunderhead of the foothills area, are rare in the mountain area, although a few were noted.

In nearly all outcrops the sandstone contains chips, pebbles, or slabs of gray slate an inch to more than a foot long, which is identical with the slate in the partings between the sandstone beds. These fragments were no doubt derived from breakup of slate layers immediately after deposition and before burial by the next layer of sand. In places, slate rubble can be traced along the outcrop into a disturbed slate layer, and that into a layer in place. Some of the slate chips and slabs are bent or curled, indicating that they had not been indurated before transportation and burial.

Slate beds

The slate mainly forms partings between the sandstone beds, a few inches to a foot thick, with a few layers more than 5 feet thick. Many are fine grained and argillaceous, but perhaps an equal number or silty or finely sandy. They are gray or dark gray and dominantly muscovitic, in contrast to the greenish chloritic or biotitic rocks of the adjoining Snowbird group. Near Blanket Mountain, however, slate in the Thunderhead and the lower tongue of the Anakeesta formation includes greenish-bronze beds in which the biotite content is probably greater.

Concretions

In places, the sandstone beds contain widely dispersed faint spherical to irregularly shaped concretionary structures as much as 6 inches in diameter (fig. 9). Many are prominently displayed in the upper unit of Thunderhead sandstone near Mount Buckley and Clingmans Dome; they are also common in the main body of the Thunderhead in the upper drainage of the main east prong of the Little River, and are sporadic elsewhere. The concretions are most prominent on weathered surfaces, where the outer shells are slightly recessed, perhaps because of greater carbonate cement than in the rock adjacent; on fresh surfaces they are indicated by a slight discoloration. Megascopic and microscopic examination suggests little difference between the sandstone within and outside the concretions. Some of the concretions on Clingmans Dome have argillaceous chips in their centers which may have aided in localizing their growth (fig. 9, upper). Where physical metamorphism is extensive,

FIGURE 9.—Concretions in Thunderhead sandstone. Upper, Trailside outcrop below Forney Ridge Parking Area at east edge of report area, Silers Bald quadrangle. Spherical to irregular concretions in coarse sandstone without directional fabric; concretion on right contains a slate chip near center. Lower, Ledge on Goshen Ridge trail at altitude of 4,900 feet, a mile north of State-line divide, Silers Bald quadrangle. Elongated concretions in foliated medium-grained sandstone; concretions tectonically elongated in plane of foliation. Photographs by P. B. King.

the concretions have been elongated into ovals in the plane of the foliation (fig. 9, lower).

Metamorphic features

Throughout the mountain area the Thunderhead sandstone contains small biotite porphyroblasts, indicating that it is a medium-grade metamorphic rock. Nevertheless, physical effects of metamorphism in most of the sandstones are slight, even where the argillaceous partings have been rendered slaty or phyllitic. Bedding, detrital grains, and other sedimentary structures are faithfully preserved.

Locally, and especially toward the south, greater physical effects of metamorphism become apparent in the sandstone. Finer grained sandstone beds are rendered schistose, and their originally spherical concretions are elongated in the plane of the foliation. Near Thunderhead Mountain, and elsewhere along the mountain crest, such sandstone beds weather along the foliation into ragged ledges that have the appearance of tilted tombstones. In the coarser sandstone beds, quartz grains are flattened in the plane of the foliation, and elongated down the dip to produce a linear fabric; feldspar grains are more resistant and retain their detrital shapes longer than the quartz.

In the upper drainage of the main east prong of the Little River the sandstone is much altered in a wide belt southeast of and above the Mingus fault. Within the belt are zones of strong internal deformation, in which foliation is more conspicuous than bedding, and detrital grains and concretions are strongly elongated. These are separated by other zones of surprisingly undeformed rocks. The overlying sandstone beds, on Mount Buckley and Clingmans Dome, also show little directional fabric, either on the outcrop or under the microscope, and the contained concretions retain their original spherical or irregular forms.

COVE MOUNTAIN AREA AND ADJACENT OUTLIERS IN FOOTHILLS

Stratigraphy

In the most of the outliers of the Great Smoky group in the foothills north of the mountain area, the Thunderhead sandstone is the only formation preserved, although in the eastern part of Cove Mountain it is underlain conformably by the Elkmont sandstone. In the outlier along the Little River the Thunderhead is adjoined on the west by the Cades sandstone; poor exposures prevent determination of the relations, but they are more likely tectonic than stratigraphic. Probably no more than 3,000 feet of Thunderhead sandstone occurs in any of the outliers; neither its upper part nor the overlying Anakeesta formation is preserved.

The Thunderhead sandstone in the western part of Cove Mountain, and in the outlier along the Little River near The Sinks, is physically identical with that of the mountain area and consists of the same kind of thick coarse graded beds with intervening slate partings; correlation of the rocks of the two areas thus seems assured. Northeastward along Cove Mountain, however, the Thunderhead grades into a much coarser less well sorted phase. In the southwestern part of the Cove Mountain block, along the Middle Prong of the Little River, rocks assigned to the Thunderhead contain fewer sandstone beds and a greater thickness of argillaceous layers; it cannot be determined whether this change in character results from another gradation or from some other relation.

The same phases of the Thunderhead sandstone as those in the Cove Mountain area occur also in the outliers northwest of it, suggesting that, although they are now physically separated, they were originally parts of the same body. Rocks in the outlier near The Sinks thus resemble closely those of the main phase in the Cove Mountain block to the southeast, whereas rocks in the outliers near Raven Den are much like the coarse poorly sorted phase of the Thunderhead in the adjacent northeastern part of Cove Mountain.

Despite the physical resemblance of the main part of the Thunderhead in the foothills to the Thunderhead in the mountain area, there are some curious mineralogic differences. Blue quartz grains, which are common in the Thunderhead of the mountain area, have been observed only at a few localities in the foothills, where most of the quartz grains are glassy or smoky at most. Pebbles of leucogranite which are rare in the mountain area are, on the other hand, common in the foothills.

These mineralogic facies appear to meet along the Gatlinburg fault. In most of the area a wide band of Elkmont sandstone lies between the two facies of the Thunderhead, but on the Middle Prong of the Little River they are juxtaposed. The Thunderhead in the block between the Mannis Branch and Gatlinburg faults commonly contains blue quartz and resembles the Thunderhead in the mountains to the south, whereas the facies north of the Gatlinburg fault contains little or no blue quartz.

The reason for these mineralogic differences is not clear. They may indicate that the rocks termed Thunderhead in the two areas, while superficially similar, are not correlative, but this possibility seems unlikely. They may indicate different sources of the sediments in the northern and southern parts of the original basin in which the Thunderhead sandstone was deposited. The apparent change from one facies to another across the Gatlinburg fault suggests, as well, the possibility that extensive displacements may have occurred along this zone of which there is little other indication. These possibilities will be discussed further in the section on tectonics. (p. 117–118, 121–124).

Main phase

In the western part of Cove Mountain and in the outlier along the Little River, the Thunderhead sandstone consists of thick graded beds of coarse to fine sandstone, separated by thin partings of dark-gray argillaceous rocks. Typical exposures occur along the trail from Fighting Creek Gap to Laurel Falls and along Tennessee Highway 73 at The Sinks and elsewhere in the gorge of the Little River.

The sandstone contains grains of white potassium feldspar and glassy quartz, as it does in the mountain area to the south, and also many grains of smoky quartz. Blue quartz is mostly lacking, and was observed only in the outlier in the northern part of the town of Gatlinburg, and along Waqulee Branch northwest of The Sinks. Pebbles of leucogranite are common. Many of the coarse bottom parts of the graded sandstone layers are conglomeratic, and contain pebbles of quartz, feldspar, and leucogranite ¼ to 1 inch in diameter, and in some places as much as 2 inches in diameter. A typical outcrop of the coarser conglomerates occurs at the mouth of Splatter Branch, on the Little River west of The Sinks. On Waqulee Branch, northwest of this locality, quartz and feldspar fragments as much as 5 inches in diameter were observed.

Northeastern phase

Northeastward from Laurel Falls (Gatlinburg quadrangle) the Thunderhead sandstone changes into a much coarser more angular less sorted phase, well displayed along Norton Creek and near Piney Butt in the northeastern part of Cove Mountain. Rocks of the same type form the outlying bodies of Thunderhead sandstone near Raven Den northwest of Cove Mountain where, however, they have been more sheared and foliated. Sandstones of this phase differs much more from the Thunderhead of the mountain area than do those of the main phase, and they are so distinctive that their locale can be recognized even in hand specimens.

The coarse beds are 5 feet or more thick and are separated by beds of fine-grained sandstone and of argillaceous rocks similar to those in the underlying Elkmont sandstone. The coarse fragments are glassy quartz, smoky quartz, feldspar, leucogranite, and scattered pieces of quartzite, aplite, or silicified slate; no blue quartz is present. Many of the beds contain chips and slabs of argillaceous rocks a few inches to as much as a foot long, similar to those which form partings between the beds, and probably of intraformational origin. Fragments vary from angular to well rounded and from small grains to pebbles more than 2 inches in diameter, the larger pebbles seemingly better rounded than the smaller. Fragments of all compositions, shapes, and sizes occur in single beds or even parts of beds, but in some the coarse fragments dominate to the exclusion of the smaller.

Southwestern phase

Southwest of Meigs Creek the sandstones of the Cove Mountain block become finer textured, and the interbedded argillaceous rocks thicken. Little is known of the nature of the transition, because the formation is only sporadically exposed between Meigs Creek and the Middle Prong of the Little River.

On the Middle Prong south of Walker Fields and on Mill Ridge and Fodderstack Mountain to the east and west are a few ledges of medium- to coarse-grained sandstone 5 to 25 feet thick. Their coarsest quartz and feldspar grains are an eighth of an inch in diameter; quartz grains are mostly glassy or smoky, a few are pale lavender, but none are blue. The greater part of the sequence in the area is dark-gray or black siltstone and argillaceous siltstone, which, without interbedded sandstone, forms units 25 feet to more than a hundred feet thick. At the mouth of Fodderstack Branch and on Mill Ridge these siltstones lie directly on Metcalf phyllite along the Greenbrier fault, the two sets of argillaceous rocks being readily distinguishable by their contrasting colors and textures.

Metamorphic features

In the Cove Mountain area, as in the mountain area to the south, the Thunderhead sandstone shows little physical effect of metamorphism. The metamorphic grade is, in fact, lower than in the mountains, for the area lies in the chlorite zone, or at most in the incipient phase of the biotite zone (pl. 13). Physical effects of metamorphism are greater in the smaller outliers of Thunderhead sandstone northwest of Cove Mountain—a testimony of their more complex structural history.

In the outlier along the Little River near The Sinks the finer grained sandstones have been widely converted to quartz-mica schist. Internal deformation has less affected the coarser rocks, but at a quarry just east of the lower bridge on the Little River, grains of the coarse sandstone and fine conglomerate possess a strong linear fabric that extends down the dip of the foliation and bedding. This fabric is produced by parallel elongation of all the detrital grains. Argillaceous chips have been stretched into wisps and quartz grains into spindles; feldspar grains have been fractured and pulled apart in the direction of the lineation.

Even greater internal deformation is evident in the tectonic slices of Thunderhead sandstone near Raven Den northwest of Cove Mountain. The sandstone is pervaded throughout by a southeast-dipping foliation, which has nearly obliterated the bedding, has shattered and stretched the quartz and feldspar grains, and has flattened and made schistose and argillaceous fragments; linear structure, nevertheless, is only weakly developed. Large quartz fragments have resisted deformation more than the smaller, and they stand out as hard knots in the sheared rock. In places quartz has been segregated, either along veins or as irregular permeations in the rock. Microscopic examination indicates that the metamorphic minerals in the rocks of the Raven Den area are sericite and chlorite.

Intensity of internal deformation of the Thunderhead sandstone in the Raven Den area is remarkable in rocks so coarse and of such low metamorphic grade, and must be largely cataclastic and dynamic. Similar coarse sandstone in Cove Mountain and the northern Great Smoky Mountains shows no comparable deformation, and it is only farther south in the mountain area, in rocks of higher metamorphic grade, that similar structures occur.

PETROGRAPHY

Sandstone

Five specimens of Thunderhead sandstone from the mountain area and two from the Cove Mountain area, which were examined in thin section by Hadley, have the mineral compositions given in tables 11 and 12. They illustrate the nature of the sandstone where it has been little affected by physical metamorphism.

All five specimens from the mountain area contain dominant large monomineralic grains of quartz and potassium feldspar (microline and microperthite), 1.0 to 5.0 mm in diameter. Most of the quartz grains show strain shadows and some are crushed. Quartz grains in T-1 enclose abundant slender needles, probably rutile, which may be related to the blue color of many of the grains as seen in hand specimen. In GB-9 are some rock fragments of quartzite and leucogranite. The plagioclase forms smaller grains in all specimens, less than 0.1 mm in diameter, lying mostly in the matrix. The sandstones are poorly sorted and the

TABLE 11.—*Estimated modes, in percent, of Thunderhead sandstone of mountain area*

[Estimated by J. B. Hadley]

	GB-8	GB-9	T-1	T-2	T-3
Detrital grains					
Quartz	68	65	75	75	70
Microcline and microperthite	10	27	20	15	20
Plagioclase (albite)	20	5	3	3	4
Zircon	Trace	Trace	Trace	Trace	Trace
Apatite	Trace	Trace	--------	Trace	--------
Sphene	--------	--------	Trace	1	1—
Magnetite, ilmenite, and leucoxene	--------	Trace	Trace	Trace	Trace
Secondary minerals					
Biotite	--------	1	Trace	2	3
Muscovite	1	Trace	1	3	1
Carbonate	2	1	Trace	Trace	Trace

NOTE.—Description of sample and locality as follows:

GB-8. Sandstone, medium-grained. Unit 1 of geologic section 5, north side of Meigs Mountain at altitude of 3,400 ft.

GB-9. Sandstone, coarse, conglomeratic, with prominent blue quartz grains. Unit 3 of geologic section 5, trail a little southwest of summit of Blanket Mountain.

T-1. Sandstone, coarse, conglomeratic. Near base of formation, Middle Prong of Little River near old site of Tremont.

T-2, 3. Sandstone, coarse. Same horizon and locality as T-1.

TABLE 12.—*Estimated modes, in percent, of Thunderhead sandstone of Cove Mountain area*

[Estimated by J. B. Hadley]

	GB-14	GB-15
Larger grains (0.1 to 6.0 mm in diameter)		
Quartz	40	25
Microcline, orthoclase, and microperthite	20	20
Leucogranite	(1)	----------
Smaller grains (<0.1 mm in diameter)		
Quartz	20	32
Potassium feldspar (microcline, and others)	10	5
Plagioclase (albite)	5	17
Sphene	Trace	Trace
Apatite	Trace	Trace
Zircon	Trace	----------
Sericite	4	1
Chlorite	Trace	Trace
Biotite	Trace	----------
Pyrite	Trace	----------
Carbonate	Trace	Trace

[1] 3 pebbles 3.0 to 6.0 mm in diameter.

NOTE.—Description of sample and locality as follows:
GB-14. Sandstone, medium-grained. Trail from Fighting Creek Gap to Laurel Falls.
GB-15. Sandstone, coarse-grained to pebbly. From same locality as GB-14.

larger grains of quartz, feldspar, and rock fragments are set in a finer grained matrix which is largely a mosaic of angular quartz and feldspar, with little argillaceous material, mainly metamorphic biotite and muscovite. In some specimens carbonate (either calcite or iron-bearing carbonate) forms grains, aggregates, and veinlets, which partly replace the matrix. The sphene in these rocks occurs largely as secondary coatings on magnetite grains.

In hand specimen the sandstones from the Cove Mountain area differ from those of the Thunderhead to the south in their lack of blue quartz grains; but in thin section this feature is not apparent, and there seems to be no significant mineralogical or textural difference between them. Both the specimens from this area are poorly sorted, and there is a notable differentiation between the larger and smaller grains. About 10 percent of both was probably originally made up of silt and clay, now represented by the micaceous minerals and the very fine grains of quartz and feldspar.

Granite pebbles

The specimens of the leucogranite which commonly occurs as pebbles in the Thunderhead sandstones of the Cove Mountain area were examined in thin section by Hadley (GB-15a, Laurel Falls trail; WZ-Z, Tennessee Highway 73 between upper bridge on Little River and Metcalf Bottoms). They consist of interlocking anhedral grains of quartz, microcline, microperthite, and albite 1.0 to 3.5mm in diameter, in variable proportions and of minor grains of sphene, zircon, apatite, and biotite. Primary minerals have been somewhat altered to chlorite and carbonate; the quartz is strained and some of the feldspars are veined by quartz.

Altered sandstone

Five specimens of Thunderhead sandstone from the belt of strongly deformed rocks southeast of the Mingus fault in the upper drainage of the main east prong of the Little River were examined in thin section by Hamilton; they have the composition given in table 13. A petrofabric analysis was also made by K. J. Neuvonen of three of the specimens (SB-N2, N215 and N25).

TABLE 13.—*Estimated modes, in percent, of altered Thunderhead sandstone of mountain area*

[Estimated by Warren Hamilton]

	SB-N2	SB-N21	SB-N22	SB-N25	SB-N26
Detrital minerals					
Quartz	67	67	77	71	44
Potassium feldspar (orthoclase and microcline)	6	9	10	4	1
Albite	11	14	5	8	5
Apatite	Trace	Trace	Trace	Trace	----------
Magnetite or ilmenite	1−	1−	1−	Trace	1
Tourmaline	Trace	----------	----------	----------	----------
Zircon	Trace	Trace	Trace	Trace	Trace
Sphene and leucoxene	Trace	Trace	----------	Trace	Trace
Allanite	----------	----------	----------	----------	1
Secondary and metamorphic minerals					
Biotite	10	5	5	6	10
Muscovite	5	4	3	9	39
Pyrite	----------	----------	----------	1	----------
Carbonate	----------	----------	----------	1	----------

NOTE.—Description of sample and locality as follows:
SB-N2. Sandstone, coarse-grained, feldspathic, foliated. Main east prong of Little River, east side, a little south of mouth of Dead Hollow.
SB-N21. Sandstone, coarse-grained, feldspathic, foliated. Same locality as N2.
SB-N22. Sandstone, conglomeratic, with elongated quartz pebbles. Northwest of SB-N2 and N21, north of mouth of Dead Hollow.
SB-N25. Sandstone, medium-grained, foliated; outcrop contains elongated concretions. Trailside outcrop on Goshen Ridge at altitude of 5,000 ft.
SB-N26. Fine-grained, quartz-muscovite schist; perhaps altered from siltstone or sandy shale; foliation parallel to bedding. Cave on Goshen Ridge trail at altitude of 4,100 ft.

The first four specimens are coarse sandstones with quartz and feldspar grains 0.02 to 3.00 mm in diameter averaging 0.20 mm; the fifth is much finer grained and probably was originally argillaceous. All show well-marked foliation in both hand specimen and thin section, produced in part by flattening and elongation of the quartz grains, in part by orientation of biotite and muscovite; the fifth, which is nearly half mica, is thoroughly schistose.

Metamorphism has been accomplished primarily by shearing, but it is accompanied by reconstitution. In the coarse rocks the sand grains and pebbles are physically crushed, split, and offset along microfaults, as well as defomed by gliding and strain without disruption; grain size has been much reduced. Quartz grains are triaxial, being elongrated as well as flattened, and the ratios between longest and shortest axes are about 3.2; recrystallization within the grains is shown by microscopic sutures. Feldspar grains also show some flattening, although to a lesser extent than the quartz. Foliation is parallel to the major shear direction. Petrofabric diagrams of the quartz and biotite prepared by Neuvonen for three of the specimens suggest the possibility of several S-planes, intersecting at acute angles along the lineation.

The fine-grained specimen (SB–N26) contains microshear foliums along which the constituents have been physically offset and along which the new micaceous minerals have grown. Quartz and feldspar grains have been reduced to lenticles, but the original clay fraction has been coarsened by reconstitution into the micas.

Three specimens of Thunderhead sandstone from the outliers northwest of Cove Mountain, which have been variously crushed and sheared were examined in thin section by Hamilton; they have the composition given in table 14. The first two illustrate the alteration in the outlier along the Little River near The Sinks; the third, the alteration in the Raven Den area.

TABLE 14.—*Estimated modes, in percent, of altered Thunderhead sandstone of southern foothill area*

[Estimated by Warren Hamilton]

	WC-K21	WC-N24	GB-N28
Detrital grains			
Quartz	70	30	57
Microline	17	5	1
Albite	3	5	1
Zircon	Trace	Trace	Trace
Magnetite or ilmenite	1−	2	[1] 1−
Leucoxene	Trace	Trace	1−
Matrix and secondary			
Sericite and muscovite	3	58	[2] 40 (Sericite and muscovite, Chlorite, Biotite, Calcite together)
Chlorite	5	----------	
Biotite	----------	1−	
Calcite	1	----------	

[1] Hematite, probably derived from magnetite.
[2] Quartz, feldspar, chlorite, and sericite.

NOTE.—Description of sample and locality as follows:
WC-K21. Sandstone, dark-gray, conglomeratic, sheared and lineated. Roadside quarry just east of lower bridge of Little River, Tennessee Highway 73.
WC-N24. Sandstone, fine-grained, altered to quartz-muscovite schist. Intercalated bed in coarse sandstone at The Sinks, 150 ft north of bridge, Tennessee Highway 73.
GB-N28. Sandstone, light bluish-gray, foliated. Crest of Raven Den, three-quarters of a mile west of Starkeytown.

The coarse sandstone of WC–K21 was examined in two sections perpendicular to the foliation, one parellel and one normal to the lineation. About 10 percent of the rock consists of large augen of quartz, microcline, and some albite, wth dimensions as great as 5 by 8 by 20 mm. The quartz grains are greatly strained by gliding and other deformation within the lattice, and have been partly granulated. The feldspar grains are broken, bent, and cut by veins of quartz and calcite. The matrix anastomoses around the larger crushed grains and includes partly recrystallized grains of quartz and feldspar, in part derived from crushing of the larger ones, as well as flakes of chlorite which also forms ragged interstitial clumps and rims on some of the quartz and feldspar grains.

In the fine-grained sandstone of WC–N24, the original clastic texture, probably coarser than the present one, has been largely destroyed by crushing and shearing. The quartz and feldspar grains are 0.02 to 3.00 mm in diameter, angular, some equidimensional, some splintery; the feldspar is much altered, many grains being islands or nets in the mica. The muscovite and biotite are oriented parellel to the foliation, and were in large part derived from alteration of the feldspar.

In specimen GB–N28, from the Raven Den area, the quartz grains are much strained and broken, but the rock is much less recrystallized than in the two specimens from near The Sinks. Quartz grains are 0.5 to 2.0 mm in diameter, equant to flattened, and have a ratio of 3 to 2; they are separated by very fine grains of quartz and feldspar, probably in part produced by crushing, and by slightly larger flakes of chlorite and sericite. In another specimen from the same area (GB–6, near Starkey Gap), all the original feldspar grains have been converted to aggregates of sericite.

Alteration of the sandstone in both the southern and northern parts of the Thunderbird area has been accomplished by strong physical breakage and shear, resulting in flattening and elongation of the quartz, and, to some extent, of the feldspar. The northern area, however is in a low-grade zone of metamorphism, and extreme physical alteration is confined to local areas where the structural history has been more complex than elsewhere. This is reflected in the specimens, in which the breakage and shear are not accompanied by extensive recrystallization, and the secondary minerals are sparse fine-grained sericite and chlorite. By contrast, the southern area lies well within the biotite zone and the sandstone is pervasively altered over wide areas; in the specimens, metamorphic biotite and muscovite are abundant.

STRATIGRAPHIC RELATIONS

In the foothill area the top of the Thunderhead sandstone is not preserved, but in the mountain area to the south the Thunderhead is succeeded conformably by the Anakeesta formation; it also intertongues extensively with the Anakeesta formation as described in other pages of this report (p. 41–42).

ANAKEESTA FORMATION

GENERAL FEATURES

Definition

The Anakeesta formation is named for Anakeesta Ridge, a high spur between Mount Le Conte and Newfound Gap east of the report area (Cartertown quadrangle) (King and others, 1958). Typical exposures occur along U.S. highway 441 from the base of the ridge up to the gap. Virtually the same beds were classed by Keith (1895a) in the Knoxville quadrangle as Hazel slate, and in later unpublished mapping to the east as Nantahala slate; but the term Hazel is now abandoned, and the true Nantahala is now known to lie at a much higher stratigraphic level.

Occurrence in report area

The Anakeesta formation crops out well back in the Great Smoky Mountains. Within the report area it forms a belt that extends from the Oconaluftee fault and main east prong of the Little River, southwestward along Fish Camp Prong and Bent Arm Ridge (Silers Bald quadrangle), across the headwaters of the Middle Prong of the Little River, nearly to Thunderhead Mountain, where it crosses the State-line divide into North Carolina (Thunderhead quadrangle). Southeast of the Mingus fault the Anakeesta is repeated in another structural block, and its lower tongue forms the north slope of Mount Buckley and Clingmans Dome (Silers Bald quadrangle).

Topographic features

The Anakeesta formation is mainly exposed on steep mountain slopes. Where the rock is dominantly argillaceous it has been carved into knife-edged steep-sided ridges, or into chimneylike peaks and knobs, such as Devils Courthouse in the southwestern part of the report area (Thunderhead quadrangle) and The Chimneys a little east of the report area (Cartertown quadrangle). Many of these ridges and knobs are covered by a dense growth of rhododendron and mountain laurel, that form the "laurel slicks" of local parlance. Where sandstone is interbedded, in places it forms ledges just as prominent as those of the underlying Thunderhead, many of which have been accentuated by the weathering and sapping of argillaceous beds which lie between them.

DETAILED FEATURES

Lithology

The most characteristic components of the Anakeesta are dark silty and argillaceous rocks, which form units a few feet to more than a thousand feet thick. These are local facies of the formation and are most prominently developed at different levels from one place to another. The lowest dark beds on Bent Arm Ridge are thus several thousand feet higher than the lowest on the Middle Prong of the Little River, 5 miles to the west.

The silty and argillaceous rocks are dark gray, blue gray, or black from the presence of considerable pigment, which apepars under the microscope as an opaque dust. Chemical analyses of specimens from east of the report area indicate as much as 2 percent of free carbon, probably in the dust; but at least part of the pigment is finely divided pyrite, which imparts the characteristic rusty-weathered surfaces of the rocks. Near Devils Courthouse layers of black fine-grained limestone less than a foot thick are interbedded.

The dark siltstone generally shows few effects of physical metamorphism and forms strong beds 1 to 6 inches thick which preserve their internal laminae even where small garnet porphyroblasts occur; interbedded argillaceous layers are commonly fissile or foliated. To the south, however, near the State-line divide, both are thoroughly schistose, with large biotite and garnet porphyroblasts; near Mount Buckley they contain small masses of "pseudodiorite" (Emmons and Laney, 1926, p. 19–21).

Interbedded with the argillaceous and silty layers are beds of fine-grained sandstone, also dark gray and pigmented, and 1 to 10 feet thick. At wider intervals are beds of coarser grained lighter gray sandstone 10 to 25 feet thick, which in part occur singly, in part as units a hundred to more than a thousand feet thick. These sandstone beds are similar to those of the Thunderhead sandstone in aspect, composition, and texture; their thicker and more persistent aggregates are classed as tongues of the Thunderhead. Many of the light-gray sandstone beds are packed with reworked black argillaceous chips and plates.

Stratigraphy

The Anakeesta formation and Thunderhead sandstone intertongue complexly (pl. 8), as shown in the outcrop between Thunderhead Mountain and the main east prong of the Little River.

Along the State-line divide west of Thunderhead Mountain the Anakeesta formation is an unbroken sequence of dark slate and schist about 4,500 feet thick. On Sams Creek a short distance to the northeast, however, these are divided into an upper and lower tongue by a unit of sandstone. The upper tongue continues eastward with little change in character to the end of the outcrop belt near the Oconaluftee fault. On Sams Creek, sandstone beds of the middle unit are mostly dark gray or black like those commonly associated with the argillaceous and silty rocks of the Anakeesta; but they are the outer end of a tongue of the Thunderhead sandstone, as farther east the sand-

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stone becomes lighter gray, coarser grained, and thick bedded. In the same direction the slate beds of the lower tongue lose the dark colors characteristic of the Anakeesta, become gray or greenish bronze, and acquire layers of light-gray sandstone. Evidently they fade into the Thunderhead sandstone beyond the end of the outcrop belt, for no thick body of argillaceous rocks like them occurs below the top of the Thunderhead sandstone on Sugarland Mountain or Mount Le Conte. There, the top of the Thunderhead is probably equivalent to the top of the tongue of the Thunderhead, and the Anakeesta is equivalent to the upper tongue of that formation of the sections farther west.

A similar correlation is suggested by relations of the unit of dark slate and schist on the north slope of Mount Buckley and Clingmans Dome, in the block south of the Mingus fault. This layer, 1,250 feet thick, is probably equivalent to the lower tongue of the Anakeesta to the northwest. Tracing of beds and matching of sections east of the report area indicate that it is the equivalent of sandstone several thousand feet below the top of the Thunderhead on Mount Le Conte (Hadley and Goldsmith, 1963).

Stratigraphic sections

Details of the relations just discussed are shown in geologic sections 4 and 5, below.

GEOLOGIC SECTION 4.—*Generalized section of Great Smoky group near Sams Creek and Defeat Ridge*

	Estimated thickness (feet)
Top of section; higher beds exposed south of State-line divide.	
Unnamed sandstone:	
5. Sandstone, coarse, and fine conglomerate, with graded bedding and interbedded argillaceous partings. Resembles Thunderhead sandstone, but of somewhat coarser average texture	4,300
Upper tongue of Anakeesta formation:	
4. Slate and schist, dark-gray to black, argillaceous, containing garnet and biotite porphyroblasts; contains interbedded black schistose sandstone and fine conglomerate and rare thin beds of black limestone. Thickness uncertain along Sams Creek because of local reversals of dip; may be as thin as 1,700 ft, or as much as	2,600
Tongue of Thunderhead sandstone:	
3. Argillaceous rocks with much interbedded dark-gray sandstone; grades into argillaceous and silty rocks a short distance to west, and is no longer traceable. At base is a bed of "black conglomerate" —a black gritty sandstone containing larger white quartz and feldspar pebbles—which is well exposed on Sams Creek and several adjacent ridges, where it projects in massive ledges	1,000

GEOLOGIC SECTION 4.—*Generalized section of Great Smoky group near Sams Creek and Defeat Ridge*—Continued

	Estimated thickness (feet)
Lower tongue of Anakeesta formation:	
2. Slate, black, argillaceous, containing much pyrite on planes of slip cleavage. In upper part contains many interbedded layers of argillaceous feldspathic sandstone and a few thicker ones of lighter gray coarse sandstone. Contact with main body of Thunderhead sandstone beneath is fairly abrupt	1,300
Main body of Thunderhead sandstone:	
1. Sandstone, gray, coarse-grained; in beds as much as 20 feet thick, many of which are graded; contains grains and small pebbles of glassy and blue quartz and white potash feldspar; separated by partings of blue-black laminated slate and siltstone. Exposed in lower course of Sams Creek and on Defeat Ridge to northwest. Thickness more than	6,300
Elkmont sandstone at base of section.	

GEOLOGIC SECTION 5.—*Generalized section of Great Smoky group between Fishcamp Prong and Blanket Mountain*

	Estimated thickness (feet)
Top of section cut off by Mingus fault; Thunderhead sandstone above.	
Upper tongue of Anakeesta formation:	
8. Argillaceous and silty rocks, dark-gray. On Bent Arm Ridge is dark gray or black lustrous muscovitic slate, interbedded with fine- to coarse-grained dark-gray feldspathic sandstone in beds a few feet thick, and some thicker ledge-making layers of light-gray sandstone. On Fishcamp Prong is mainly dark-gray to black siltstone in 1- to 6-in. beds, showing only slight physical effects of metamorphism, although it contains small garnet porphyroblasts; some bedding surfaces coated with detrital muscovite; interbedded with silty fine-grained sandstone layers a few feet thick	1,000-2,000
Tongue of Thunderhead sandstone:	
7. Sandstone, much darker gray than below on both fresh and weathered surfaces, and containing much pigment; many beds crowded with reworked chips of black argillaceous rock. Some layers of argillaceous sandstone with marked cleavage, and many partings of gray and black argillaceous rocks	200
6. Sandstone, coarse, and fine conglomerate in graded massive beds 25 ft or more thick, with few agrillaceous partings. Contains abundant grains of blue quartz; a pebble of leucogranite observed at one locality. Forms massive cliffs on northwest slope of Bent Arm Ridge	800
5. Sandstone, as above, in thick beds, but with more interbedded argillaceous layers. One of these is partly dark-gray slate, partly greenish-bronze slate, the latter probably biotitic	1,500

GEOLOGIC SECTION 5.—*Generalized section of Great Smoky group between Fishcamp Prong and Blanket Mountain*—Continued

	Estimated thickness (feet)
Lower Tongue of Anakeesta formation:	
4. Argillaceous rocks, including dark-gray and greenish-brown slate, but no black slate, with some thick interbedded layers of coarse light-gray sandstone. Crops out at Jakes Gap and in saddles and benches northeastward	1,000
Main body of Thunderhead sandstone:	
3. Sandstone, coarse, light-gray, massive, standing in great rounded ledges 25 to 50 ft thick, with conspicuous graded bedding. In coarser basal parts of layers, pebbles average a quarter of an inch in diameter, but in a few beds are as large as 1 in.; some pebbly beds are as much as 20 ft thick. In some beds, blue quartz composes fully 75 percent of pebbles; other constituents are glassy quartz, white potash feldspar, and chips of dark argillaceous rock. Argillaceous partings are thin and dark gray. Forms crest and dip slope of Blanket Mountain	1,900
2. Argillaceous rocks, poorly exposed; float consists of both dark-gray and greenish-bronze slate. Outcrop belt passes through Bearpen Gap north of Blanket Mountain	250
1. Sandstone, thinner bedded and finer grained than that above, with fewer gritty or conglomeratic beds, and sparse blue quartz. In lower part, on north slope of Meigs Mountain, consists of fine- to medium-grained sandstone in 5- to 15-ft. beds, with gritty seams at wide intervals; grits are less than one-eighth inch in diameter and include white feldspar, glassy quartz, and rare, faintly tinted blue quartz. Coarser and more massive beds come in higher up, on crest of Meigs Mountain. On Blanket Creek to east, much interbedded dark-gray and greenish-bronze slate	3,400
Elkmont sandstone at base of section.	

STRATIGRAPHIC RELATIONS

In the head drainage of the Middle Prong of the Little River the Anakeesta formation is succeeded conformably by higher unnamed sandstone beds of the Great Smoky group. Near Starkey Gap and Miry Ridge at the east and west ends of the outcrop belt the upper beds of the Anakeesta are dark gray or black, silty, laminated slate or schist, which is succeeded abruptly by the sandstone. The upper beds of the Anakeesta vary considerably along the strike, however, for on Seng Patch Branch in the intervening area they are sandstone only a little less coarse and massive than the unnamed sandstone which overlies them.

UNNAMED SANDSTONE

DEFINITION

In the south-central part of the report area (Thunderhead and Silers Bald quandrangles) the Anakeesta formation is succeeded by higher sandstone beds. These were mapped as part of the Clingman conglomerate by Keith (1895a), but they are at a higher stratigraphic level than the type Clingman on Clingmans Dome to the east; they overlie the upper tongue of the Anakeesta, whereas the type Clingman overlies the lower tongue. In view of the varied stratigraphic relations of these upper sandstone beds, the name Clingman is inappropriate for them; it seems best, therefore, to class the beds west of Clingmans Dome as an unnamed upper formation of the Great Smoky group.

OCCURRENCE IN REPORT AREA

The unnamed sandstone crops out along the State-line divide from Starkey Gap to Buckeye Gap, forming such high summits as Greenbrier and Cold Spring Knobs, and extends northward into the head drainage of the Middle Prong of the Little River, where it overlies the Anakeesta formation. East of Buckeye Gap along the divide it is adjoined by other sandstone beds, believed to be part of the Thunderhead raised along the Mingus fault. Within the report area about 4,500 feet of sandstone is exposed, but higher strata no doubt succeed it in North Carolina south of the divide.

LITHOLOGY

The unit consists of coarse sandstone and fine conglomerate, with graded bedding and thin argillaceous partings. These rocks closely resemble the Thunderhead sandstone lower in the section in the same area, but they are of somewhat coarser average texture, with many more beds of conglomerate and grit, and somewhat fewer beds of medium-grained sandstone. Coarsest grains are 1/8 to 3/4 inch in diameter and are mostly quartz and feldspar, including blue quartz at many localities.

Rocks of the unit show strong effects of physical metamorphism, the quartz grains of the coarser beds being flattened and elongated, the finer grained sandstone and the argillaceous rocks being converted into schists.

STRATIGRATHIC RELATIONS

The top of the unnamed sandstone is not exposed in the report area, and the unit is overlain on the North Carolina side of the divide to the south by higher beds which have not been mapped. About 12 miles to the southeast, near Bryson City, the Great Smoky group is overlain by the Nantahala slate (Hadley and Goldsmith, 1963). An unknown number of faults and folds may exist in the intervening area, but the Nantahala certainly lies at a much higher stratigraphic level than any beds of the Great Smoky group in the report area.

UNCLASSIFIED FORMATIONS OF OCOEE SERIES

GENERAL FEATURES

In parts of the foothills just north of the Great Smoky Mountains are coarse-grained clastic rocks that lie beneath the Greenbrier fault or north of it and, where least disturbed, lie conformably on the finer grained clastic rocks of the Snowbird group; elsewhere, they are semiallochthonous or allochthonous. These rocks differ markedly from the Snowbird and have many kinships with the Great Smoky; but as their relations to the latter are not demonstrable, they are not included in either group, although they are clearly parts of the Ocoee series.

These unclassified formations appear to be parts of a transitional facies, now so fragmented by the Greenbrier thrusting that their original relations are difficult to reconstruct. They may have been deposits on the margin of the area of sedimentation of the Great Smoky group, and perhaps transitional from that group into the Snowbird group. They have less affinities with the typical Great Smoky group of the mountain area than they do with the Great Smoky group in Cove Mountain and adjacent foothills, which itself is of transitional character; the whole may represent successive parts of a gradational sequence.

Within the report area only small bodies of these unclassified formations are preserved; their principal occurrence is to the east and west. They are associated with the Thunderhead and Elkmont sandstones of the Cove Mountain and foothill areas, but lie beneath rather than above the Greenbrier fault, as do the latter; hence they are everywhere separated tectonically from them, as they are from the greater part of the Snowbird group.

RICH BUTT SANDSTONE

The Rich Butt sandstone is named for Rich Butt Mountain, east of the report area near the northeast end of the Great Smoky Mountains (Hartford quadrangle) (King and others, 1958), where the unit lies conformably on the Pigeon siltstone.

Within the report area, sandstone which is probably equivalent to the Rich Butt forms Dudley Bluff and Big Ridge, north of the town of Gatlinburg, and is well exposed on each side of the West Prong of the Little Pigeon River along U.S. Highway 441 (Gatlinburg quadrangle). This sandstone lies conformably on the carbonate-bearing unit of the Pigeon siltstone on the south, and both it and this unit are cut off by transverse faults short distances east and west of the river. On the north it adjoins the lower part of the Pigeon siltstone, and is probably faulted against it. The sandstone and the carbonate-bearing unit of Pigeon thus lie in a fault block, isolated from its surroundings; this block may be a fragment of a subsidiary slice beneath the Greenbrier fault, the fault at the base emerging next to the lower part of the Pigeon on the north.

The sandstone on Dudley Bluff and Big Ridge stands nearly vertical and is about 1,500 feet thick. It is much like sandstone of the Roaring Fork, being gray and fine grained, and composed of quartz and feldspar in about equal proportions. It forms massive layers 5 feet or more thick, with widely spaced bedding planes and indistinct laminae. At wide intervals, however, these sandstone layers are interbedded with layers a few feet to more than 50 feet thick of blue-black argillaceous slate. On Big Ridge east of the river the otherwise fine-grained sandstone contains several much coarser layers a few feet thick made up of quartz and feldspar grains as large as one-eighth inch in diameter.

The carbonate-bearing siltstone which underlies the sandstone on the south resembles siltstone which is interbedded with the Rich Butt sandstone in its type area. Here, where no sandstone is interbedded with them, they are more appropriately classed as an upper unit of the Pigeon siltstone.

CADES SANDSTONE

The Cades sandstone, derived from the Cades conglomerate of Keith (1895a) is now restricted to beds in the foothill area in the vicinity of Cades Cove (King and others, 1958). The eastern tip of the main tract of Cades sandstone projects three-quarters of a mile into the report area on Turkeypen Ridge (Wear Cove quadrangle), bounded on each side by Metcalf phyllite. Similar sandstone, faulted on each side against Metcalf phyllite, reappears in another belt a mile to the north near Schoolhouse Gap. This belt extends eastward near the Little River until it joins the outlying area of Thunderhead sandstone near The Sinks. The relation of this sandstone to the rocks adjacent to it is uncertain; but it more closely resembles the Cades on the west than the Thunderhead on the east, hence is so classified.

The Cades sandstone of the belt along the Little River is mostly finer grained and thinner bedded than the Thunderhead sandstone, with fewer gritty and conglomeratic beds and thicker layers of argillaceous rocks.

The only uninterrupted sequence of the Cades in the belt is along the Middle Prong of the Little River for half a mile south of Tremont Junction, where 1,500 feet of beds lies between the Greenbrier and Sinks faults, dipping regularly to the southeast. They consist of fine- to medium-grained gray to dark-gray sandstone in layers 1 to 10 feet thick, and a few coarser beds that contain quartz and feldspar grains as much as one-eighth inch in diameter; no blue quartz occurs. Dark-gray silty argillaceous layers 1 or 2 feet thick separate the sandstone beds.

The Cades on the other prongs of the Little River shows no evident sequence, because of complex folds, and because the meanders of the river do not cut across the strike. Here the sandstone resembles that on the Middle Prong, but on the main prong east of Tremont Junction argillaceous beds are thicker and more numerous, some being as much as 50 feet thick. These beds are blue gray, dark gray, or sooty black, heavily pigmented and pyritic, and have lustrous cleavage surfaces.

WALDEN CREEK GROUP [3]

GENERAL FEATURES

Definition

The Walden Creek group is named for Walden Creek (King and others, 1958), a western tributary of the West Fork of the Little Pigeon River, which drains the southeast slope of Chilhowee Mountain and the northern foothills of the Great Smoky Mountains, an area underlain by rocks of the group. The Walden Creek group crops out in a belt a few miles to 8 miles wide along the northwest edge of the foothill area and extends along the strike many miles northeast and southwest. Rocks of identical character form an important part of the exposures of the type Ocoee series in the gorge of the Ocoee River south of the Great Smoky Mountains.

The Walden Creek group corresponds approximately to the Whilhite slate, Citico conglomerate, and Pigeon slate as mapped by Keith (1895a) in the northern foothills of the Knoxville quadrangle, but these units do not have the stratigraphic order originally supposed. The term Citico conglomerate expresses a characteristic rock type which occurs in beds of varying thickness at many levels in the group. Neither it nor the supposedly underlying and overlying slates have stratigraphic meaning, and the name Citico is now abandoned. The names Whilhite and Pigeon have been retained, but they are redefined with respect to rocks near their type localities.

The Walden Creek group also corresponds approximately to the more inclusive Hiwassee slate of Keith's later terminology (1904, p. 3). The Hiwassee was, however, named for a locality in the Murphy quadrangle, for which no description was published, and the name was used so confusingly elsewhere that it is now abandoned and the name Walden Creek substituted.

[3] Based mainly on observations by King, but includes observations by H. W. Ferguson and G. D. Swingle (Wear Cove and Walden Creek quadrangles) and by J. K. Lydecker and Warren Hamilton (Pigeon Forge quadrangle). Description of Sandsuck formation is based largely on work of Ferguson and Swingle.

Lithology

The Walden Creek group is a heterogeneous body of slightly metamorphosed sedimentary rocks, mainly argillaceous or silty, but with discontinuous masses of conglomerate and sandstone and minor layers of quartzite, limestone, and dolomite. Many of its rock types are unique in the Ocoee series, especially noteworthy being its conglomerates made up of large rounded quartz pebbles (the Citico of Keith).

Structural disorder of the Walden Creek group exceeds that of the other groups of the Ocoee series, and stratigraphic and structural interpretations are uncertain. The conglomerate and other competent beds form discontinuous layers that either were originally lenticular, structurally broken, or both. The incompetent silty and argillaceous rocks are nearly everywhere so folded and crumpled as to give little idea of their gross structure and sequence.

In mapping the rocks of the Walden Creek group in the report area, main emphasis was given to tracing the "hard" beds of conglomerate, sandstone, and quartzite, which are represented in considerable detail on the geologic maps (pls. 2–7). Less attention was given to the "soft" silty and argillaceous rocks, partly because of their complex structure, partly because their varieties can be separated only in fresh outcrops and not on weathered hill slopes. Contacts between different units of argillaceous and silty rocks are therefore sketched on the map from their gross aspect over considerable areas.

Subdivisions

In the foothills of the Great Smoky Mountains the most convincing sequence of the Walden Creek group is that south of English Mountain east of the report area (Richardson Cove and Jones Cove quadrangles) where, despite much small-scale deformation, the rocks form a series of broad northeast-plunging folds that expose a section perhaps 8,000 feet thick. This area is therefore selected for subdivision of the group. Here, the group is divided, in ascending order, into the Licklog, Shields, Wilhite, and Sandsuck formations (King and others, 1958; Hamilton, 1961).

Within the report area the Walden Creek group has been broken into a succession of fault blocks, and no uninterrupted sequence of the whole is exposed. Partial sections reveal units which are comparable to those south of English Mountain, and the rocks of the group are classified on that basis. The total of various sections of unlike rocks in the area indicates a thickness of about 8,000 feet, comparable to that to the east, although no such thickness now occurs at any one locality, the whole group being underlain at shallow depth by the Great Smoky fault.

LICKLOG(?) AND LICKLOG FORMATION

GENERAL FEATURES

At several places in the report area and eastward the lowest preserved strata of the Walden Creek group are rocks which differ from the overlying and more extensive Shields formation. They appear to be fragments of an originally extensive formation, most of which has been cut off by the underlying Great Smoky fault. A few hundred feet of these strata east of the report area are termed the Licklog formation (King and others, 1958).

Within the report area, notably north of Tuckaleechee Cove, beds below the Shields are preserved in greater thickness than the typical Licklog, and with a greater variety of rock types, although even here their preservation is fragmentary and their base undefined. It seems undesirable to extend the name Licklog to these beds unreservedly, and equally so to propose a new name for them; the beds below the Shields in the report area are therefore referred to as the Licklog(?) formation, except in the northeast corner adjacent to the type area.

LOCAL FEATURES

Area north of Tuckaleechee Cove

North of Tuckaleechee Cove, on the spurs of Alie, Grassy, and Rocky Mountains, 1,200 to 1,900 feet of beds intervene between the Shields formation and the Great Smoky fault beneath (Wear Cove quadrangles). They include two sandstone units, one in the middle and one at the top, differentiated on the geologic map (pl. 4), which are separated and underlain by argillaceous rocks. Toward the west the middle sandstone is 250 feet thick and the upper more than 500 feet thick. Each becomes less continuous eastward, partly by original thinning, partly by an extensive shearing that develops in this direction.

Argillaceous rocks below the middle sandstone are thinly fissile phyllite, dull greenish or bluish gray, which closely resemble the Metcalf phyllite of the Snowbird group south of the coves. Foliation is strongest in the lowest part, where cleavage surfaces are silky, lustrous, and chloritic, and have been much wrinkled and distorted, perhaps by movements related to the Great Smoky faulting. Cleavage is less distorted higher up, where it does not completely obliterate the bedding; toward the top, close to the middle sandstone, the phyllite is much pigmented and blue black. In Walker and Rudd Hollows are interbedded lenses of oolitic dolomite a few inches thick.

The middle sandstone caps Alie Mountain and forms strong ledges on Listening Top and Borden Top. It is medium to fine grained, nowhere pebbly or gritty, and is strongly foliated. It is less like the other sandstones of the Walden Creek group and more like the more impure sandstones of the Snowbird and Great Smoky groups to the south. The sandstone forms beds a few feet thick, marked by dark laminae, with some thin argillaceous partings. The upper sandstone resembles the middle sandstone, but contains rare gritty and pebbly seams which indicate a transition into the coarser sandstone and conglomerate of the Shields above.

Other areas

Along Cove Creek at the northeast end of Wear Cove, conglomerate of the Shields formation lies with sharp contact on blue-gray or greenish-gray laminated slate, without sandy or conglomeratic beds (Wear Cove quadrangle).

Much farther northeast, north of Shields Mountain (Pigeon Forge quadrangle), the Shields is again underlain by several hundred feet of slate, with interbedded siltstone and fine-grained sandstone. These rocks are traceable into the type Licklog to the east (Richardson Cove quadrangle).

PETROGRAPHY

Two specimens from the middle sandstone north of Tucklaleechee Cove (KS–K1) were collected on a lumber road on Cedar Branch, just west of the meridian between the Wear Cove and Kinzel Springs quadrangle. In hand specimen, one rock is darker gray than the other, but microscopic study indicates little difference, other than in the amount of dark opaque material.

According to Hadley, both rocks were probably originally somewhat feldspathic sandstones; but they have been highly altered and recrystallized, although without development of strong foliation. Quartz forms a recrystallized mosaic of grains 0.3 to 1.0 mm in diameter, but original detrital outlines have been lost by growth into, and replacement of, the matrix. All the quartz is strongly strain shadowed, and many grains are crushed or fractured, especially along the edges. Fractures in the quartz are filled by sericite; calcite, ilmenite, and graphite have grown in the crushed areas. Sericite forms patches of finely felted aggregates about the same size as the quartz grains, which were probably altered from original detrital grains of potassium feldspar.

A specimen from one of the dolomite lenses in the lower argillaceous unit north of Tuckaleechee Cove (WC–K15, Rudd Hollow at altitude of 1,300 feet) was examined in thin section by Warren Hamilton. About 25 percent of the rock consists of oolite grains 1 mm in diameter, which appear as dark spots in hand specimen. A few of these, made up of chloritic material resembling chamosite, have a concentric structure around cores of quartz or dolomite. The rest are altered to dolomite, which forms single crystals. The oolites lie in a groundmass of finely crystalline dolomite.

STRATIGRAPHIC RELATIONS

The Licklog(?) formation is everywhere underlain by the Great Smoky fault, so that its basal relations are undetermined. The strong resemblance of its phillites and sandstones, in the area north of Tuckaleechee Cove, to those of the Metcalf and other formations of the Snowbird group suggests that the unit might be transitional from the Walden Creek group into the Snowbird group beneath.

The Licklog(?) formation is conformable with the Shields formation. On Rocky Mountain north of Tuckaleechee Cove the contact is well exposed and little disordered: fine-grained sandstone of the Licklog(?) is succeeded by coarse sandstone of the Shields, although in the latter, pebbles and conglomeratic layers are rare in the lower hundred feet or so, and dark argillaceous layers are more common than higher up. Farther east and northeast on Rocky Mountain the strata near the contact are much sheared, and the original stratigraphic relations are less evident.

SHIELDS FORMATION

GENERAL FEATURES

The Shields formation is named for Shields Mountain southeast of Sevierville, a high ridge at the north edge of the foothills that extends eastward beyond the report area (Pigeon Forge and Richardson Cove quadrangles) (King and others, 1958). Best exposures of the formation near Shields Mountain are at its eastern end, along the road up the main fork of the Little Pigeon River.

The Shields formation in its type area overlies the Licklog formation and forms a homoclinal south-dipping sequence 2,000 to 2,500 feet thick. Toward the west (Pigeon Forge quadrangle) its top is faulted against the Snowbird group, but further east its contact with the overlying Whilhite formation is preserved. Partial sections at different places in the report area suggest that the formation maintains about the same thickness as in the type area.

The most prominent components of the Shields formation are bodies of sandstone and conglomerate, some more than a thousand feet thick, which crop out in strong ledges and ridges. These are of the facies designated "Citico" by Keith (1895a) and are its principal representative in the report area, although they probably occur at a lower level than the type Citico southwest of the Great Smoky Mountains.

The sandstone and conglomerate bodies are interbedded with, and lens out into, argillaceous slate. In some sections the slate forms only thin partings between the coarser rocks, in others thicker beds and units, part of which can be differentiated on the geologic maps (pls. 2–7). Near Shields Mountain, and at many other places, slate increases in volume upward by interbedding and intertonguing with the coarser rocks, finally passing at the top into an uninterrupted slate body several hundred feet thick.

Contacts of the sandstone and conglomerate units with the slate units are thus merely of local stratigraphic significance. Of more general significance appears to be a contact between argillaceous slate and a body of overlying siltstone; the boundary between the Shields and Wilhite formations is therefore placed at that level.

LOCAL FEATURES

The Shields formation is exposed discontinuously within the foothills of the report area. The formation in the type area is thus separated from its occurrences elsewhere, although a correlation of the rocks in all the areas is assured by their lithologic similarity and stratigraphic relations. Two main belts occur—one in the north, extending from the type locality westward, and another farther south—the two being separated in most places by a belt of Wilhite formation.

Northern belt

West of the exposures of Shields formation on Shields Mountain, whose sequence is noted above, the formation reappears beyond the West Prong of the Little Pigeon River, where its upper argillaceous slate is extensive and its sandstone and conglomerate are discontinuous. The latter form small to large outcrops on the north side of Pine Mountain, Valley Ridge, and Benson Mountain (Pigeon Forge and Walden Creek quadrangles) and probably represent the top of a larger underlying body. Southest of Walden Creek the upper slate is followed by siltstone of the Wilhite formation, which forms a broad synclinorium.

Southern belt

To the south the Shields formation reappears in Grassy, Rocky, Davis, and Hatcher Mountains, and the hills about Little Cove, along the north sides of Tuckaleechee and Wear Cove (Wear Cove and Pigeon Forge quadrangles), and it has been raised along the

Happy Hollow fault against the Wilhite formation of the synclinorium.

On Grassy and Rocky Mountains, toward the west, about a thousand feet of the lower sandstone and conglomerate are synclinally downfolded in the Licklog(?) formation; similar sandstone and conglomerate are well exposed along Cove Creek northeast of Wear Cove. On Davis Mountain in the intervening area, and near Little Cove to the northeast, argillaceous rocks form nearly half the sequence. In the latter area, where the strata dip gently, about 1,500 feet are exposed, with four or five lenticular sandstone and conglomerate beds, the lower of which are the thickest and coarsest. Argillaceous slate dominates above, to the southeast, and is probably equivalent to the upper slate of the type area.

The Shields formation also borders the south sides of Tuckaleechee and Wear Coves for a distance of 4 miles, and is connected across the gap between them with the Shields on the north side. Near the center, conglomerate makes up more than half the unit and forms beds as much as 150 feet thick, but it interfingers eastward and westward with argillaceous slate. On the county road north of Wear Cove Gap, near the eastern end of the belt, only a single 10-foot bed of conglomeratic sandstone persists in the slate. Conglomerate and sandstone of the Shields formation in the area are much sheared and foliated, probably as a result of movements along the Line Springs fault to the south, which brings the Metcalf phyllite against them.

LITHOLOGY

Coarse-grained rocks

The most striking components of the Shields formation are its rounded quartz pebbles, which average 1 inch in diameter, but range from ¼ inch to more than 3 inches. These pebbles are embedded in variable amouts of course sandstone matrix, so that truly conglomeratic and truly sandy layers are complexly interrelated, and vary in proportion from locality to locality.

In some layers, 5, 15, or even 50 feet thick, coarse pubbles are closely packed, with little matrix; in many beds no sorting of fragments is perceptible so that attitude of bedding is difficult to make out, except in rare sandy lenses. In other layers of about the same thickness, finer pebbles are more dispersed in the matrix; in some they are lacking entirely, in others they form gravelly layers or tapering lenses a few feet thick, part of which fill surfaces of scour. Except for the latter, little or no grading of the component fragments is apparent.

The quartz pebbles are nearly all milky or glassy, although a few of perceptible blue color were observed on Shields Mountain; most are probably vein quartz. They approach the form of spheres or ellipsoids, even the more irregular ones showing rounded edges or blunted corners. On most weathered surfaces, especially in the southern outcrop belts, quartz pebbles seem to be the dominant or exclusive component. Nearly all the beds, however, contain 5 or 10 percent of minor constituents. These constituents are most apparent on fresh rather than weathered surfaces and seem most abundant in the coarsest layers and northern outcrop belt. Commonest are gray, dark gray, or black quartzite, but rarer pieces are graphic granite, aplite, potassium feldspar, chert, and siltstone; all their pebbles are of about the same size and shape as those of the quartz. Many beds contain chips or slabs of dark argillaceous rocks, and a few contain angular fragments of gray, fine-grained limestone as much as a foot in diameter; both are probably intraformational.

The sandstone matrix is medium grained to course grained, and has a textural range of about 0.5 to 5.0 mm. Freshly broken surfaces are blue gray; most weathered surfaces are dull gray, but some are dull brown. Grains are dominantly quartz, but as much as 15 percent are feldspar, and potassium feldspar and plagioclase are in variable proportions. Small amounts of iron-bearing carbonate cement are indicated by the brown-weathered surfaces. Carbonate is probably best preserved in the least altered parts of the sandstone; in the more altered parts the cement is largely fine-grained sericite and chlorite.

Alteration of coarse-grained rocks

Nearly all the coarse rocks of the Shields formation are altered to some extent by internal deformation and metamorphism, and thus contrast greatly with those of the Sandsuck formation, and to some extent with those of the Wilhite formation, described below.

In most places, grains and pebbles have been strained, crushed, and shattered, and the rock reconstituted by veining or partial impregnation by quartz that was perhaps "sweated out" of the parent rock during deformation. Where pebbles have been released from their matrix on weathered surfaces, many are seen to be broken, offset, and reconstituted. In part, the pebbles are also slightly ovoid or flattened, although it generally cannot be determined whether these are original detrital forms or are the products of deformation.

Internal deformation of the coarse rocks reaches its maximum in the southermost exposures, in the area between Tuckaleechee and Wear Coves, and in the belt south of the coves. In some outcrops south of the coves, rock that was originally conglomeratic sandstone has been thoroughly sheared and thinly cleaved, and relics of the more resistant pebbles persist as knots or eyes in the plane of foliation.

Best exposures of these altered rocks are on ridges near Pawpaw and Lemon Hollows between the two coves. Here, the sandy matrix is strongly foliated, and pebbles, instead of being crushed, are flattened in the plane of the foliation and drawn out down its dip, very much as if they had been balls of putty (fig. 10). Dimensional ratios average about 1:2:4. Many of the pebbles have been warped against those adjoining and have become wavy flakes or wafers. Curiously, the quartz veining and impregnation that is common in areas where the pebbles are merely crushed is poorly developed in this area.

Argillaceous rocks

The argillaceous rocks interbedded with the coarser rocks are slate, mostly gray or greenish gray where fresh, but weathering to tan or yellowish surfaces. All are marked by closely set parallel bedding laminae a tenth of an inch thick or less, compositional differences between which are slight, although some alternate ones are darker, more silty, or marked by flakes of detrital mica lying parallel to the bedding; a few contain a small amount of iron-bearing carbonate and weather brown. At wide intervals, more silty layers as much as an inch thick are interbedded. Most of the thin argillaceous partings between the sandstone and conglomerate layers are blue black and contain much dark pigment. The thicker units are less pigmented, although even the greenish-gray slates of the upper argillaceous part of the formation in places contain interbedded inconstant dark-gray or black units 10 to 25 feet thick.

In the thicker argillaceous units, bedding has been much folded and contorted and is crossed by thinly fissile axial plane cleavage, on whose lustrous surfaces the laminae are visible in cross section; original argillaceous components have probably been converted largely to sericite and chlorite. Cleavage for the most part dips regularly and steeply southeast. On fresh outcrops, these thinly fissile slates contrast notably with the more massive siltstone of the adjacent Wilhite formation, but the distinction fades on weathered slopes.

PETROGRAPHY

Sandstone

A specimen of sandstone typical of that interbedded with the conglomerate of the Shields formation (PF–K7) was collected on Cove Creek road, six-tenths of a mile south of Cove Creek Cascades (Pigeon Forge quadrangle). Thin-section study by Hadley indicates that it is composed of 48 percent quartz and 16 percent feldspar in larger grains, the remainder being a matrix of smaller grains and sericite flakes.

According to Hadley, grains and matrix are sharply differentiated. Grains are 0.7 to 5.0 mm in diameter, the largest well rounded, the smaller increasingly angular; both quartz and fedspar reach maximum grain size. The larger feldspar grains are irregularly twinned plagioclase, extensively replaced by carbonate and sericite; the smaller include albite with lamellar twinning. The grains of quartz and feldspar in the matrix are less than 0.7 mm in diameter; the sericite was probably altered from the feldspar and from original argillaceous constituents.

Minor constituents of conglomerate

H. W. Ferguson made collections of the minor pebble constituents from the conglomerate of the northern belt of the Shields formation; these were studied petrographically by Hadley. About 50 specimens were obtained from two localities just southeast of Walden Creek (WdC–39, ridge between Walden Creek and Valley Branch, northwestermost of three conglomerate layers. WdC–40, north slope of Benson Mountain on spur east of Lick Branch, at altitude of 1,340 ft, Walden Creek quadrangle). Specimens from the two localities are for the most part similar.

Of the 50 pebbles, 27 are quartzite, mostly dark gray and impure, but some light gray and vitreous. Of these, 12 show various degrees of tourmalinization, and are dark gray to black; a few of the tourmalinized specimens are coarse and gneissic. There are, besides, 7 pebbles of medium- to dark-gray siltstone; 12 of light-gray chert, flint, or novaculite; and 1 of brownish-gray limestone.

Deformed conglomerate

A specimen of sheared conglomerate from the area of highly altered rocks between Tuckaleechee and Wear Coves (WC–K18, north of county road near Lemon Hollow, Wear Cove quadrangle) was examined in two thin sections perpendicular to the foliation, one parallel to the lineation and one normal to it.

According to Warren Hamilton, the rock consists largely of deformed quartz pebbles with dimensions of 5 by 10 by 20 mm, a few large siltstone chips, and minor small grains of leucoxene, magnetite or ilmenite, zircon, and tourmaline.

The quartz is sheared into lenses and enormously strained, but has no preferred crystallographic orientation. In the section parallel to the lineation three general directions of feathery aggregation and microcracks are apparent in the quartz, the strongest parallel to the foliation, the others diverging 40° from it on either side. In the section normal to the

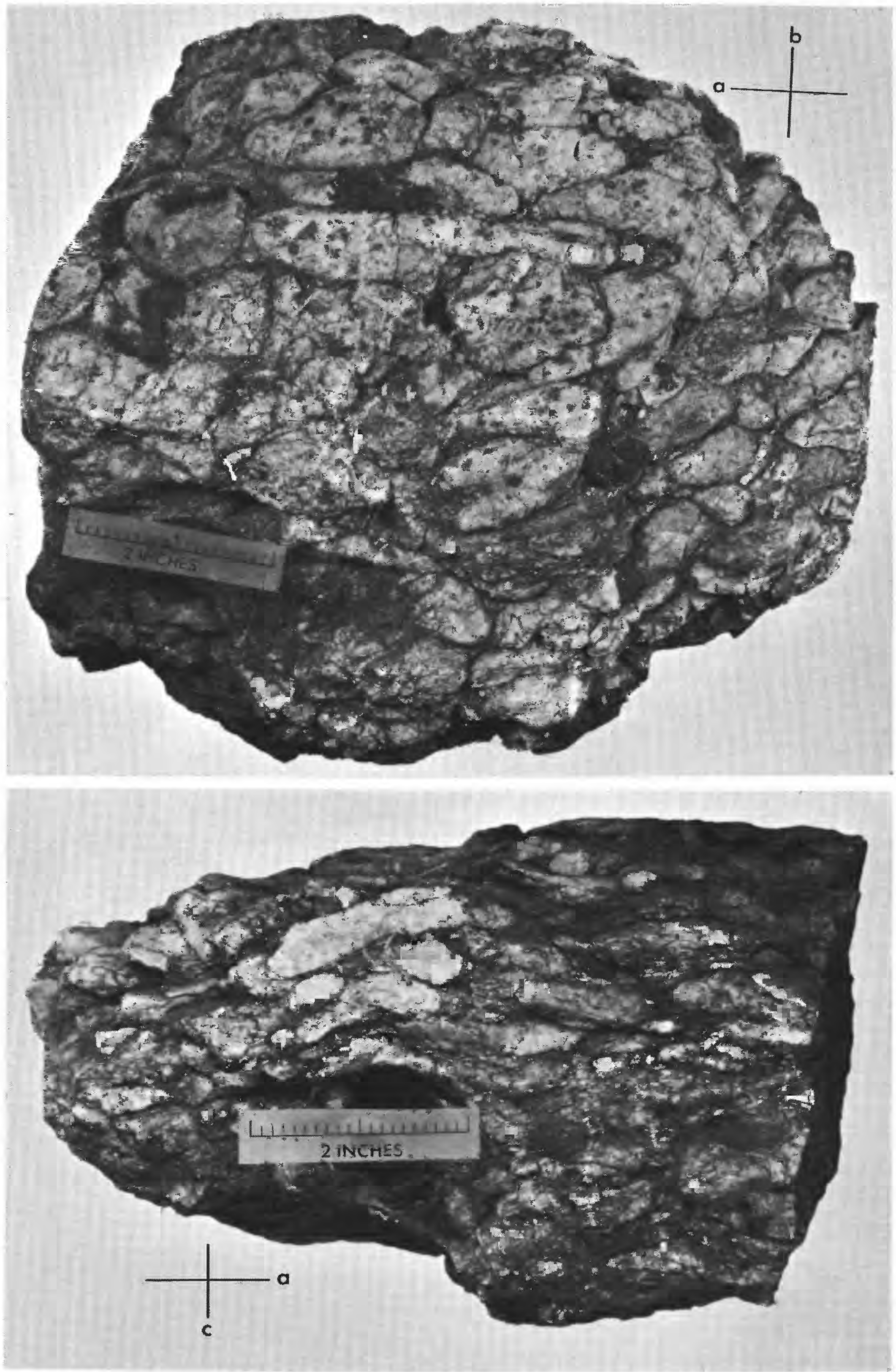

FIGURE 10.—Views of a specimen of deformed quartz conglomerate of Shields formation. Pebbles were probably nearly spherical originally, and have been flattened in plane of foliation and elongated parallel to *a* structural axis. Upper View normal to plane of foliation. Lower, View parallel to foliation, in plane of *a* and *c* structural axes. From ridge between Lemon and Pawpaw Hollows, Wear Cove quadrangle.

lineation, all three are parallel to the foliation, but the directional fabric is not so plain. Between the larger grains are smaller quartz lenses of all sizes, minutely crushed quartz with anastomosing foliums, and fine-grained sericite.

Microscopic examination of the rock indicates a greater amount of slicing, shearing, and crushing, and less "plastic" deformation of the detrital grains than would have been anticipated from the hand specimens.

STRATIGRAPHIC RELATIONS

The Shields formation appears to be overlain conformably by the Wilhite formation, although this is difficult to prove in rocks so crumpled and faulted. The conglomerate and slate of the northern belt of the Shields are bordered southeast of Walden Creek by siltstone of the Wilhite, which has a synclinal structure. The Shields on the flank of the syncline is so much contorted that local dips have little meaning; but the formation appears to pass southeastward beneath the Wilhite, and it is so represented on the structure sections (pl. 9). The Shields of the southern belt is separated from the Wilhite by the Happy Hollow fault, and has probably been upthrust from a lower level. Northwest of the fault, conglomerate and slate of the Shields emerge anticlinally in Happy Hollow and seemingly pass beneath the Wilhite of the synclinorium on the northwest.

WILHITE FORMATION

GENERAL FEATURES

The Wilhite formation is named for Wilhite Creek, which drains southward from English Mountain into East Fork (Richardson Cove quadrangle). The name is adapted from the Wilhite slate of Keith (1895a), but with very different interpretation of the sequence and stratigraphic relations (King and others, 1958).

The great bulk of the Wilhite consists of silty and argillaceous rocks, but lesser constituents—interbedded with them in thin to thick layers—are more varied than in most other formations of the Ocoee series; they include conglomerate, sandstone, quartzite, limestone, and dolomite. In the type area, the formation is divisible into a lower, or Dixon Mountain member, and an upper, or Yellow Breeches member, the two being of about equal thickness, and the whole about 3,500 feet thick.

The Wilhite formation is extensively exposed in the northern foothills of the report area, but a continuous sequence like that in the type area is not preserved. Rocks resembling those of both the Dixon Mountain and Yellow Breeches members occur, but in separate fault blocks, so that their sequence must be inferred by analogy with that in the type area. Because of these uncertainties, it seems best in the report area to refer to the two parts informally as "lower" and "upper units" of the Wilhite formation. Of the lower unit about 2,000 feet is preserved, and of the upper unit perhaps 1,000 feet.

LOWER UNIT

The lower unit of the Wilhite formation crops out in an area of synclinal structure about 10 miles long, lying southeast of Walden Creek, and extending from Bates Mountain and Long Ridge (Wear Cove quadrangle) eastward to Sweat Hill (Pigeon Forge quadrangle). Outlying masses of the same rocks, probably in separate fault blocks, form Sugar Camp Knob and the southern part of Pine Mountain. The main area includes two synclinal basins, the Bates Mountain on the northwest and the Little Rocky on the southeast, separated by faults—the first openly folded, the second more complexly folded and faulted.

The lower unit consists mainly of siltstone, but includes interbedded layers of quartzite, sandstone, and conglomerate in its upper part. On the north flank of the Little Rocky syncline an apparent thickness of about 3,500 feet is exposed, but the siltstone has been locally contorted and the quartzite layers repeated one or more times, so that the original thickness was probably no more than 2,000 feet. In this area the unit overlies the Shields formation, but its top is missing, so that its total thickness is undetermined.

Siltstone

The main body of the lower unit is siltstone and silty argillite or slate, which resemble the Pigeon siltstone of the Snowbird group, although somewhat thinner bedded and more argillaceous. These are typically exposed along Cove Creek near Cove Creek Cascades (Pigeon Forge quadrangle). They form rough steep topography, with sharply incised valleys, and ridge slopes as steep at 35° or 45°. In valleys they project as strong ledges, over which streams pass in cascades; higher on the ridges they weather into chips and plates which are difficult to distinguish from weathered products of argillaceous rocks.

The siltstone is variably deformed and metamorphosed. Along Cove Creek and elsewhere in the east it is thrown into a succession of symmetrical folds, 10 to 50 feet across, which are cut by coarse axial plane cleavage. In the west it dips more regularly into the Bates Mountain syncline and has little cleavage or other metamorphic structures, so that original sedimentary features are well preserved.

Most of the siltstone is dull green or blue where fresh, probably from presence of chlorite, but it weathers gray. Thin brighter green siltstone layers are present in places, as well as units 5 or 10 feet thick of maroon-red siltstone, which are inconstant both vertically and laterally. Most of the rock is of uniform silty texture, although some thicker layers are coarser and verge on fine-grained sandstone; some thin interbedded layers are argillaceous.

The siltstone mainly forms beds a few inches to several feet thick, with thin closely spaced light or dark laminae between bedding planes. In part, the laminae and some of the thicker layers are iron-bearing carbonate, gray where fresh, but weathering brown. Some coarser carbonate-bearing layers an inch or so thick are load cast, current rippled, or minutely crossbedded. In the Bates Mountain area, where the siltstone is little altered, most bedding surfaces are smooth and featureless except for flakes or detrital mica, but a few contain shallow ripples and a variety of current marks. Where the rock is more altered farther east, as along Cove Creek, bedding surfaces have been deformed into pseudoripples by small-scale slippage along cleavage planes; these pseudoripples differ from true ripples in their rigid parallelism to the strike of the cleavage and to each other, both on single and succeeding bedding surfaces (fig. 11).

FIGURE 11.—Pseudoripple marks on bedding surfaces of sandy siltstone of Wilhite formation at Cove Creek Cascades, Pigeon Forge quadrangle. Folded siltstone in quarry on north side of bridge. Bedding and cleavage directions may be seen in cross section in rock face on right; rest of surfaces in view are folded bedding. Photograph by H. E. Malde.

Quartzite

Interbedded in the siltstone are various coarser rocks, of which the most distinctive and prominently exposed are quartzite. The quartzite crops out in light-colored scarps, ledges, and cliffs that sustain some of the highest ridges of the northern foothill area and give rise to blocky float that chokes most of the stream valleys of the adjacent area.

Wherever they occur, the quartzite beds are near the top of the siltstone sequence, and all probably lie at about the same stratigraphic level. In its typical facies the quartzite closely resembles those of the Nebo and Hesse sandstones of the Chilhowee group, but northwestward it passes into less quartzose sandstone and interbedded conglomerate, similar to coarser rocks elsewhere in the Walden Creek group.

Quartzite beds are best developed on the northwest fllank of the Little Rocky syncline where they form Little Rocky, The Hogback, and prominent ridges nearby. Farther west they sustain Bates Mountain on the southeast flank of the Bates Mountain syncline, and to the east they form Sugar Camp Knot and the southeastern part of Pine Mountain, in the outlying fault slice noted above.

On Bates Mountain, where the structure is relatively simple, 2 quartzite beds 100 to 150 feet thick occur in a stratigraphic interval of 600 feet, underlain by, interbedded with, and overlain by siltstone. Near Little Rocky at least 6 quartzite beds 50 to 150 feet thick lie in homoclinal sequence in the siltstone, but most pinch out along the strike, and at least some have been repeated by thrust slicing. On Benson and Sinkhole Mountains to the north they overlie siltstone, and near the head of Clear Fork to the south they are overlain by siltstone and interbedded conglomerate. Parts of Pine Mountain contain 2 beds 50 to 200 feet thick, the thickest forming the cap of the mountain.

The quartzite is vitreous, buff, gray, or white, and is made up of fine- to medium-grained quartz sand, thoroughly cemented by quartz, and a few grains of feldspar or other detrital minerals. It stands in massive ledges 10 to 30 feet thick, many of which are so jointed, shattered, and veined by quartz that the original sedimentary structure is largely destroyed; between are thinner better laminated quartzite layers, some of which are crossbedded, and a few thin argillaceous partings.

Basal parts of some of the quartzite layers contain rounded pebbles, cobbles, and boulders a few inches to 18 inches in diameter, mostly of quartzite like the matrix, but including some that have weathered to voids, and probably were originally limestone. Scattered quartz pebbles occur, and numerous small chips and plates, now weathered to voids, that probably were originally slate or slaty limestone. Conglomeratic quartzite is succeeded in each bed by massive nonconglomeratic quartzite; in a few places there is a succession of quartzite beds, each with a conglomeratic base. In others, the massive quartzite itself has a peculiar lumpy, knotted surface, not unlike partly kneaded dough, and was perhaps originally laid down as quartzite rubble, since thoroughly cemented and reconstituted.

At several places on Pine Mountain the upper few feet of the surface of the quartzite has weathered into quartz sand or friable sandstone, which has been mined for use in local construction.

Sandstone and conglomerate

Northwestward the quartzite passes into sandstone and conglomerate of a different facies. Sandstone and conglomerate are interbedded with the quartzite at the west end of The Hogback and on Bates Mountain. They replace the quartzite entirely to the north across the Bates Mountain syncline, the 2 quartzite beds of Bates Mountain merging on the north flank on Long Ridge into a single conglomeratic sandstone body 600 feet thick. At the eastern end of the syncline near the junction of Walden Creek with its South Fork, sandstone and conglomerate identical with the main body form a thick lens in the siltstone beneath.

The sandstone of Long Ridge is blue gray where fresh, weathers brown and friable, and is cemented by iron-bearing carbonate rather than quartz; quartz remains the dominant detrital mineral, but grains of feldspar and other minerals are common. Most of the sandstone beds contain rounded grits and pebbles of quartz and rock fragments, dispersed in the matrix or forming more closely packed seams or lenses. Scattered lenses 3 to 5 feet thick are formed of much coarser rubble conglomerate. Conglomeratic beds increase in abundance westward along the strike.

Most of the conglomerate of the Long Ridge area consists of rounded pebbles half an inch to more than 1 inch in diameter, lying in a sandstone matrix like that described. Half or more of the pebbles are generally vein quartz, the remainder being rock fragments, but in places quartz is rare or lacking. The rock fragments, mostly foreign to the area, include quartzite, some dark-gray and possible tourmalinized, siltstone, limestone, and leucogranite; most of the calcareous pebbles have weathered to voids.

The coarser rubble conglomerate of the scattered lenses contains all these constituents, and also rounded to angular cobbles, boulders, blocks, and slabs, closely packed and lying without order in the matrix; the larger fragments are quartzite, sandstone, sandy limestone, or limestone, probably intraformational. The largest observed, a block of calcareous sandstone embedded in the conglomerate at the junction of Smith Branch and Middleset Hollow a little west of the report area (Kinzel Springs quadrangle), measures 3 by 5 feet on exposed face, but many others here and elsewhere are almost as large.

Calcareous sandstone

Eastward along the strike of the quartzite beds of the Little Rocky syncline, on Wildcat Spur and the valley to the east, beds of calcareous sandstone 3 to 5 feet thick are interbedded in the siltstone. They are composed of rounded grains of quartz and some feldspar several millimeters in diameter, widely spaced in a calcite matrix that is flecked with dark grains. in the same vicinity are a few thin beds of brown-weathered sandy limestone, containing angular limestone pebbles and chips.

UPPER UNIT

The upper unit of the Wilhite formation occurs north of the lower unit, in a belt about 8 miles long, bordered on each side by faults, that extends from Davids Knob southeast of Sevierville, up the lower course of Walden Creek. It is composed mainly of argillaceous shales and slates, but is characterized especially by interbedded limestone, which forms thin to thick layers. The thickness of the unit is indeterminate in the report area, for it is faulted against other rocks and is much contorted internally. Its outcrop belt is as much as a mile wide and its beds dip mostly at steep angles to the southeast, although with local overturns and reversals. Probably at least 1,000 feet of beds is preserved.

Carbonate rocks

The largest limestone body is on the west bank of Mill Creek half a mile southwest of Pigeon Forge (Pigeon Forge quadrangle). This body has been opened in a small quarry which exposes contorted blue-gray fine-grained limestone in 6-inch to 1-foot beds, cut by numerous gash veins of calcite, with partings of black noncalcareous slate between nearly every layer. South of the quarry the limestone passes into limy sandstone made up of coarse rounded quartz grains in a calcareous matrix. The limestone and limy sandstone near the quarry are at least several hundred feet thick, but complex folding and erratic dips prevent determination of their sequence, structure, or trend; on the map their outline is indicated schematically (pl. 3). They may form a thick lens in the argillaceous rocks, for elsewhere in the vicinity only thin limestone beds occur in the shales.

Elsewhere in the upper unit, carbonate rocks form laminae or beds a foot to less an inch thick in the dominant argillaceous rocks. In places, presence of carbonate rocks is indicated only by small float blocks of limestone or leached sandstone in the fields. Carbonate rocks are poorly developed or absent along Walden Creek in the western part of the outcrop belt.

Argillaceous rocks

Most of the argillaceous rocks are drab- or dull-green laminated shale, but include some silty layers that contain fine detrital grains of quartz, feldspar, and mica, and a few thin beds of fine-grained noncalcareous sandstone. Metamorphism of the argillaceous rocks is slight and cleavage is weak, differing in apparent strength from outcrop to outcrop, depending partly on original structure and partly on freshness of exposure. Cleavage is most prominent in unweathered outcrops, but fades on long-exposed surfaces where bedding is emphasized by selective disintegration of layers of different composition.

PETROGRAPHY

Siltstone

Six specimens of siltstone and related rocks from the lower unit of the Wilhite formation were examined in thin section by Hadley and Hamilton; they have the mineral composition given in table 15. Chemical composition of two of the specimens is given in table 16.

These silty rocks have much the same character over wide areas and through considerable textural range. They consist of alternating laminae a few hundredths of a millimeter to several millimeters thick, one being made up of fine detrital grains of quartz, feldspar, and other minerals, and the next of argillaceous constituents, largely altered to chlorite.

In the siltstone and silty argillite detrital quartz grains are 0.01 to 0.10 mm in diameter; in the sandstone (PF–302) they are as coarse as 0.30 mm. Associated with the quartz is plagioclase in grains of about equal size—difficult to differentiate from the quartz in thin section except where twinned—as well as small but undetermined amounts of potassium feldspar. Detrital constituents also include muscovite and biotite in tabular grains 0.05 to 0.30 mm in diameter, the latter largely altered to chlorite. The argillaceous laminae are made up largely of recrystallized flakes of sericite and chlorite less than 0.01 mm in diameter, unoriented or laid parallel to the bedding.

Variants of the normal siltstone are illustrated by the sandstone containing iron-bearing carbonate (PF–302) and the red silty argillite containing hematite dust (KS–KLLC), both of which, as shown by field relations, have considerable areal extent.

Foliation is poorly developed in all the specimens, being strongest in the two eastern ones (PF–302 and 301), where it is expressed by widely spaced discontinuous microshear planes, most conspicuous in the more argillaceous layers; it is faint or absent in the specimens from farther west.

TABLE 15.—*Estimated modes, in percent, of siltstone and related rocks of Wilhite formation*

[Estimated by J. B. Hadley and Warren Hamilton]

	PF–302	PF–301	WC–30	KS–K11A	KS–K11B	KS–K11C
Detrital grains						
Quartz	32. 4	28. 3	Dominant	} 35	} 40	} 30
Plagioclase (albite); may include some orthoclase	23. 7	24. 2	----	}	}	}
Zircon	. 3	----	----	Trace	Trace	----
Tourmaline	Trace	----	----	Trace	Trace	----
Apatite	. 7	. 7	----	----	----	----
Epidote	3. 1	----	----	----	----	----
Ilmenite or magnetite	----	. 4	----	----	Trace	1
Sphene and leucoxene	2. 2	. 5	Minor	1	1	1
Muscovite	10. 9	[1] 27. 3	----	1	1–	1–
Biotite (and pseudomorphs of chlorite from biotite)	. 5	[1] 17. 9	Minor	5	2	2
Matrix and secondary						
Chlorite	0. 5	(1)	Common	} 53	} 56	} 62
Sericite and muscovite	----	(1)	Dominant	}	}	}
Carbonate	25. 7	. 6	----	4	1	----
Hematite	----	----	----	----	----	4
Carbon	----	. 1	----	----	----	----
Pyrite	----	----	Rare	1	----	----

[1] Includes both large detrital grains and smaller flakes in groundmass.

NOTE.—Description of sample and locality follows:

PF-302. Sandstone, fine-grained, gray, containing iron-bearing carbonate. Quarry north of bridge at Cove Creek Cascades, Pigeon Forge quadrangle. Petrographic report by Hadley; mineral percentages verified from chemical analysis.

PF-301. Siltstone, dark-gray. Same locality as 302. Petrographic report by Hadley; mineral percentages verified from chemical analysis.

WC-30. Siltstone, lying above quartzite and sandstone of Bates Mountain syncline. Middleset Hollow on meridian between Wear Cove and Kinzel Springs quadrangles. Petrographic report by Hadley.

KS-K11A. Silty argillite, gray-green. Fresh cut on lumber road a short distance east of Fowler Hollow, Kinzel Springs quadrangle. Petrographic report by Hamilton.

KS-K11B. Same locality and horizon as K11-A; brighter green. Petrographic report by Hamilton.

KS-K11C. Same locality and horizon as K11-A; dull red. Petrographic report by Hamilton.

TABLE 16.—*Chemical composition, in percent, of sandstone and siltstone of Wilhite formation*

[Lois D. Trumbull, analyst]

	PF-302 (52-1496 CD)	*PF-301 (52-1495 CD)*
SiO_2	54.77	61.80
Al_2O_3	10.46	18.49
Fe_2O_3	.23	.67
FeO	5.23	5.67
MgO	2.72	2.22
CaO	8.61	.39
Na_2O	2.67	2.85
K_2O	1.32	3.13
H_2O-	.05	.12
H_2O+	1.32	3.26
TiO_2	1.30	.72
ZrO_2	.19	.00
CO_2	10.38	.25
P_2O_5	.31	.16
MnO	.31	.02
C	.00	.08
	99.87	99.83

Quartzite and sandstone

Seven specimens of quartzite, quartzitic sandstone, and sandstone were examined in thin section by Hadley and Hamilton; they have the mineral composition presented in table 17.

Specimens PF–K5, WC–K14, and WC–K12 are typical orthoquartzites, made up largely of quartz which originally formed rounded grains 0.1 to 2.0 mm in diameter, but which is now recrystallized and extended into the interstices to form a sutured mosaic. In some specimens original grain boundaries are well preserved; in others they are indicated only by sporadic cloudy zones. One of the quartzite specimens may originally have contained iron-bearing carbonate, as suggested by small voids in the slide and by limonite stain; others may have contained a few feldspar grains, now altered to patches of unoriented sericite flakes.

Two of the sandstone specimens (WC–K13 and KS–K3) have the megascopic appearance of quartzite Hence, they are labeled quartzitic, but lack the characteristic regrowth of the quartz grains; they are transitional to the facies of the remaining sandstone specimens (WC–K10 and KS–K9). In the sandstone, quartz grains are of about the same dimensions as in the quartzite, but they have not been recrystallized or extended into the matrix. Grains of potassium feldspar and plagioclase are abundant and are of about the same dimensions as the quartz. Carbonate of K3 and K9 is iron-bearing dolomite which forms subrhombohedral masses in the matrix; carbonate of K13 and K10 is largely calcite, formed by replacement of the feldspar.

Petrographic study suggests that the lateral change in facies from quartzite to sandstone is accomplished by change from quartz-cemented sandstone to carbonate-cemented sandstone and by an increase in content of feldspar.

Conglomerate

Of the smaller rounded pebbles in the conglomerate, many are vein quartz, but numerous rock fragments occur at most localities. Of a suite of eight of these fragments examined by Hadley and Hamilton, collected near the west end of The Hogback (WC–38, WC–16), one is quartz sandstone, one orthoquartzite, three metaquartzite, two highly altered quartz rocks containing tourmaline, and one metasiltstone. The first two are unmetamorphosed and may be intraformational; the remainder, probably of foreign origin, show varying degrees of shearing, foliation, veining, and hydrothermal alteration, although they lack high-grade metamorphic minerals.

Two cobbles from the coarser rubble conglomerate (KS–K9A, junction of Smith Branch and Middleset Hollow, Kinzel Springs quadrangle; WC–K17A, South Fork of Walden Creek at west end of Whetstone Ridge, Wear Cove quadrangle) were examined in thin section. The first is a thoroughly recrystallized quartzite, the second a dolomitic sandstone; both are probably intraformational.

STRATIGRAPHIC RELATIONS

South of English Mountain and east of the report area the Wilhite formation is succeeded conformably by beds that are probably the same as the Sandsuck formation of Chilhowee Mountain (Hamilton, 1961). Within the report area the Wilhite is separated by faults from the Sandsuck of Chilhowee Mountain north of it, so that their relations cannot be determined. The two sequences might overlap, but lithologic differences suggest that they do not; moreover, the position of the Sandsuck just beneath the Chilhowee group implies that it is a higher unit. Differences in degree of deformation and metamorphism of the Wilhite and Sandsuck formations in the report area indicate that they were originally deposited far apart and were later brought into juxtaposition by movements on low-angle faults.

SANDSUCK FORMATION

GENERAL FEATURES

The Sandsuck shale was named by Keith (1895a) for Sandsuck Branch, southeast of Chilhowee Mountain near its northeastern end (Walden Creek quadrangle). The shale lies beneath sandstone and conglomerate which Keith considered to be basal Cochran formation, but it actually intertongues widely with these coarser rocks. The base of the Cochran is therefore reedefined at a higher level, at the base of persistent beds of arkose and quartzite, in part maroon;

TABLE 17.—*Estimated modes, in percent, of quartzite, quartzitic sandstone, and sandstone of Wilhite formation*

[Estimated by J. B. Hadley and Warren Hamilton]

	Quartzite			Quartzitic sandstone		Sandstone	
	PF-K5	WC-K14	WC-K12	WC-K13	KS-K3	WC-K10	KS-K9
Detrital grains							
Quartz	98	98	99	52	80	61	71
Potash feldspar (orthoclase and microcline)				9		3	5
Plagioclase (albite)				11	5	10	5
Tourmaline	Trace	Trace	Trace	Trace	Trace	Trace	Trace
Zircon		Trace	Trace	Trace	Trace	Trace	Trace
Apatite				Trace	Trace	Trace	
Magnetite or ilmenite		Trace			Trace		Trace
Sphene and leucoxene		Trace	1	Trace	1	1–	1–
Muscovite						Trace	1
Biotite (pseudomorphs of chlorite from biotite)							1
Interstitial and secondary							
Matrix (fine-grained quartz, feldspar, sericite, and chlorite)						14	10
Chlorite		} 1	1	{ 4	Trace		
Sericite	1	}		{ 7			
Carbonate	leached?			17	10	12	8
Limonite	1						
Quartz veinlets		1					

NOTE.—Description of sample and locality as follows:
PF-K5. Quartzite, white. South slope of Sugar Camp Knob, Pigeon Forge quadrangle. Petrographic report by Hadley.
WC-K14. Quartzite, white. West side of Clear Fork a little north of Chambers Hollow, Little Rocky syncline, Wear Cove quadrangle. Petrographic report by Hamilton.
WC-K12. Quartzite, light-gray, slabby. South slope of Whetstone Ridge, Little Rocky syncline, Wear Cove quadrangle. Petrographic report by Hamilton.
WC-K13. Sandstone, calcareous and feldspathic. Summit of Little Rocky, Little Rocky syncline, Wear Cove quadrangle. Petrographic report by Hamilton.
KS-K3. Quartzitic sandstone. Upper bed on Bates Mountain a little west of meridian between Kinzel Springs and Wear Cove quadrangles. Petrographic report by Hadley.
WC-K10. Sandstone. Cut on Reed Creek road, south foot of Long Ridge, a little east of west meridian of Wear Cove quadrangle. Petrographic report by Hamilton.
KS-K9. Sandstone. Smith Branch at mouth of Middleset Hollow, Kinzel Springs quadrangle. Petrographic report by Hamilton.

the shale, sandstone, and conglomerate beneath is redefined as the Sandsuck formation.

The best section of the formation is not along Sandsuck Branch, but on the opposite, northwest slope of Chilhowee Mountain, near the heads of the North and South Forks of Ellijoy Creek. In this area about 2,500 feet of the formation is exposed beneath the Cochran formation, but its base is cut off by the Great Smoky fault. Beds similar to the Sandsuck formation of the type area reappear east of the report area and south of English Mountain, where about 4,000 feet is preserved above the Wilhite formation, but the top beds are missing.

LOCAL FEATURES

Within the report area the Sandsuck formation occurs only northwest of the Miller Cove fault and west of the West Fork of the Little Pigeon River, where it forms the lower slopes of Chilhowee Mountain.

On the northwest slope of Chilhowee Mountain, most of the sequence is shale, but sandstone and conglomerate are interbedded in discontinuous bodies. The units in the lower part are thin and lenticular; those near the top are as much as 800 feet thick, but of basinlike form, so that in places the Cochran formation of the Chilhowee group lies on the basins, and in others on the underlying shale (fig. 12).

The Sandsuck formation southeast of Chilhowee Mountain is raised against the Chilhowee group on the northwest along the Bogle Spring fault and is cut off a mile or two farther southeast by the Miller Cove fault. Here, the upper sandstone and conglomerate are a continuous body more than 1,000 feet thick, which forms most of the surface southwest of Big Bridge Branch; underlying shale, with some interbedded sandstone and conglomerate, emerges as inliers to the west, along Sandsuck Branch and the upper course of Walden Creek near Hornet, and forms all the surface east of Big Bridge Branch.

East of the end of Chilhowee Mountain the lower shale of the Sandsuck formation crops out in a wide expanse of hilly ground, in which the blocks northwest and southeast of the Bogle Spring fault are difficult to distinguish. The shale generally dips steeply southeastward, with minor reversals, crumpling, and shearing, which increase northward toward the trace of the Great Smoky fault.

Unlike the rocks of the Walden Creek group southeast of the Miller Cove fault, the Sandsuck formation is merely broadly folded, and there is little contortion

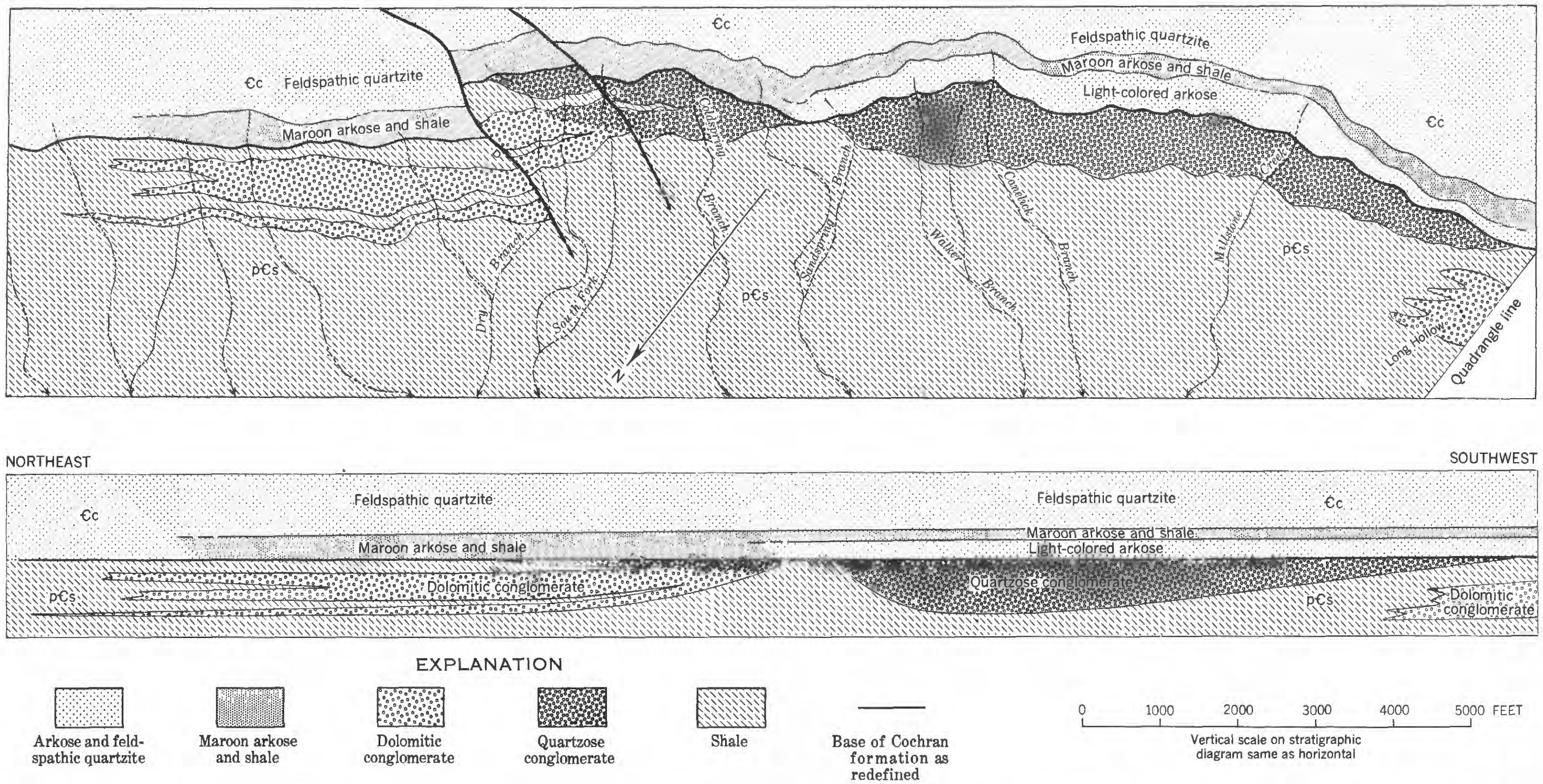

FIGURE 12.—Map and stratigraphic diagram showing relation between Cochran formation (€c) and Sandsuck formation (p€s) on northwest face of Chilhowee Mountain Walden Creek quadrangle. Shows contrast between persistent units in Cochran formation and lenticular irregularly shaped units in Sandsuck formation. This contrast suggests considerable differences in environment of deposition of the two formations and a possible intervening unconformity. From field data by H. W. Ferguson.

or shearing except near the Great Smoky fault. Its rocks are virtually unmetamorphosed; the shale possesses only faint dull cleavage at most; pebbles of the conglomerate retain their detrital shapes and are not crushed or flattened.

LITHOLOGY

Argillaceous rocks

Shale of the Sandsuck formation is olive green or gray, noncalcareous, and largely argillaceous, but it contains numerous thin silty or finely sandy laminae, and much detrital mica on bedding surfaces; it weathers to hard rusty chips. The shale resembles the Nichols and Murray shales of the Chilhowee group, but differs much from the calcareous shale of the Tellico formation that adjoins it across the Great Smoky fault; on prolonged weathering, however, distinctive characters of the Sandsuck and Tellico shales fade out, making the fault contact between them difficult to map.

In the eastern part of the outcrop area, between Guess Creek and the West Prong of the Little Pigeon River, shale down the dip to the southeast contains interbedded sandstone, in layers a few inches to a foot thick, composed of well-rounded quartz grains as much as 1 mm in diameter and a few smaller feldspar grains. One larger sandstone bed 100 feet thick forms a ledge across Guess Creek northwest of the head of Sharp Hollow (Pigeon Forge quadrangle).

Sandstone and conglomerate

Coarser clastic rocks of the Sandsuck formation, both in the thick units at the top and the thinner units below, are mostly medium- to coarse-grained sandstone, partly feldspathic, nearly everywhere with small dispersed pebbles, interlayered or interlensed with much conglomerate containing coarser and more closely packed pebbles. Their matrix includes varying quantities of iron-bearing carbonate, which causes their fresh dark-gray color to change to rusty brown on weathering; where carbonate content is greatest, weathered surfaces are furrowed and pinnacled by solution. In places, weathering of the sandstone and conglomerate releases enclosed pebbles from their matrix, to strew the surface in countless numbers.

All the pebbles of the sandstone and conglomerate are well-rounded; most are ¼ to 1 inch in diameter, but larger ones are common in the more pebbly beds, some exceeding 6 inches in diameter. The greater number are colorless, white, or smoky quartz; afew smaller ones are blue quartz, and some are feldspar. About 5 percent of the pebbles at most localities are rock fragments, mainly light- to dark-gray quartzite, whose character is indicated below.

PETROGRAPHY

Argillaceous rocks

A specimen of typical silty shale of the Sandsuck formation (WdC–34) was collected on Sandspring Branch on the northwest side of Chilhowee Mountain. Thin-section study by Hadley indicates that it contains 38 percent detrital grains, dominantly quartz, but also includes muscovite, biotite, iron oxides, sphene, and plagioclase. The remainder of the rock is sericite and chlorite, altered from the original argillaceous constituents. These minerals are concentrated along the bedding laminae, but have no preferred orientation; the only foliation in the rock is a primary sedimentary structure, produced by orientation of the detrital muscovite and biotite flakes parallel to the bedding.

Sandstone

A typical specimen of conglomeratic sandstone of the Sandsuck formation from southeast of Chilhowee Mountain (WdC–1, on Walden Creek, 1,000 ft. southeast of Hornet, Walden Creek quadrangle) is shown by Hadley's thin-section study to consist of large rounded quartz and feldspar fragments in a fine-grained matrix.

The quartz fragments are grains, granules, and small pebbles, all strain-shadowed, some fractured, but none crushed. Feldspar grains are much less abundant and consist wholly of microcline and orthoclase. A single pebble of quartzite 7 mm in diameter is made up of an aggregate of interlocking quartz grains. Matrix of the specimen consists of smaller more angular quartz and feldspar grains and a few thick flakes of detrital muscovite. Secondary sericite forms isolated shreds along grain boundaries. Iron-bearing carbonate, probably siderite or ankerite, constitutes 2 to 3 percent of the section and weathers brown in hand specimen. Pyrite forms abundant small cubic crystals, mainly in the matrix, but in part invading the larger fragments.

In this specimen no "heavy" detrital mineral grains were observed, but specimens of similar sandstone collected by G. D. Swingle (written communication, 1949) northwest of Chilhowee Mountain contain abundant subrounded grains of normal zircon and a few of hyacinth zircon.

Minor constituents of conglomerate

To determine the nature of the rock fragments which are associated with the dominant quartz pebbles in the conglomerates, Ferguson collected nearly 100 pebbles, weathered from the matrix, from 2 localities northwest of Chilhowee Mountain (Wd C–37, ridge southwest of Canelick Branch; W C–38, head of Dry Branch, Walden Creek quadrangle) and 2 localities southeast of the mountain (Wd C–4, ridge southwest of Sandsuck

Branch; Wd C–300, Sandsuck Branch to east end of Chilhowee Mountain, Walden Creek quadrangle). Rock types at all four localities are virtually the same.

According to Hadley, 72 of the pebbles are of various sorts of quartzite. Most are fine grained and impure, light gray, dark gray, to black; a few are coarse, quartzose, and vitreous. Darker varieties, about a third of the number, show varying degrees of replacement by black tourmaline which constitutes 25 to 95 percent of each specimen. Most of the quartzite specimens were strained before tourmalinization, but none are foliated. One pebble of quartz-tourmaline vein rock and one of medium-grained leucocratic granite containing tourmaline are present.

The collection also includes 7 pebbles of dark-gray fine-grained siltstone and light-gray chert or novaculite and 2 pebbles of quartz porphyry, made up of rounded to euhedral quartz grains in an aphanitic felsic groundmass.

All the pebbles are of hard, physically and chemically resistant rocks, able to withstand long weathering and transportation. They were subjected only to lowest grades of metamorphism before transportation; none are foliated or contain high-grade metamorphic minerals. The purer, more vitreous quartzites might be orthoquartzites, and the tourmalinized quartzites were probably produced by low-temperature hydrothermal alteration.

STRATIGRAPHIC RELATIONS

Relations between the Sandsuck and Cochran formations are generally not clearly shown in the Great Smoky Mountains region, because of poor exposures, complex structure, or both; but they are well displayed on the northwest slope of Chilhowee Mountain in its northeastern segment (fig. 12). Here, the beds dip southeastward at moderate angles, and the Cochran forms a series of regular traceable beds, which surmount a slope formed by the less regularly bedded Sandsuck. The Sandsuck formation is largely shale, but contains interbedded and interfingered layers of sandstone and conglomerate, the upper of which form a series of lenses and basins below the Cochran.

At the east end of Chilhowee Mountain the Cochran lies on a basinlike mass of conglomerate three-quarters of a mile long and several hundred feet thick. Southwestward along the northwest face of the mountain as far as Little Double it lies with clean-cut contact on shale continuous with that beneath the conglomerate basin. Beyond Little Double, beds of sandstone and conglomerate intertongue with the shale and thicken southwestward into a solid body 800 feet thick. Near the head of Sandspring Branch, however, these conglomerate beds are all cut off beneath the Cochran, so that the latter again overlies shale. This relation persists only a short distance to the southwest, as conglomerate reappears beyond, expanding into another basinlike body, 800 feet thick, which extends along the face of the mountain for 1½ miles, before being cut off again beneath the Cochran at Long Hollow at the west edge of the report area.

On the southeast slope of Chilhowee Mountain, between the Bogle Spring and Miller Cove faults, sandstone and conglomerate at the top of the Sandsuck form a continuous body of wide extent and more than a thousand feet thick. This body probably joins beneath the mountain with the less continuous basinlike bodies on the northwest side, and is so represented on the structure sections (pl. 9).

These relations indicate, at the least, a marked change in sedimentation from Sandsuck to Cochran time. The heterogeneity of the Sandsuck deposits on which the Cochran was laid is certainly in part due to irregular deposition, but the basinlike form of the conglomerate bodies on the northwest slope of the mountain suggests that they may also have been warped and truncated by erosion before the Cochran was deposited over them. The reddish arkosic and shaly layers of the basal and lower parts of the Cochran suggest derivation from a weathered, eroded surface.

From this evidence, it would appear that the Sandsuck formation of the Walden Creek group is separated by a significant change in sedimentation and a moderate unconformity from the Cochran formation of the Chilhowee group.

PROBLEMS OF OCOEE SERIES[4]

REGIONAL RELATIONS OF OCOEE SERIES

The Ocoee series is a feature of the mountains of the Unaka province, or northwestern part of the Blue Ridge. It extends along these mountains from north of Asheville in west-central North Carolina, southwestward to Cartersville in north-central Georgia, forming a belt as much as 40 miles wide for a distance of at least 175 miles (fig. 13). Northeast of Asheville the series wedges out along the outcrop, but precisely how far it extends has been disputed. Southwest of Cartersville, equivalents of the Ocoee may occur in the Talladega slate, but much of the Talladega is younger and of Paleozoic age. Along the northwestern edge of the

[4] Based in part on data from central Great Smoky Mountains given in previous sections of this report, but with extensive additions from surrounding areas. Data on eastern Great Smoky Mountains are from reports by Hadley and Goldsmith (1963) and by Hamilton (1961), and those on western Great Smoky Mountains from a report by Neuman and Nelson. Data on other areas are from various published sources, supplemented by reconnaissance by King. Sources of information are indicated in the text as far as possible, but specific credit for all items is impracticable. King is solely responsible for the interpretations offered.

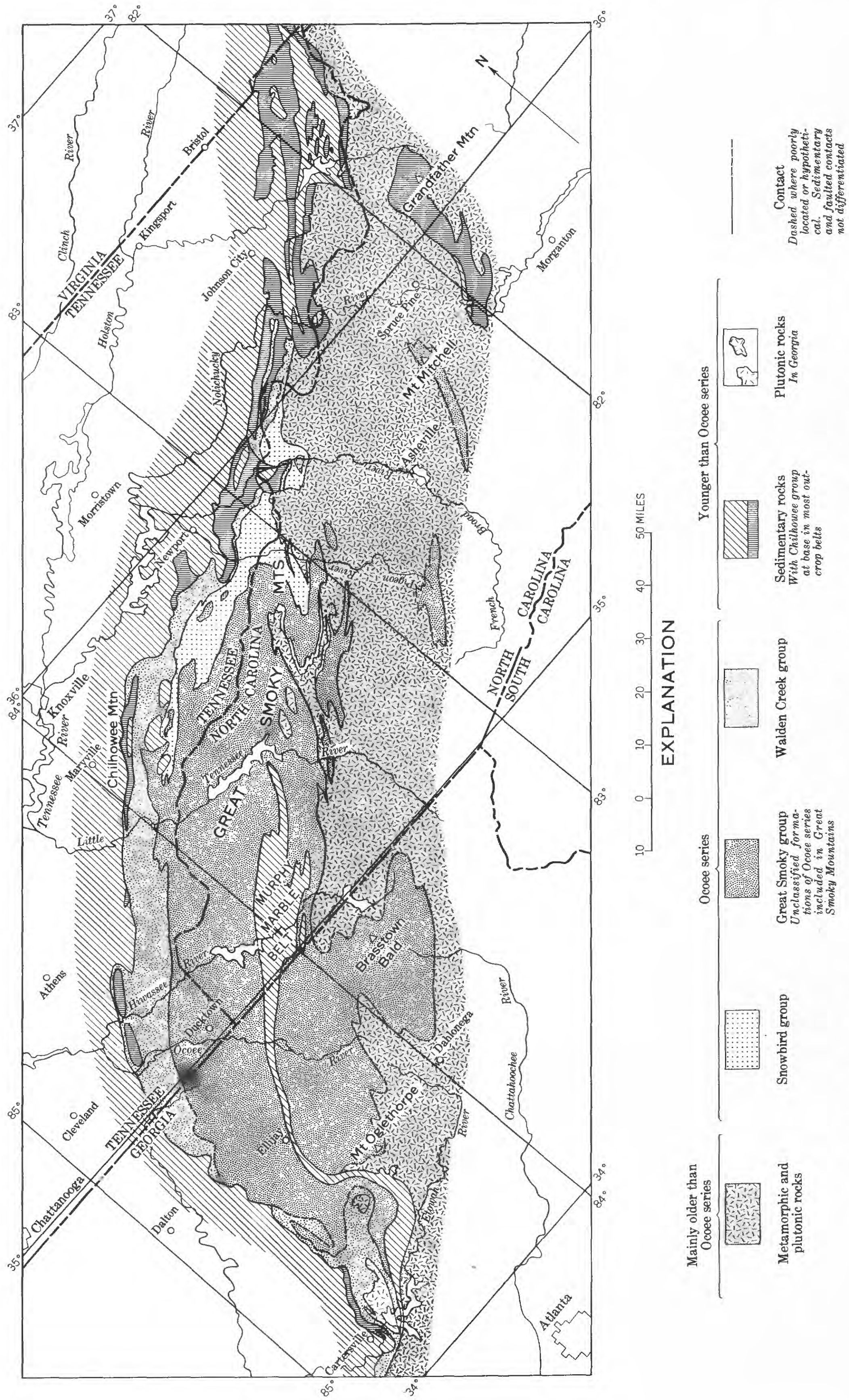

FIGURE 13.—Map of parts of Tennessee, North Carolina, and Georgia showing extent of Ocoee series, its subdivisions, and related rocks.

outcrop of the Ocoee series it has been thrust over the Paleozoic rocks of the Valley and Ridge province, and its original extent in this direction is no longer visible. Toward the southeast its extensions are obscured by the increasing deformation, metamorphism, and plutonism of the rocks. Most of the highly metamorphosed rocks of the main part of the Blue Ridge are probably older than the Ocoee series, but small to large outliers of the Ocoee may be downfolded, as near Mount Mitchell, N.C., and Brasstown Bald, Ga.

Throughout most of the extensive outcrop belt of the Ocoee series, neither its base nor top is visible, and the only rocks exposed are those of the series itself, strongly deformed, steeply tilted, and of great thickness. Base and top can be observed in a few places, mainly along its edges.

Basal relations are clearest from the Great Smoky Mountains northeastward, where the series lies unconformably on gneisses and silicic plutonic rocks (Hadley and Goldsmith, 1963)—the Carolina and Roan gneisses and Cranberry and Max Patch granites of Keith (1904). The gneisses originated during a depositional cycle earlier than that of the Ocoee, probably as geosynclinal sediments, and were metamorphosed, granitized, and injected by granite before Ocoee time. The gneisses and plutonic rocks that extend farther southwest along the edge of the Ocoee outcrop may likewise include rocks older than the Ocoee.

Along its northwestern side the Ocoee series is overlain in many places by the Chilhowee group of Cambrian(?) and Cambrian age. Farther southeast, formations of the Murphy marble belt extend longitudinally through the Ocoee area. They appear to be synclinally downfolded and downfaulted in the Ocoee (Keith, 1907a; Hurst 1955), although this interpretation has been questioned (Stose, G. W., and Stose, A. J., 1944, p. 377; Van Horn, 1948, p. 18–20), and their age has not been definitely established. The formations of the Murphy marble belt are here interpreted as overlying the Ocoee series and to be equivalent to the Chilhowee group and younger Cambrian rocks farther northwest. (See p. 75–76.)

SUBDIVISIONS OF OCOEE SERIES

In the Great Smoky Mountains, which form a segment near the center of the Ocoee outcrop belt, the series has been divided into the Snowbird, Great Smoky, and Walden Creek groups (King and others, 1958, p. 951), the Walden Creek occurring on the northwest, the Snowbird mainly in the center, and the Great Smoky on the southeast. Rocks lithologically like those of the three groups form the Ocoee series elsewhere in its outcrop belt and crop out in similar positions (fig. 13). In many places, as in the report area, stratigraphic relations between the three groups cannot be determined, because they are faulted against each other. Elsewhere, it can be seen that the Snowbird group is the basal deposit and is overlain at one place or another by the Walden Creek group or the Great Smoky group, but the mutual relations between the last two are uncertain.

The Snowbird group near its type locality in the eastern part of the Great Smoky Mountains is about 13,000 feet thick (Hadley and Goldsmith, 1963). A thin poorly sorted basal deposit, the Wading Branch formation, lies on the basement rocks, an is followed by a much thicker body of coarse quartzite and arkose, the Longarm quartzite. Westward along the north side of the mountains the Longarm is overlain by, and interfingers into, the finer grained Roaring Fork sandstone and Pigeon siltstone. In the central part of the mountains these fine-grained formations attain a thickness of more than 17,000 feet. In the western part of the mountains the Snowbird group wedges out at the surface amidst fault slices of the Great Smoky and Walden Creek groups (Neuman and Nelson, 1964), and has not been identified farther southwest.

In places along the north side of the Great Smoky Mountains the Snowbird group is followed conformably by the Rich Butt sandstone; Snowbird and Rich Butt are overlain, in turn, by the Great Smoky group, but the contact is faulted and the original relations have been lost. In the southeastern part of the mountains, however, the Snowbird is overlain with sedimentary contact by the Great Smoky; but it is very thin, and wedges out farther southeast, beyond which the Great Smoky group lies directly on basement rocks (Hadley and Goldsmith, 1963).

Northeast of the Great Smoky Mountains, the Snowbird group maintains its position above the basement rocks. Near the French Broad River it is 4,500 feet or more thick (Oriel, 1950, p. 25–30) and is largely arkosic quartzite like the Longarm, but includes fine-grained beds which resemble the Roaring Fork and Pigeon. It is followed by about 700 feet of beds which have been termed Hiwassee slate (Keith, 1904) or Sandsuck shale (Oriel, 1950, p. 23–25; Rodgers, 1953, p. 27), and which are overlain by the Chilhowee group. The Sandsuck of this area is clearly equivalent to at least the upper part of the Walden Creek group of the Great Smoky Mountains, but the presence in the upper part of the Snowbird of sandstone of Shields type and carbonate rocks of Wilhite type (Oriel, 1950, p. 27; Ferguson and Jewell, 1951, p. 16) suggests that the Snowbird as here defined may include equivalents of the lower part of the Walden Creek sequence in the

Great Smoky Mountains. Snowbird and Sandsuck apparently thin northeast of the French Broad River, but their northeastern terminus is uncertain. They may not continue beyond the Nolichucky River, or they may be represented in the lower parts of some of the sequences of the Unicoi formation in northeastern Tennessee (King and Ferguson, 1960, p. 33).

The Walden Creek group forms the northwestern part of the Ocoee belt from the Great Smoky Mountains southwestward (fig. 13). On Chilhowee Mountain and at some other places it is overlain by the Chilhowee group, but its original realtions are not otherwise apparent. Toward the northwest it is thrust over the Paleozoic rocks of the Appalachian Valley, and toward the southeast, in the foothills of the Great Smoky Mountains, it is faulted against the Snowbird group. Southwest of the Great Smoky Mountains, beyond the end of the Snowbird outcrop, the Walden Creek group is in contact with the Great Smoky group, but their relations have not been determined. The Walden Creek group is more heterogeneous and varied than either the Snowbird or Great Smoky; it is dominantly shale and siltstone, but it contains many beds and lenses of sandstone, conglomerate, and carbonate rocks. In the Great Smoky Mountains it is more than 8,000 feet thick (Hamilton, 1961), and its width of outcrop farther southwest suggests a similar thickness. Along the Ocoee River near the south edge of Tennessee the Walden Creek group forms the western 8 miles of the belt of Ocoee outcrop (Sandsuck, Pigeon, Citico, and Wilhite of Hayes, 1895), and its contact with the Great Smoky on the east is sharply marked. The extent of the group in northern Georgia is less certain, but its characteristic rocks have been observed by the writer at several places as far south as Cartersville.

The Great Smoky group occupies a much larger area than either the Snowbird or Walden Creek groups and forms the southeastern part of the outcrop belt of the Ocoee series, terminating a little northeast of the Great Smoky Mountains, beyond the Pigeon River (fig. 13). From the Great Smoky Mountains it forms a belt, generally more than 20 miles wide, that extends into northern Georgia. Throughout its extent the Great Smoky is a remarkably homogeneous body of coarse feldspathic sandstone, in graded beds, with interbedded thin to thick units of dark slate or schist; in Georgia, however, the sandstone beds are finer grained and thinner than farther northeast, and the slate and schist units are thicker. The Great Smoky group is at least 25,000 feet thick in the Great Smoky Mountains (this report), and more than 15,000 feet thick in Georgia (Hurst, 1955, p. 9). In the southeastern part of the Great Smoky Mountains the Great Smoky group lies with sedimentary contact on the Snowbird group, and where that wedges out, unconformably on metamorphic and plutonic basement rocks. It may also lie unconformably on metamorphic and plutonic rocks which form its southeastern border farther southwest (Keith, 1907a). The rocks of the Murphy marble belt, referred to above, are implanted in the belt of outcrop of the Great Smoky group somewhat southeast of its center, and are probably a younger sequence.

The three groups of the Ocoee series are akin, as all lie within the stratigraphic interval between earlier Precambrian basement rocks and Cambrian(?) and Cambrian rocks. They consist, however, of contrasting suites of sedimentary rocks, which occur for the most part in separate belts of outcrop. Original relations of the groups are visible in only a few places, and fail to clarify the startigraphy of the series as a whole, for some of the groups appear to be mutually exclusive. Interpretation of the history of the Ocoee series requires a solution of the puzzle of the interrelations between its groups. A complete solution may never be possible because of the antiquity of the series, and the consequent loss of many of its critical features by deformation and erosion. The nature of the several groups in their present areas of outcrop, and the environments in which they formed, can be deduced with more confidence. These will now be examined, before attempting a reconstruction of the relations and history of the whole Ocoee series.

SEDIMENTARY ENVIRONMENTS OF WALDEN CREEK AREA

Sedimentary rocks of the Walden Creek group more nearly resemble those of later ages in the Valley and Ridge province and continental interior than do those of the rest of the Ocoee series. Like similar younger rocks, they doubtless formed in a subaqueous and a marine environment; but they were probably laid down under less stable conditions than most of these rocks, as attested by extreme alternation and lenticularity of deposits of contrasting composition and texture and by their contained sedimentary structures.

Argillaceous and silty rocks dominate the Walden Creek group, and for the most part consist of alternating thin even laminae of slightly different textures and compositions; in some parts, one set of laminae contains iron-bearing carbonates. Presumably the argillaceous and silty sediments were laid down below wave base in quiet water, which was at least of moderate depth. Their deposition was interrupted from time to time by incursions of other deposits, which form less cotinuous, more irregular rock units.

Most of these other deposits were sands and gravels, which now form units of sandstone and conglomerate, a few feet to more than a thousand feet thick. Many of the units are lenticular along the strike, but several groups of layers or lenses are extensive in the central Great Smoky Mountains in the Shields formation, in the upper part of the lower division of the Wilhite formation, and in the upper part of the Sandsuck formation. Other equally thick but lenticular units of coarse material, at these or other levels, occur elsewhere in the outcrop belt of the Walden Creek group. The original shape of these units would be of much interest, but little three-dimensional data are available, because of structural complications and uncertainties as to startigraphic correlation.

Fragments in the conglomerates are heterogeneous, but fall into two main classes; those of foreign and local derivation. Proportions of the two vary from unit to unit and from bed to bed, but the foreign fragments generally dominate, and in places are overwhelming.

Foreign fragments in the conglomerates are all of physically and chemically resistant rocks, mostly vein quartz, and presumably were the last residue of a terrain, the rest of which had been broken down into finer products by weathering. The nature of this terrain is uncertain. Part of it was probably granitic, as shown by scattered granite pebbles and by a considerable content of potassium feldspar in the sandstone matrix. Part was metamorphic, as shown by the quartzite pebbles, many of which have been tourmalinized by hydrothermal alteration; however, no pebbles of schist or other regionally metamorphosed rocks occur. Prolonged transportation of the fragments from their source, probably by streams, is indicated by their rounding, yet their common diameter of an inch or more is greater than that of most of the other Ocoee sediments. The foreign fragments could have been derived only from an extensive landmass; probably this was toward the northwest, in the continental interior, which the Walden Creek group borders throughout its extent.

Locally derived fragments are slate, calcareous slate and sandstone, quartzite, and limestone, generally of small dimensions, but they include slabs and blocks many feet in diameter, mostly angular rather than rounded. In many conglomerate beds they are sparsely intermingled with the foreign rock fragments, but in others they dominate. The larger fragments ordinarily do not occur singly, but are crowded together in certain layers.

The conglomerate units are probably the product of deposition on unstable submarine shelves (Dapples and others, 1948, p. 1934–1936). Streams from the continental interior supplied well-rounded pebbles of resistant rocks which were built up on shelves along its edge. In parts of these shelves, sandstone, limestone, and other rocks also accumulated. Periodically the shelf deposits slumped or slid into the deeper water where argillaceous and silty sediments were accumulating, producing the lenticular units now interbedded with the latter. These slumps and slides were of small extent and seldom developed into turbid flows, as attested by the dominant scour-and-fill structures in the sandstone and conglomerate layers and by the rarity of graded bedding.

The quartzite, limestone, and dolomite layers of the Walden Creek group are all of local extent on the outcrop; the limestone and dolomite interfinger laterally with argillaceous and silty rocks, and the quartzite with feldspathic sandstone and conglomerate. Quartzite, limestone, and dolomite are closely related in origin, for the quartzite layers contain carbonate fragments, and many of the limestone and dolomite layers contain well-rounded quartz grains. All probably originated as shallow-water shelf deposits, part of which may be preserved in the present outcrops. To a considerable extent, however, they are resedimented deposits like the conglomerate, which have slumped or slid for greater or less distances into deeper water. Many are brecciated, and consist of angular fragments in a matrix of the same material.

SEDIMENTARY ENVIRONMENTS OF SNOWBIRD AREA

All the Snowbird deposits have much in common mineralogically, yet consist of two facies of somewhat different composition and texture, which were probably laid down in different environments.

Coarse deposits dominate in the east. Here, the thin basal deposits represented by the Wading Branch formation were muddy poorly sorted clastic sediments and reworked residual clays, laid on an eroded surface of the earlier granites and gneisses from which they were derived (Goldsmith and Hadley, 1955). In the eastern Great Smoky Mountains, and farther northeast and southeast, the bulk of the succeeding Snowbird deposits, represented by the Longarm quartzite, were quartz-feldspar sands, in which the dominant feldspar is potassic. The quartzite beds are light gray, moderately sorted, crossbedded, and in places ripple marked, in the manner of typical arkoses and subarkoses (Pettijohn, 1957, p. 322–324), and were probably laid down in shallow water.

The Snowbird group, consisting mostly of quartzite of Longarm type and related coarse deposits, thins and wedges out southeastward across the strike and northeastward along the strike, as though overlapping toward the edges of an original basin of deposition.

Southeastward thinning is abrupt, due in part to crustal shortening. Northeastward thinning is more gradual, so that the Snowbird extends well beyond the French Broad River (fig. 13); in this direction, deposits of Longarm type may invade higher parts of the sequence, equivalent to part of the Walden Creek group of the Great Smoky Mountains. Crossbedding in the Longarm quartzite indicates transport of sediments toward the west or west-northwest, and deformation within the layers resulting from penecontemporaneous slumping indicates sediment movement in the same direction; the quartzite contains many minerals like those in the basement granitic rocks now exposed toward the east (Hadley and Goldsmith, 1963). Sedimentary structures and mineral composition thus harmonize with the southeastward and northeastward thinning and overlap of the whole deposit and suggest its derivation from the eastern quadrant.

Fine-grained deposits overlie the coarser part of the Snowbird in the east and also replace it westward by intertonguing, probably away from the edge of the depositional basin. They form the whole of the Snowbird as it is exposed in the report area, where they constitute the Roaring Fork sandstone, the Pigeon siltstone, and a more altered phase, the Metcalf phyllite. Sediments of the three units form a closely related suite, generally darker hued than the Longarm deposits, consisting mainly of silt, variable amounts of clay, and interbedded sand of fine uniform texture. Sandstone layers are most abundant in the Roaring Fork part of the sequence, but these thin out and are less numerous westward (Hadley and Goldsmith, 1963); the siltstone of the Pigeon also becomes finer grained in the same direction (Hamilton, 1961); the end phase on the outcrop is the Metcalf phyllite, whose original sediments contained a greater volume of argillaceous material and less silt and sand than those of the other two units.

Detrital grains in both the sandstone and siltstone of the western facies of the Snowbird are much alike throughout, consisting of quartz and subequal amounts of feldspar—mainly sodic plagioclase rather than potassium feldspart as in the Longarm. On the other hand, minor detrital minerals of the western facies are nearly identical with those of the Longarm, although in greater volume, with dominant epidote, sphene, and magnetite (Hadley and Goldsmith, 1963). Clay, now altered to micaceous minerals, was originally present in both the sandy and silty sediments, but it is important only in the latter. On the basis of mineral composition the sandy sediments would be classed as arkoses and the silty sediments as graywackes; but the latter designation is inappropriate, for the sediments are finer grained and their constituents are differently arranged from those in true graywackes (fig. 14*C*).

The sandstone beds of the fine-grained facies are mostly massive or faintly laminated, are crossbedded in part, but are not graded; at a few places, as in the Longarm, sediments within the layers are deformed by penecontemporaneous slumping. The silty and argillaceous rocks are more conspicuously laminated, being characteristically marked by fine regular laminae, mostly a few millimeters thick, which represent a minute grading from silt below to more argillaceous sediment above. Current-ripple bedding (Kuenen, 1953, p. 1051–1052) occurs at intervals, in places in solitary layers, but mainly in sequences of some thickness. Orientation of these various sedimentary structures is ordinarily difficult to measure, as they are exposed only in single outcrop faces. The few observations which have been made east of the report area on current-ripple bedding in the Roaring Fork and Pigeon indicate current movement to the west and west-southwest, but slump structures in the Roaring Fork sandstone are directed northward (Hadley and Goldsmith, 1963; Hamilton, 1961).

Laminae in the siltstone somewhat resemble varves, but it is not assured whether they are annual deposits or represent some other form of cyclical deposition. They certainly formed in water undisturbed by waves, although general lack of carbon and sulfides suggests that the water was not stagnant. Similarly laminated sediments of about the same texture which form much of the Delaware Mountain group of Permian age in Texas are known to have been deposited in more than a thousand feet of water; these have been attributed to the action of turbidity currents (Hull, 1957, p. 296–298). It is uncertain to what extent the laminated silty deposits of the Snowbird resulted from clouds of sediment settling from the surface or from sediment that traveled along the bottom; at least occasional bottom currents are indicated by the layers with current-ripple bedding.

The great thickness of this body of fine-grained sediments in the western facies of the Snowbird group is truly impressive. Within the report area about 17,000 feet of Roaring Fork sandstone and Pigeon siltstone is exposed and more complete sections just to the east are even thicker (Hadley and Goldsmith, 1963; Hamilton, 1961). It is far from clear how so large a body of silty and fine sandy sediments could have been produced, yet their mineral composition suggests no contribution from an unusual source, such as an area of volcanic activity, but rather from a terrain of plutonic and metamorphic rocks.

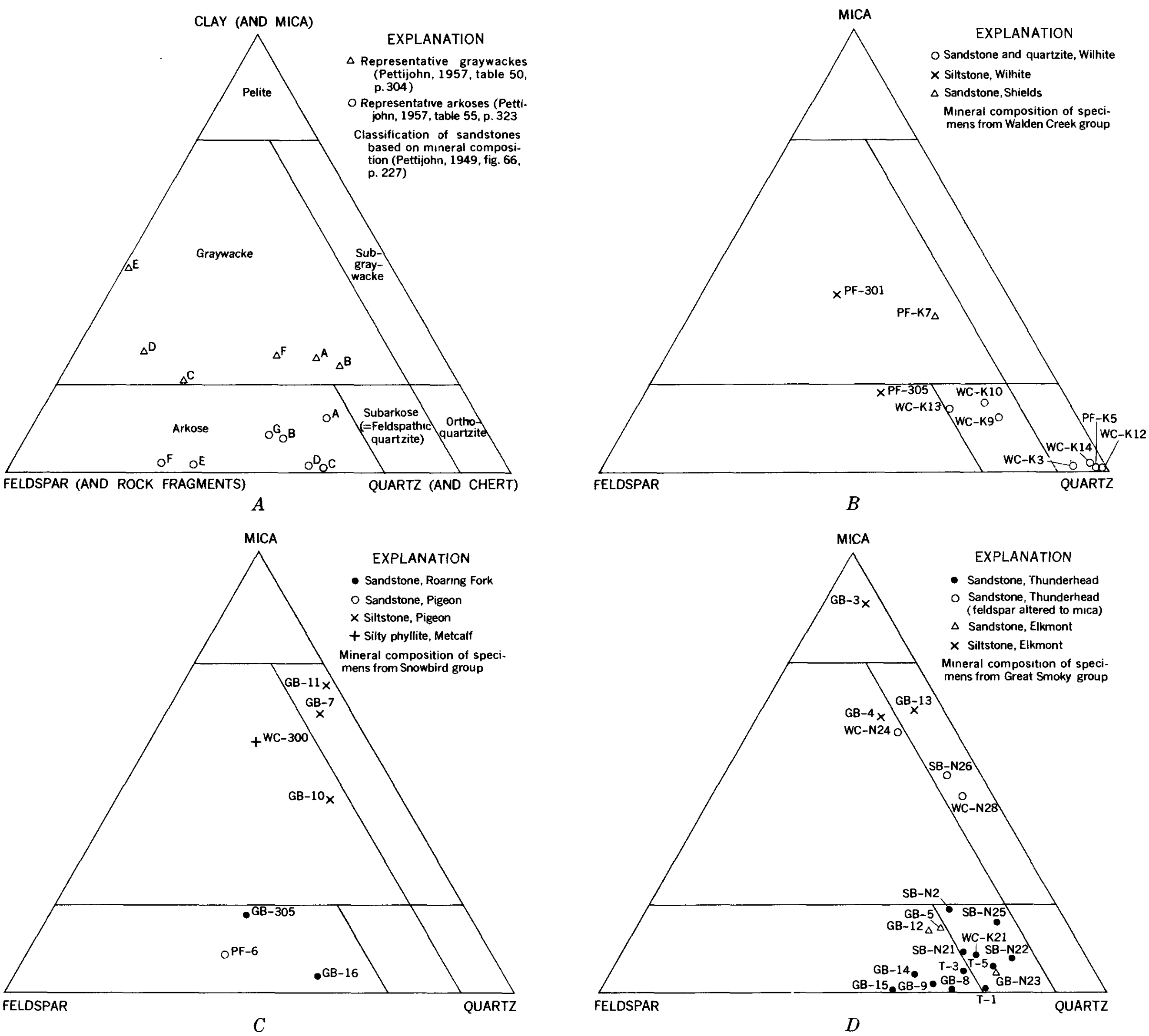

FIGURE 14.—Mineral composition of rocks of Ocoee series, based on thin-section determinations of modes of specimens from central Great Smoky Mountains. The three principal detrital constituents are plotted: quartz, feldspar (potassium feldspar and plagioclase), and micaceous minerals (biotite, muscovite, sericite, and chlorite, mostly altered from original clay). Minor detrital constituents, such as carbonate cement, are omitted. *A*, Classification of sandstones based on mineral composition; positions on diagram of representative arkoses and graywackes are indicated (after Pettijohn, 1949, p. 227; 1957, p. 304, 323). *B*, Specimens of Walden Creek group. *C*, Specimens of Snowbird group. *D*, Specimens of Great Smoky group.

In part at least, the fine-grained Snowbird sediments were derived from the same source area as the coarser Longarm sediments, as shown by similar accessory minerals in the sands, by westward-directed currents implied by various sedimentary structures, and by intertonguing of the two facies. Textural, and even some mineralogic, differences might be accounted for by farther transport of the fine-grained sedimentary fraction from a common source area. However, the great volume of the fine-grained sediments suggests that at least the clays and silts might be a residue from more diverse sources, which was carried into relatively deep water and trapped by rapid subsidence. It is of interest that siltstone of a composition similar to that in the Snowbird forms thick units in the Wilhite formation of the Walden Creek group on the northwest. Age relations between the siltstone of the Walden Creek and that of the Snowbird are uncertain, but the former indicate extensions of silt deposition into an area where it is less plausible to ascribe the same source as that from which the Longarm was derived.

SEDIMENTARY ENVIRONMENTS OF GREAT SMOKY AREA

Great Smoky deposits are of two general facies. Medium to very coarse sandstones and fine conglomerates dominate the sequence from base to top, especially in the Thunderhead and Elkmont sandstones, but in the upper part they are interlayered and interfingered with thin to thick units of dark silty and argillaceous rocks, which characterize the Anakeesta formation (pl. 8).

The sandstones of various parts of the Great Smoky group were described in general terms in earlier reports on the region, and many details of their mineral and chemical composition were given later by Moneymaker (1938), Hurst (1955, p. 9–45), and Carroll, Neuman, and Jaffe (1957); but the most detailed published account of their sedimentary structures is by Mellen (1956), who recorded features in northern Georgia similar to those observed during the present investigation in the Great Smoky Mountains.

As shown by descriptions of the Elkmont and Thunderhead sandstones given on pages 32–35, 38–40 of this report and by descriptions of the Great Smoky group given in reports by other geologists, the sandstones are composed of subequal amounts of quartz and feldspar—potassic feldspar dominating over plagioclase—very small amounts of accessory detrital minerals, and minor amounts of micaceous minerals that were altered from an original argillaceous component. Some of the accessory detrital minerals differ significantly from those of the Snowbird, as the assemblage lacks epidote and sphene and includes abundant tourmaline (Hadley and Goldsmith, 1963). The only foreign rock fragments are scattered small pebbles and grains of leucogranite and quartzite, but chips and slabs of argillaceous rocks, of intraformational source, are common in many beds.

Composition of the sandstones alone would require that they be classed as arkoses or subarkoses (cf. fig. 14*A* and 14*D*), yet they have many of the physical characters of rocks of the graywacke suite (Packham, 1954, p. 470–473; Pettijohn, 1957, p. 615). This duality illustrates the difficulty of applying precise lithologic names to many coarse clastic sedimentary rocks and justifies a use throughout this report of the more inclusive term "sandstone."

Like graywackes, the sandstones of the Great Smoky group are texturally immature sediments, with angular to subangular grains, so poorly sorted that fragments of wide ranges in size lie together. Nearly every bed is graded, and most of them are separated by slate partings (fig. 7); these beds are persistent, so far as it is possible to trace them. The sandstones are, further, of somber aspect—partly from their content of metamorphic biotite, but as much from their original nature, resulting from deposition in a reducing environment (Barrell, 1925, p. 19). Unlike the usual arkoses, subarkoses, and quartzites, the sandstones of the Great Smoky group lack crossbedding, except for current-ripple bedding in the thinnest layers; scour-and-fill structures are rare and lenticular bedding is absent.

Nevertheless, the sandstones differ from graywackes as commonly defined (for example, by Pettijohn, 1957, p. 301–302). Most of them contain much less argillaceous material (represented by the micas) than they do quartz and feldspar (cf. fig. 14*A* and 14*D*). Layers of muddy sandstone and gritty slate which occur in many parts of the Thunderhead and Anakeesta formations do meet the textural specifications of graywacke, but they are subordinate to the other sandstone layers (Hadley and Goldsmith, 1963). All the sandstones lack fragments of metamorphic, cherty, and volcanic rocks which are common in many graywackes, and most of their beds are thicker and coarser grained than graywackes described in other regions.

Reasons for these differences are not far to seek. The sandstones of the Great Smoky group were probably derived from a granitic terrain, rather than one of metamorphic, volcanic, or basic igneous rocks—hence a terrain that would yield dominant monomineralic grains of quartz and feldspar rather than rock fragments. Nevertheless, under proper conditions sediments derived from a wide variety of source rocks will be deposited in the manner of graywackes, and their compositions will differ accordingly (Packam, 1954, p. 471–473; Gilbert, *in* Williams and others, 1955, p. 295). Lack of an argillaceous matrix in the sandstones is a result of their coarse texture; their "matrix" is silt and fine sand, made up of quartz and feldspar rather than clay, and is thus not reflected in the mineral and chemical composition of the rock. Farther southwest, in Georgia, equivalent sandstone beds are thinner, finer grained, and true graywackes, with more than 26 percent argillaceous matrix (Mellen, 1956, p. 49); these beds more nearly resemble the exceptional muddy sandstones and gritty slates of the Great Smoky Mountains. Contrasts between the sandstones in the Great Smoky Mountains and in Georgia probably result from differences in the distance from their common source area; the coarse sands of the former area were not carried so far as the finer sands and clays of the latter.

The sandstones of the Great Smoky group were once supposed to be of continental origin, laid down on piedmont alluvial slopes (Barrell, 1925, p. 12). Similar interpretations have been made for many of the other deposits of the graywacke suite, but modern knowledge indicates a very different origin—in deep marine waters, as a result of transportation by turbidity currents. The sedimentary features of the sandstones of the Great Smoky group previously described, and especially their graded bedding, are now thought to be characteristic products of the action of turbidity currents. It is true that graded beds can be formed by other processes, such as stream deposition and volcanism, but those beds have readily distinguishable features (Kuenen, 1953, p. 1044–1045).

A turbidity current is initiated by slumping or sliding of sediments from shallow water down a steep submarine slope, but once set in motion it travels through otherwise quiet water for great distances along the bottom, on slopes of much lower declivity. When velocity and turbulence of the current are lost, its load becomes a graded layer. Extensive individual layers can thus be spread widely in a matter of days or less, or much more rapidly than the average rate of pelagic sedimentation (Kuenen, 1953, p. 1045–1046); it follows that considerable time intervals must elapse between deposition of the layers. In most of the Great Smoky group, one graded sandstone bed generally overlies another with only the interposition of an argillaceous parting, probably the final residue of the load of the turbidity current which deposited the underlying bed. In the upper part of the Great Smoky group, however, the units of graded beds are separated by thin to thick units of the other sedimentary facies of the group—the dark silty and argillaceous deposits of the Anakeesta formation. These deposits are products of much slower accumulation, by more normal sedimentary processes than the graded beds, and their considerable content of sulfides and carbon suggest that they accumulated on stagnant bottoms (Hadley and Goldsmith, 1963).

Formation of graded beds by the action of turbidity currents is believed to take place in deep water (Packham, 1954, p. 467). Abundant proof of deep-water origin is available for graded beds in younger formations and on the modern ocean bottoms. The graded beds of the Great Smoky group possess the same sedimentary features, and although no independent evidence for their deep-water origin is available, the analogy would seem to require the same origin for them also. Certainly the Great Smoky deposits were laid down in water of much greater depth than any of the Snowbird or Walden Creek deposits.

The deep-water environment of the Great Smoky area developed toward the beginning of the accumulation of the Great Smoky group itself. Its basement consists of plutonic and metamorphic rocks, consolidated during an earlier orogenic cycle, which was undergoing subaerial erosion immediately before Great Smoky deposition. In the southeastern part of the present Great Smoky Mountains the eroded basement was covered first by a thin sheet of Snowbird deposits—basal sediments of the Wading Branch and sands of the Longarm—but even here these are succeeded quickly by characteristic Great Smoky deposits; throughout the rest of the Great Smoky area, wherever their base is visible, Great Smoky deposits appear to have been laid directly on basement. Presumably the Great Smoky area was transformed rather rapidly from an eroded land surface to a deep-water environment by tectonic forces which produced a subsidence so great tht sedimentation could not keep pace with it.

The general uniformity of composition of the sands of the Great Smoky group throughout their extent implies derivation from a terrain of nearly homogeneous source rocks, probably granitic. Only exceptions are scattered grains or pebbles in the sands, and cobbles in the coarser beds, which consist of quartzite derived from rocks laid down during some earlier sedimentary cycle of a very different kind. Those fragments of the original granitic rocks which are preserved intact are leucogranite, formed mostly of quartz and feldspar. The rest of the parent rock has been disaggregated into grains and pebbles which form the overwhelming bulk of the sands. They rarely exceed a common maximum diameter—in most beds an ⅛ or ¼ of an inch, in a few ½ inch or more—which were probably grains or crystals in the source rock, weathered by granular disintegration.

Evidence is conflicting as to the degree of maturity attained by the sedimentary materials during their initial stages of weathering and transportation. As their final transportation to the site of deposition was by turbidity currents, "theoretically the detritus could have reached any stage of textural and chemical maturity before redeposition" (Packham, 1954, p. 469). Clearly, large volumes of relatively homogeneous material were made available rapidly for transportation by these currents, but this implies merely high relief and tectonic instability in the source area, rather than any specific weathering or climatic conditions (Pettijohn, 1957, p. 314). The large feldspar content of the sands suggests a lack of chemical decay during weathering and of mechanical attrition during early stages of transportation. Nevertheless, the assemblage of accessory detrital minerals is relatively simple (Carroll and others, 1957, p. 191); this might have been due to an original mineral simplicity in the source rock, although it suggests the possibility that the sedimentary materials underwent mineral loss during a rather prolonged period before their transportation by the turbidity currents.

The gross uniformity of the Great Smoky deposits through great thicknesses and over wide areas makes it difficult to determine the direction of their source. Differences in texture from place to place are relatively slight within dimensions as small as those of the present report area, but they become more apparent when the whole outcrop area of the group is considered, in the Great Smoky Mountains and elsewhere.

Within the Great Smoky Mountains the Thunderhead sandstone coarsens eastward and northward across the outcrop. This coarsening is indicated on a small scale by textural changes in the formation along Cove Mountain (this report) and on a larger scale farther east, where the coarsest sandstones occur in the northeasternmost exposures, and by finer grained sandstone and thicker interbedded slate and siltstone to the south and west (Hadley and Goldsmith, 1963). Similar relations are suggested, in part, by the shapes of the dominantly argillaceous and silty Anakeesta deposits, which intertongue with the dominantly sandy Thunderhead deposits northeastward along the mountains, both in the report area and to the east; nevertheless, many of the outlying lenses of Anakeesta material have no apparent systematic arangement. Textural variations in the Great Smoky group also occur over a wider area. Southwest of the Great Smoky Mountains, in northern Georgia, pebbly layers are exceptional, sandstone beds are thinner, contain a greater clay fraction, and are interbedded with thicker argillaceous layers (Mellen, 1956, p. 49). In Georgia the Great Smoky group also contains two very thick units like the Anakeesta formation—the Hughes Gap and Dean formations (Hurst, 1955, p. 21–45).

These textural changes suggest derivation of the Great Smoky sediments from the northeast and their transportation southwestward. In most places this is difficult to confirm from sedimentary structures in the rocks; bedding-plane surfaces which might possess flow or current markings are seldom exposed, or if exposed, have been so modified by deformation and metamorphism that any such markings have been destroyed. Neuman reports that he has observed furrows at the bases of sandstone beds of the Great Smoky group at five localities in the Great Smoky Mountains; all trend northwestward and taper southeastward, suggesting current movement toward the northwest (R. B. Neuman, written communication, 1958). In northern Georgia, measurements on many current-rippled beds indicate a current movement toward the southwest (Mellen, 1956, p. 57, 61). These observations are clearly too scanty to afford a basis for generalization on the whole Great Smoky group.

The source area of the Great Smoky sediments, whether to the northeast or otherwise, has not been specifically identified. The mineralogy of the Great Smoky sediments does not closely resemble that of nearby outcrops of basement rocks, in the manner of the Snowbird sediments (Carroll and others, 1957, p. 186; Hadley and Goldsmith, 1963). Nevertheless, the age range of determinations of detrital zircons from the Great Smoky group broadly resembles that of determinations on basement rocks of the Blue Ridge province (p. 70–71), suggesting their derivation from somewhere in the general region—perhaps well to the northeast or north, where plutonic rocks are known to dominate over the gneisses and schists.

GENERAL INTERPRETATION OF OCOEE SERIES

Three contrasting suites of deposits have been discused, representing the three groups of the Ocoee series, which formed in different sedimentary environments. In part, these contrasting deposits lie in sequence, but to a larger extent they are preserved in separate fault blocks, and have been brought into juxtaposition by thrusting of undetermined magnitude. They are, therefore, merely fragments of the original Ocoee deposits, and show only incompletely the nature of its original basin of deposition.

Because of the fragmentary preservation of the different parts of the Ocoee series, not all the relations between them are readily explainable. Thus, although the Snowbird group lies stratigraphically below the Great Smoky group in the southeastern part of the Great Smoky Mountains, it is very thin here and wedges out completely nearby; whereas it is more than 17,000 feet thick elsewhere, where it is not in sequence with the Great Smoky group. Moreover, both the Great Smoky group and the Walden Creek group form the top of the Ocoee series in their respective areas. They are followed by strata which are probably correlative; hence, they themselves may be partly correlative also.

These and other puzzles might be explained by assuming a separation of two or more of the groups by unconformities or by assuming abrupt shifts with time of the locus of maximum subsidence from one part of the Ocoee area to another, but such concepts seem implausible to the writer. A more likely clue to a solution of the puzzles is afforded by relations between the formations of the Ocoee series. By tracing along the outcrop, most of these subdivisions can be proved to intertongue or to intergrade with their neighbors. What is true for the lesser units of the Ocoee series may also be true for the greater; the problem is not whether the groups of the Ocoee series are equivalent to each other, but the extent of their equivalence. The contrasting deposits in the groups of the Ocoee series are thus probably features of different parts of a single Ocoee basin of sedimentation, rather than features of several unrelated basins.

Extremes of sedimentary environments in the deposits of the Ocoee series are expressed by the Walden Creek and Great Smoky groups. The Walden Creek was apparently laid down on or near an unstable shelf fringing the continental interior, which lay to the northwest, from which most of its sediments were derived. The Great Smoky was apparently laid down farther away from the continent, in much deeper water, by the action of turbidity currents which brought in sediments from a distant source, perhaps toward the northeast. Great Smoky deposits perhaps accumulated in a submarine trough along the edge of the continent, produced by tectonic forces. The northwestern edge of the trough must have been limited by the Walden Creek area; its southeastern edge is undefined and there is no convincing evidence in the Ocoee deposits themselves of any lands to the southeast; this side might have been merely open ocean. Great Smoky sediments could, then, have been derived from the continent like those of the Walden Creek, but from an area farther northeast, and the submarine trough might have been filled from its northeastern end, rather than from the sides. Accumulating evidence from other regions indicates that such longitudinal filling of submarine troughs is rather common (Kuenen, 1957).

In the southwestern part of the outcrop belt of the Ocoee series, where the Walden Creek and Great Smoky groups are alone present, the problem is thus between two groups of deposits laid down in contrasting environments. If the two groups are contemporaneous, the contrasts between them are explainable in terms of the different depths of water in which each accumulated, the different means of transport by which they arrived at their destinations, and the different sources from which they were derived.

The problem is complicated farther northeast by the geographical interposition of the Snowbird group between the Walden Creek and Great Smoky groups. The sands of the coarse eastern facies of the Snowbird were derived from the eastern quadrant, from an obvious source in basement rocks exposed in that direction, hence from a source different from that of either the Walden Creek or Great Smoky groups. The Snowbird is a basal deposit, at least part of which is older than either the Walden Creek or the Great Smoky, yet it attains its greatest thickness where neither of these groups overlie it.

In the southeastern part of the Great Smoky Mountains the Snowbird group, lying between basement rocks and Great Smoky group, is far thinner than in its type area farther northwest. This thinning might be toward the southeastern margins of its basin of subsidence, as a result of overlap; such overlap is suggested by southeastward thinning of formations and replacement of fine-grained by coarse-grained sediments along the outcrop of the Snowbird in the eastern Great Smoky Mountains (Hadley and Goldsmith, 1963). Moreover, the Great Smoky deposits which overlie the Snowbird were derived from more distant, probably northeastward sources; hence they must have traveled across the Snowbird area to reach their destinations.

Nevertheless, the rocks of the Great Smoky group which overlie the Snowbird in this southeastern area were laid down in the same marine trough as the rest of the group. If the southeastward overlap of the rocks of the Snowbird group is valid, the locus of maximum subsidence was shifted southeastward between Snowbird and Great Smoky time. An alternative possibility is that both Snowbird and Great Smoky were laid down in a single subsiding basin. At first, this basin was covered widely by sediments of Snowbird type, but to the southeast these gave way quickly to sediments of Great Smoky type, because of excessive subsidence in that area. Farther northwest, where subsidence was less, deposition of sediments of Snowbird type continued longer.

Such an assumption would imply an intergradation between the Great Smoky group on the southeast with the Snowbird group on the northwest, where it attains its maximum thickness. The original relations in this direction between the two groups are difficult to prove. The lithologic discontinuity between them was a zone of weakness which was utilized by the Greenbrier thrust, movement along which has destroyed so many beds that the nature of the original contact can no longer be determined. However, the Rich Butt sandstone, which overlies the Snowbird and is preserved in places beneath the thrust, has features in common with both the Great Smoky and the Snowbird (Hadley and Goldsmith, 1963). Its sandstones resemble those of the Elkmont sandstone of the Great Smoky group on the southeast, and its siltstones resemble the dark-pigmented laminated siltstones in the upper part of the Pigeon siltstone of the Snowbird group on the northwest. The Rich Butt might be a fragment of originally more extensive intergrading and intertonguing beds, intervening between the Great Smoky and the Snowbird, which elsewhere have been lost by movements along the Greenbrier fault.

The Snowbird group may, in turn, be partly equivalent to the Walden Creek group farther northeast and northwest. The possibility has already been noted (p. 64) that rocks of the coarse-grained eastern facies of the Snowbird may replace equivalents of the Walden Creek group northeast of the Great Smoky Mountains. Moreover, the fine-grained upper siltstones of the Snowbird might intertongue northwestward with the lower part of the Walden Creek group, which also contains thick units of siltstone.

In the segment represented by the central Great Smoky Mountains, in later Ocoee time, there may thus have been a sequence southeastward, away from the continent, from varied Walden Creek deposits, laid down on or near the edge of an unstable shelf, into the less varied fine-grained deposits of the western facies of the Snowbird, laid down in somewhat deeper waters, and thence into the sandstones of the Great Smoky group, laid down in much deeper waters in a submarine trough and derived from distant sources by turbidity currents. Northeastward along the strike this picture is confused by the setting in of coarser shallower water deposits of the eastern facies of the Snowbird, derived from local sources nearby. Southwestward along the strike, the picture simplifies, owing to disapparence of the Snowbird, so that the Walden Creek and Great Smoky alone crop out at the surface. The simplification may be due to failure of the Snowbird to project to the surface, but it might well be that the fine-grained western Snowbird deposits have become indistinguishable in that direction from those of the Walden Creek.

AGE OF OCOEE SERIES

The age and relations of the Ocoee series have been variously interpreted and much debated, ever since it was first described by Safford a century ago (1856, p. 151–152). It has been interpreted as lying at the base of the sedimenetary column (Safford, 1869, p. 158; Keith, 1904; Stose, G. W., and Stose, A. J., 1944, p. 416); as lying well above the base of the column, and a southeastern facies of the normal Paleozoic rocks of the Valley and Ridge province (Willis, *in* Walcott, 1891, p. 299–300; Lombard, 1948, p. 720); as wholly allochthonous, hence without proven relations to Paleozoic rocks (Stose, G. W., and Stose, A. J., 1944, p. 380–386; Lombard, 1948, p. 720); and as composite, consisting of several unrelated sequences of different ages (Jonas, 1932, p. 240-241; Crickmay, 1936, p. 1391; Stose and Stose, 1949, p. 269). In terms of formal age assignment, the Ocoee has therefore been classed variously as Precambrian; as occuping a sort of "twilight zone" between Precambrian and Cambrian, hence either Precambrian(?), Cambrian or Precambrian, or Cambrian(?); as Cambrian, and partly equivalent to fossiliferous Cambrian elsewhere; as Ordovician or younger; and as partly Precambrian and partly Cambrian or Ordovician. (For further details, see King, 1949, p. 622–623.)

Many of these interpretations were based on misapprehensions as to the structure of the Ocoee series—the earlier ones from lack of recognition of the great faults and thrust sheets of the region, some of the later ones from postulation of faults and thrust sheets which do not exist. The notion that the Ocoee series is a southeastern facies of the younger Paleozoic rocks has appealed to many geologists, especially because facies changes take place across the strike in Paleozoic rocks farther northeast in the Appalachians, but it cannot be justified by the field relations. Relations as observed during modern field investigations in the Great Smoky Mountains and elsewhere confirm the view, expressed by some of the earlier geologists, that the Ocoee series lies at the base of the sedimentary column, is older than the Paleozoic rocks, and is of Precambrian age.

As the Ocoee series contains no known fossils, its age must be determined primarily by its relations to other rocks. As indicated above (p. 59), the Walden Creek group of the Ocoee series is overlain by the Chilhowee group, with a change in sedimentation from one to the other, and perhaps with an intervening disconformity. As indicated below (p. 76–77), the Chilhowee group itself contains Early Cambrian fossils only in its upper half and is therefore properly classed as of Cambrian(?) and Cambrian age. The Walden Creek group beneath it can therefore be none other than of Precambrian age. The rest of the Ocoee series to the southeast is not in sequence with the fossiliferous rocks, but would seem to fall into the same category. As indicated below (p. 75–76), the formations which overlie the Great Smoky group in the Murphy marble belt are probably equivalent to the Chilhowee group and younger units farther northeast.

The Ocoee series is, on the other hand, younger than other Precambrian rocks—the Carolina and Roan gneisses of former usage and the Max Patch granite and Cranberry gneiss—which constitute a metamorphic and plutonic basement that lies unconformably beneath the Snowbird and Great Smoky groups.

Relations of the Ocoee series to rocks above and below indicate relative ages, which cannot be translated into absolute dates. Eventually, absolute dates may perhaps be afforded by radiometric determinations. Available determinations on the basement rocks near the Great Smoky Mountains indicate ages of 350 to 880 million years (Carr and Kulp, 1957, p. 782; Hadley and Goldsmith, 1963), and on detrital zircon grains from the Great Smoky group ages of 600 to 1,100 million years (Carroll and others, 1957, p. 186–188).[5] Presumably, the apparent ages which have been determined on both the basement rocks and the detrital grains are products of plutonism or metamorphism of the former, the earlier being before the deposition of the Ocoee series. However, the specific dates require verification. It is now believed that apparent ages between 350 and 1,100 million years in the southern Appalachian region are the variable products of superposition of one metamorphism at about the time of the latest recorded age on another metamorphism at about the time of the earliest recorded age; apparent intermediate ages thus have little meaning. Presumably the Ocoee series was deposited at some time between the earliest and latest recorded ages, but these ages are so far apart in time that they give little indication as to the age of the Ocoee series.

CHILHOWEE GROUP (CAMBRIAN(?) AND CAMBRIAN)[6]

GENERAL FEATURES

DEFINITION

The Chilhowee group is derived from the "Chilhowee sandstone" of Safford (1856, p. 152–153; 1869, p. 198–203), named for Chilhowee Mountain, the ridge intervening between the foothills of the Great Smoky Mountains and the Appalachian Valley (fig. 2). Later geologists have followed Safford in applying the name to the clastic rocks at the base of the Paleozoic column, both here and elsewhere in east Tennessee, and have extended it at well to strata farther northeast and southwest.

The base of the Chilhowee group was at first not clearly defined. Safford (1869, p. 190) indicated that Ocoee as well as Chilhowee was exposed on the northwest face of Chilhowee Mountain, but it is not clear from his description what beds were placed in each. In the Knoxville report Keith (1895a) included the Sandsuck shale in the Cambrian, hence by implication in the Chilhowee, but the base of the group was later placed by the U.S. Geological Survey at the base of the Cochran formation.

SUBDIVISIONS

The "Chilhowee sandstone" of Chilhowee Mountain was divided by Keith (1895a) into six formations (including the Sandsuck at the base), on the basis of interbedding of the sandstones with shaly units. Names of two of the formations of the present Chilhowee group, the Murray and Nichols, are based on localities within the present report area; the rest are based on localities farther southwest in Chilhowee Mountain.

When Keith (1903, 1907b) extended his mapping of the group into northeastern Tennessee he there substituted a new set of formation names, partly because of fading out of one of the shale layers. Later work indicates that in part of that area it is still possible to recognize the units of the Chilhowee Mountain area as members (King and Ferguson, 1960). It is equally feasible, moreover, to recognize one of the members established in northeastern Tennessee, the Helenmode, in the section on Chilhowee Mountain.

Table 18 shows the relation of terminology of the Chilhowee group of Chilhowee Mountain to that of northeastern Tennessee, and is included to explain references in the text to units outside the report area.

TABLE 18.—*Terminology of Chilhowee group of Chilhowee Mountain and of northeastern Tennessee*

Chilhowee Mountain	*Northeastern Tennessee*
Shady dolomite overlies Chilhowee group in both sections	
Chilhowee group: Helenmode formation Hesse sandstone Murray shale Nebo sandstone	Chilhowee group: Erwin formation: Helenmode member Hesse quartzite member Murray shale member Nebo quartzite member
Nichols shale	Hampton formation
Cochran formation	Unicoi formation
Disconformity(?)	Unconformity

COCHRAN FORMATION

The Cochran conglomerate was named by Keith (1895a) for Cochran Creek in the southwestern part of Chilhowee Mountain (Tallassee quadrangle). Its occurrence there has been described by Neuman and Nelson (1964), and they have designated a type section at Chilogatee Gap, northwest of the head of Cochran Creek. Keith originally described the Cochran as comprising an underlying conglomerate and an overlying white sandstone, separated by a thin unit of red sandstone and gray sandy shale. As the Cochran is heterogeneous, and as at least part of the lower conglomerate is more closely related to the Sandsuck, it is more appropriate to use the term Cochran formation.

Correlation of the top of the Cochran in the report area with that at the type locality seems assured, but there is more uncertaintly as to precise correlation of beds below the top. The sequence below the top differs somewhat in the two areas, and outcrops are not con-

[5] Redeterminations on these grains by improved spectrochemical methods indicates a minimum age of 820 million years, rather than the smaller figure given here. See Stern. T.W. and Rose, H. J., Jr., 1961, New results from lead-alpha measurements: Am. Mineralogist, v. 46, table 3. p. 609.

[6] Based on observations of H. W. Ferguson and G. D. Swingle with minor additions by King.

tinuous between them. The base of the formation as here designated is thus at a level which appears most appropriate within the report area, and may or may not correspond to the base at the type section, as designated by Neuman and Nelson.

The Cochran formation is 1,000 to 1,250 feet thick in the report area. It is the most resistant to erosion of the formations of the Chilhowee group, and forms a steep cliff or rimrock around the northeast and east sides of Chilhowee Mountain, locally known as Bluff Mountain (Walden Creek quadrangle).

The lower half of the formation on the sides of Chilhowee Mountain is largely maroon, crossbedded, finely pebbly arkose, with streaks and layers of maroon shale and siltstone, in part micaceous. Some of the crossbedded laminae contain dark hematite grains. In places, maroon beds lie directly on shale and conglomerate of the Sandsuck formation, but in other places a basal layer of light gray vitreous arkose a few feet thick intervenes. Beds with these lithologic features persist for long distances along the face of the mountain, and can be recognized in successive exposures. About midway in the formation layers of light-gray vitreous arkose alternate with the maroon beds and increase in number and thickness upward, constituting a transition into the upper half of the unit.

The upper half of the formation is light-gray, white, or faintly pinkish vitreous arkose and quartzite, containing coarse sand grains and a few granules or pebbles. In this half, feldspar grains fade out upward, so that the highest part is nearly pure quartzite. The top 40 or 50 feet consists of particularly massive quartzose layers which cap the rimrock and form broad dip slopes that extend toward the Nichols shale in the interior of Chilhowee Mountain.

On the southeast side of the main ridge of Chilhowee Mountain the upper unit of the Cochran reappears in steeply tilted ledges, part of which are the southeast flank of the Chilhowee Mountain syncline and part are slices or wedges along the Bogle Spring fault.

Between the Bogle Spring and Miller Cove faults farther southeast, broad areas were mapped as Cochran by Keith (1895a). Here, most of the rock is conglomerate, now classed as part of the Sandsuck formation, but in places the conglomerate is overlain by remnants of maroon shale and arkose, and by light-gray arkosic quartzite, evidently belonging to the basal unit of the Cochran as here restricted.

The solid, massive quartzites of the Cochran formation are overlain abruptly by the Nichols shale, but the contact is probably conformable.

NICHOLS SHALE

The Nichols shale is named for Nichols Branch of Walden Creek (Keith, 1895a), within the report area. The type locality lies west of the head of Nichols Branch, up the slope toward Greentop.

In the report area, the Nichols shale crops out almost continuously near the crest of Chilhowee Mountain, except for a gap of less than a mile near Doyle Springs (Walden Creek quadrangle). Estimates at several places indicate that the formation is about 700 feet thick. Through most of its extent the formation is represented at the surface by float of brown-weathered shale chips. The few exposures along stream channels consist of olive-gray or olive-green shale, formed of silty or finely sandy laminae a few millimeters thick, interbedded with argillaceous laminae of about equal thickness; bedding surfaces are commonly strewn with flakes of detrital mica.

Near the northeast end of Chilhowee Mountain, southeast of Greentop, the shale contains two interbedded layers, as much as 30 feet thick, of white fine-grained medium-bedded quartzite, the lower being slightly feldspathic and the upper more quartzose and containing *Scolithus.* These are probably related to the quartzites and arkoses characteristic of the lower part of the Hampton farther northeast in Tennessee (King and others, 1944, p. 36).

The Nichols shale is overlain conformably but with abrupt contact by the Nebo sandstone, although, as noted above, the Nichols contains some interbedded quartzite layers which foreshadow Nebo sedimentation.

NEBO SANDSTONE

The Nebo sandstone was named for Mount Nebo Springs (Keith, 1895a) west of the report area, the type locality being at Mount Nebo on the crest of the mountains above the springs (Kinzel Springs quadrangle).

In the northeastern segment of Chilhowee Mountain the Nebo sandstone forms the two areas of outcrop, one around Bench Mountain from Greentop southwest to The Wolfhook, the other farther southwest on the rim of a syncline that plunges southwestward toward Miller Cove (Walden Creek quadrangle). Smaller bodies of Nebo may occur among the quartzite slices along the Bogle Spring fault, and possibly also along the Great Smoky fault.

The Nebo near Bench Mountain is about 250 feet thick, and forms prominent ledges that project as an intermediate step between the rimrock of the Cochran formation below and the cap of Bench Mountain formed by Hesse sandstone above. Slopes of Nichols shale below the Nebo ledges are widely strewn by quartzite float and talus. Talus of one area, along

Compton Branch, has been quarried for building stone for local use, the bedding and the *Scolithus* tubes normal to it permitting the sandstone to be shaped into cubes and rectangular blocks.

The Nebo is a white vitreous quartzite made up of fine quartz grains, and forms even beds a few inches thick that weather into sharp-angled slabs. Most of the layers are crowded with *Scolithus* tubes, but some are crossbedded. A few feldspar grains are present in the lower part and stand out prominently on weathered surfaces.

The Nebo sandstone is succeeded abruptly and conformably by the Murray shale.

MURRAY SHALE

The Murray shale was named for "Murray Branch of Walden Creek" (Keith, 1895a). The name was, however, not marked on the accompanying map of the Knoxville quadrangle, nor does it appear on modern maps, so that it can only be identified by interference. The only branch of Walden Creek which crosses the outcrop of the shale is now marked as Compton Branch; the type locality of the Murry is therefore presumably on the northwest slope of Bench Mountain near the head of Compton Branch. The shale is poorly exposed in this area, but better outcrops occur elsewhere in Chilhowee Mountain, as at Murray Gap (Blockhouse quadrangle) farther to the southwest.

In the report area the Murray shale occurs on the slopes surrounding Bench Mountain (Walden Creek quadrangle) in the southeastern part of Chilhowee Mountain. On the northwest slope of Bench Mountain the Murray is about 500 feet thick, but it thins to 100 feet on the southeast side, apparently as a result of tectonic complications.

Within the area the Murray is poorly exposed and is mainly represented at the surface by float of shale chips. A few exposures on Compton Branch and elsewhere show that it consists of argillaceous to silty laminated dull-green shale, with some detrital mica, very similar to the Nichols shale beneath.

The Murray is conformable with the overlying and underlying Hesse and Nebo sandstones, but it lacks any interbedded sandstone layers like those adjacent and forms a well-defined interval.

HESSE SANDSTONE

The Hesse sandstone was named for exposures on the upper course of Hesse Creek (Keith, 1895a), a stream which enters the Little River from the southwest in Miller Cove (Kinzel Springs quadrangle).

In the report area, the Hesse sandstone caps Bench Mountain (Walden Creek quadrangle). It also occurs in the large slice along the Bogle Spring fault to the southeast, where it forms the second broad ridge southwest of Compton Branch and a narrower belt southeast of Compton Branch.

On Bench Mountain, 100 to 200 feet of Hesse sandstone is preserved, which is probably close to the whole thickness of the unit, although the overlying Helemode formation has been removed. In the slice to the southeast the whole formation probably occurs between the Helenmode formation and Murry shale; but the rocks are poorly exposed and the strata overturned, so that the thickness cannot be determined.

On Bench Mountain the Hesse is a white quartzite made up of medium to coarse rounded quartz grains, some of which appear to be frosted. It forms massive ledges 10 feet or more thick, which break off in castellated crags and rounded boulders, characteristically pitted by cavities half an inch or less across that were formed by removal of some soluble cementing material. Some layers and lenses in the sandstone are also less cemented than the rest and weather crumbly or friable. The Hesse in the slice to the southeast is similar, but float blocks are more prominent than ledges.

The massive ledges of the Hesse on Bench Mountain differ greatly from the more slabby outcrops of the Nebo sandstone lower in the section. In this area, moreover, the Hesse lacks the *Scolithus* tubes that are abundant in the Nebo, although *Scolithus* occurs in the Hesse farther southwest in Chilhowee Mountain.

The Hesse sandstone is overlain conformably by the Helenmode formation.

HELENMODE FORMATION

The Helenmode member of the Erwin formation was named for the Helenmode mine, Carter County (King and others, 1944, p. 31). The Helenmode also forms a well-marked persistent unit in the Chilhowee Mountain area, although in early work there Keith (1895a) either grouped it with the Hesse sandstone or mistakenly identified it as Murray shale. In Chilhowee Mountain, beds equivalent to the Erwin formation of northeastern Tennessee, of which the Helenmode is a member, consists of several well-marked units considered to be of formation rank. It is therefore appropriate here to class the Helenmode as a separate formation of the same rank as the other units.

In Miller Cove, west of the report area (Kinzel Spring quadrangle), the Helenmode formation lies in sequence between the Hesse sandstone and Shady dolomite, and is about 200 feet thick.

In the report area itself both the Helenmode and Shady occur out of sequence, being preserved only in

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the large slice along the Bogle Spring fault southeast of Bench Mountain (Walden Creek quadrangle); the Helenmode formation forms the south and southeast sides of the slice, bordering on, and dipping away from, the Shady dolomite. West of the first valley southwest of Compton Branch, and eastwyard along Compton Branch, are small outcrops of dark greenish-gray micaceous shale, with interbedded 2-foot layers of coarse sandstone cemented by dolomite; the sandstone layers give rise to numerous blocky masses in the float.

Within the report area exposures are not sufficient to indicate the relations between the Helenmode formation and the Shady dolomite, but in nearby areas the two are conformable.

SLICES OF CHILHOWEE GROUP ALONG GREAT SMOKY FAULT

The Chilhowee group not only forms the cap of Chilhowee Mountain, but its sandstones and quartzites occur in numerous wedges or slices along the Great Smoky fault. Although the rocks of the slices are not in stratigraphic sequence, most of them have the lithologic character of the Cochran formation; for convenience all have been so mapped, although small bodies of Nebo and Hesse sandstones may also occur.

The largest and most prominent slices extend 4½ miles along the foot of Chilhowee Mountain near its northeast end and project as the prominent knobs of Sugarloaf, Little Pine, and Big Pine Mountains (Walden Creek quadrangle). Sugarloaf Mountain preserves nearly the entire section of the Cochran, dipping southeast, but inverted so that lower maroon arkose forms the southeast slope and upper thick-bedded gray quartzite the northwest slope; the latter is much brecciated, jointed, and veined. Knobs to the southwest all consist of the lower part of the Cochran, a fine- to coarse-grained arkose, mostly maroon or red, with some interbedded maroon shale. Near the South Fork of Ellijoy Creek, conglomerate of the uppermost part of the Sandsuck formation is preserved in the slice.

East of the end of Chilhowee Mountain smaller and less continuous slices of the Chilhowee group appear in places along the Great Smoky fault, forming Jackson Knob west of Guess Creek, Davids Knob southeast of Sevierville, and many smaller unnamed hills (Pigeon Forge quadrangle). These knobs and hills consist mostly of white or light-gray quartzite of varied texture, in part feldspathic, generally of the aspect of the middle or upper part of the Cochran. On some of the hills, presence of a Chilhowee slice is indicated only by loose quartzite boulders; on others, actual outcrops occur, but the quartzite is so broken and jointed that bedding and structure are scarcely discernible.

Small slices of quartzite of the Chilhowee group are also preserved along the Great Smoky fault on the southeast side of Wear Cove (Wear Cove quadrangle). One, on the west slope of Buckeye Knob near the meridian between the Gatlinburg and Wear Cove quadrangles, includes quartzite with traces of *Scolithus*, suggesting that it may be Nebo sandstone, but another farther west is made up of feldspathic sandstone and probably belongs to the Cochran formation. Much of the quartzite of these slices has been reconstituted internally, probably by cataclasis during thrusting, and is much brecciated and veined.

PROBLEMS OF CHILHOWEE GROUP

REGIONAL RELATIONS

The Chilhowee group is recognizable throughout eastern Tennessee and western Virginia; its equivalents extend southwestward into Alabama and northeastward beyond Pennsylvania for a total distance of more than 1,000 miles (King, 1949, 1952; Rodgers, 1956). Throughout this distance it is exposed along the northwest edge of the Blue Ridge and Unaka provinces, except where interrupted by faulting, its outcrop generally lying along their boundary with the Valley and Ridge province (fig. 13). Southeastward, where Precambrian rocks older than the Chilhowee group came to the surface, it has largely been removed by erosion; northwestward it passes beneath Cambrian and younger carbonate rocks.

The Chilhowee group on Chilhowee Mountain is about 3,100 feet thick. The group and its equivalents are of similar thickness in Alabama, northern Virginia, and Maryland, but they are as much as 7,500 feet thick in northeastern Tennessee; they are much thinner in most of Pennsylvania and New Jersey. So far as can be determined from the internal stratigraphy of the Chilhowee these variations are shared to some extent by all its formations, although greatest irregularities in thickness seem to be in the lower part of the group.

The Chilhowee group and its equivalents are divided, depending on locality, into various sets of formations, but the sequence is actually remarkably similar in all places. The lower half (like the Cochran on Chilhowee Mountain) is more coarsely clastic and poorly sorted than the upper half; conglomerate occurs in the lower part and arkosic or feldspathic sandstone is present throughout, but it becomes more quartzose toward the upper part. Red layers like those in the lower part of the Cochran are common elsewhere in Tennessee; in northeastern Tennessee and in Virginia minor basalt flows and tuffaceous rocks are interbedded at one or more levels. The upper half of the group consists of interbedded units of silty shale (like the Nichols and Murray of Chilhowee Mountain) and of relatively pure quartzose sandstone or quartzite (like the Nebo and Hesse), the latter dominating upward. In places, the mixed clastic rocks of the lower half are followed abruptly by the shale of the upper half (as at the contact between the Cochran and Nichols); in others, the lower part of the shale contains much interbedded feldspathic sandstone. Between the quartzite at the top of the group and the succeeding Cambrian carbonate rocks (Shady and equivalents) is generally a small thickness of more varied clastic strata (like the Helenmode)—sandstone and shale, in part calcareous, ferruginous, or glauconitic.

The Chilhowee group and its equivalents have a somewhat variable relation to the rocks beneath. Along considerable segments of outcrop they lie on different sorts of stratified rocks of Precambrian age—in Chilhowee Mountain on the Walden Creek group of the Ocoee series, in Alabama on part of the Talladega slate, and in much of Virginia, Maryland, and Pennsylvania on the Catoctin greenstone and other volcanic rocks. In places, as on Chilhowee Mountain and in northern Virginia (King, 1950a, p. 13–14), the two sets of strata appear to be disconformable. Elsewhere, transitional phases have been reported, and the reality of a significant break between the Chilhowee group and the beds beneath is doubted by some geologists (Bloomer and Werner, 1955, p. 598–599; Rogers, 1956, p. 405–06). In some extensive segments of outcrop, however, from northeastern Tennessee into Virginia and beyond, the Chilhowee is the basal deposit and lies on deeply eroded Precambrain plutonic and metamorphic rocks.

Within the Chilhowee group and its equivalents no break in sedimentation is known; all parts of the group are clearly conformable and gradational. The group is also conformable with the succeeding carbonate rocks (Shady and equivalents), although the boundary between them is sharply marked at all places. It may represent a time-stratigraphic horizon; but there is a possibility, as yet unverified, that it transgresses time lines, and that clastic rocks in one area are equivalent to carbonate rocks in another.

EQUIVALENTS OF CHILHOWEE GROUP TO SOUTHEAST

The generalizations of the Chilhowee group and its equivalents, given above, are based on a great length of outcrop, but they indicate mostly the nature of these rocks parallel to the strike of the Appalachian structures, and probably parallel to the axis of the geosyncline in which the sediments formed. Very little is known of the stratigraphy of the Chilhowee group across the strike. To the northwest in the Valley and Ridge province the group is buried beneath younger rocks, but it certainly passes out by overlap eventually on the continental surface. To the southeast in the Blue Ridge province rocks older than the Chilhowee are widely exposed; whether any equivalents of the Chilhowee or later Paleozoic are preserved is not certain.

A reconstruction of relations to the southeast was made by Keith (1904, p. 6; 1907a, p. 3, 11), who correlated the Cochran "conglomerate" of the Chilhowee group with the Great Smoky "conglomerate" of the Ocoee series. This is supported at no place by physical continuity and is based on the supposed affinities of the two "conglomerates." However, the Great Smoky is a coarse poorly sorted deposit with characteristic graded beds, whereas the Cochran is not truly a "conglomerate," as Keith termed it, but an evenly well-sorted deposit of arkose, sandstone, and quartzite. Moreover, the Great Smoky is more than 25,000 feet thick and the Cochran only a few thousand feet thick. The two are not comparable deposits: they were derived from different sources and were laid down in contrasting environments. Their lithographic characters neither prove nor disprove a correlation; one unit might have been laid down earlier, at the same time, or later than the other. The writer prefers to believe that the Great Smoky is more closely related to the other groups of the Ocoee series than it is to any part of the Chilhowee group (p. 62).

A more plausible clue as to possible changes in character of the Chilhowee group across the strike to the southeast is afforded in northeastern Tennessee, where exposures of the group on the northwest side of the Blue Ridge province widen to more than 15 miles and express a much greater original width, now compressed by folding and thrusting (King and Ferguson, 1960, p. 33–35). Here, sequences that were originally laid down to the southeast are thicker than those originally laid down to the northwest, but not with the extreme disparity that exists between the thicknesses of the Cochran and Great Smoky. The sequences laid down to the southeast also contain a greater volume of silty and argillaceous rocks and less volume of quartzite, sandstone, and arkose than those laid down to the northwest. These relations suggest that greater changes of the same nature took place in the Chilhowee deposits farther southeast, in and beyond the Blue Ridge province.

South of the Great Smoky Mountains, in the Murphy marble belt (fig. 13), the Great Smoky group of the Ocoee series is overlain by the Nantahala slate, Tusquitee quartzite, Brasstown schist, and Valleytown formation, 2,200 to 3,500 feet thick, and these rocks by the Murphy marble (Keith, 1907a, p. 4–5; Hurst, 1955, p. 45–53). The age of the sequence in the Murphy marble belt is undetermined; but the Murphy marble has been plausibly correlated on lithologic grounds by Keith (1907a, p. 11) with the Shady dolomite, which overlies the Chilhowee group.

If this correlation is accepted, relations similar to those in northeastern Tennessee may have existed, the dominantly sandy rocks of the Chilhowee group passing southeastward into the slightly thicker dominantly argillaceous formations which intervene between the Murphy marble and the Great Smoky group. A similar correlation has been suggested in Virginia between the Chilhowee group and the dominantly argillaceous lower part of the Evington group (Candler formation) in the James River synclinorium southeast of the Blue Ridge (Bloomer and Werner, 1955, fig. 4, p. 588; Rodgers, 1956, p. 393–394).

It is appropriate here to speculate on the extent to which the Ocoee series was originally covered by the Chilhowee group and its equivalents and by later Paleozoic deposits: The Walden Creek group of the Ocoee series is overlain on the northwest by the Chilhowee group, and the Great Smoky group is overlain on the southeast by formations of the Murphy marble belt; but in most of its outcrop area the Ocoee is the highest unit preserved. The possible equivalence of the Chilhowee and Shady with formations of the Murphy marble belt suggests that deposits of these ages formerly extended over the Ocoee series, their facies becoming more argillaceous toward the southeast. Former existence of later Cambrian and Early Ordovician deposits over the Ocoee cannot be proved. If they were ever present, one would suspect from relations farther northeast in the Appalachians that they were represented by an argillaceous facies, rather than by a carbonate facies like that in the Valley and Ridge province.

Any former presence in the Ocoee area of younger Ordovician deposits, or deposits of still later Paleozoic periods, appears unlikely. Middle Ordovician clastic rocks in the Valley and Ridge province indicate that at least part of the area to the southeast was undergoing erosion, probably as a result of orogenic deformation during this part of Ordovician time (Neuman, 1955, p. 171).

FOSSILS OF CHILHOWEE GROUP

In the Chilhowee group of the Chilhowee Mountain area, the principal occurrence of fossils is at the east end of the gap cut by the Little River through the mountain (Kinzel Springs quadrangle), where *Olenellus*, *Hyolithus*, and other shells were collected in 1889, by Walcott (Walcott, 1890, p. 570; Resser, 1938, p. 25). The beds in which they occur were at the time interpreted to be in the Murray shale (Keith, 1895a), but they are now known to be in the Helenmode formation. During the present investigation, fragments of brachiopods were obtained from about the same horizon and locality by R. B. Neuman and A. R. Palmer.

Another occurrence of similar fossils, also ascribed to the Murray shale, is reported (Keith, 1895a) "from the crest of the mountain above Montvale Springs" (Blockhouse quadrangle). This locality is certainly in the Murray shale, which is well exposed in the vicinity; but no additional fossils were found there during the present investigation, and the original collections are no longer available.[7]

Besides these occurrences, *Olenellus* has been reported from the Nichols shale, lower in the section (Butts, 1940a, p. 5), but this citation appears to be erroneous.

Much more abundant than fossil shells in the Chilhowee group of Chilhowee Mountain is the trace fossil *Scolithus*, a tubular structure oriented normal to the bedding which is the mark of a burrowing worm. In the report area *Scolithus* occurs in great numbers in the Nebo sandstone; it also occurs farther southwest in Chilhowee Mountain above the Nebo in sandstone and quartzite beds of the Helenmode and Hesse formations. It occurs less abundantly below the Nebo in quartzite and arkose layers interbedded in the Nichols shale. In addition, Cloud (P. E. Cloud, Jr., memorandum of Jan. 6, 1959, to King and Neuman) has observed in the Nichols "organic markings unlike any that have yet been recorded from accepted Precambrian rocks, but resembling some of the branching *Chondrites* burrows that are well known in many younger shales."

Fossil occurrences in the Chilhowee group and its equivalents in other parts of the southern Appalachians are similar to those of the Chilhowee Mountain area. *Olenellus* and other fossil shells were discovered years ago by Walcott (1892a,) at a number of places in Maryland and Virginia, and a few other occurrences have been added later (Butts, 1940b, p. 36; Stose and Stose, 1944b, p. 15; 1946, p. 42). These occurrences are, for the most part, in the upper part of

[7] This fossil locality was relocated by R. A. Laurence in 1962, who collected the bivalved arthropod *Indiana* from new roadcuts in the Murray shale above Montvale Springs (Laurence, R. A., 1963, Rediscovery of Murray Gap fossil locality. Blount County. Tennessee: Geol. Soc. America, Southeastern Section, program of Roanoke, Va., meeting.)

the Chilhowee group, some in beds clearly belonging to the Helenmode formation, others at a similar horizon or only a little lower. As on Chilhowee Mountain, the trace fossil *Scolithus* is more extensive than the fossil shells and is widespread in equivalents of the Helenmode, Hesse, and Nebo formations—the Erwin formation, Antietam quartzite, and the upper part of the Weisner formation. It occurs somewhat lower, as well, in equivalents of the Nichols shale—the Hampton and Harpers—mostly in quartzite beds like those above, but partly in arkosic crossbedded sandstone which is transitional from the lower, more varied part of the Chilhowee group. *Scolithus* is also reported from the basal formation in Pennsylvania, the Chickies quartzite (Stose and Stose, 1944b, p. 9), but the beds containing it may be equivalent in age to the middle part of the Chilhowee group farther southwest.

In summarizing the fossils of the Chilhowee group, it is worth emphasizing that there is no clear level of "lowest fossiliferous Cambrian rocks" in the southern Appalachians. All the Lower Cambrian rocks are unrewarding paleontologically. The Shady and Rome formations are nearly as barren of fossils as the Chilhowee group, except in a few favorable places. Between the part of the Chilhowee group in which a few fossils have been found and the lower part in which none have been discovered is a "twilight zone" marked by trace fossils and reported occurrences of other shells. The level of "lowest fossiliferous rocks" may vary from one locality to another and from year to year, depending on favorable preservation and on the accidents of collecting.

Besides the fossil occurrences just noted, a few radiometric determinations have been made on the ages of beds in the Chilhowee group. Glauconitic shale from the Murray yielded an age of 575 million years by the rubidium-strontium method,[8] and basalts from the middle part of the Unicoi (table 18) yielded an age of 440 to 465 million years by the helium method (Urry, 1936, p. 1218, 1225). These results are not only contradictory between themselves but with determinations made elsewhere on Cambrian rocks, and require further verification.

CONDITIONS OF SEDIMENTATION

The Chilhowee group and its equivalents were clearly the initial deposit of a marine cycle of sedimentation which continued into later Cambrian time; they were the basal unit of the Paleozoic Appalachian miogeosyncline. Although possessing some unique features, their deposits resemble in many respects the initial transgressive deposits of later marine cycles—within the writer's experience, for example, those of the Cretaceous of Texas.

The Chilhowee group and its equivalents were laid in part over a surface of deeply eroded metamorphic and plutonic rocks, in part over stratified rocks. Whether they succeed the latter unconformably or conformably has been debated, but a marked change in conditions is evident—from dominant volcanic products in some areas, or poorly sorted irregularly bedded sediments in others, to better sorted more regularly bedded deposits in the Chilhowee group and its equivalents. The contrast expresses a change from restricted accumulation under conditions of much crustal unrest to widespread accumulation under conditions of crustal stability.

Initial deposits consist of the readily available waste of the earlier plutonic and metamorphic rocks—pebbles of resistant rocks, arkosic debris, and finer red clastic deposits perhaps derived from a regolith. Apparently they contain little, if any, debris from the Precambrian stratified rocks which intervene in places. Conglomeratic and red deposits extend only a little above the base, and arkosic sands to near the middle of the deposit; as they decrease, quartz sand increases proportionately. The varied clastic sediments of the lower half of the deposit give way near the middle to finer grained argillaceous and silty sediments which are interbedded with, and succeeded by, nearly pure quartz sands, a product of prolonged weathering, transportation, and sorting. These sediments are followed by the great Cambrian carbonate sequence.

Occurrence of fossils parallels the sedimentary history. None are known in the varied clastics of the lower half of the group, where it is unlikely that organisms would thrive in any event. In the middle of the group, worm tubes, or *Scolithus*, appear in quantity in the quartz sands and other trace fossils in the shales; these are associated with the shells of more highly organized forms of life in the higher clastic deposits. It has been thought that the appearance of the latter, low in the Cambrian sequence, marks some sort of abrupt evolutionary development, but in the Chilhowee group this is overshadowed by local conditions resulting from the transgressive nature of the deposit. An adequate record of such an evolutionary development, if it occurred, would only be found in

[8] Cormier, R. F., 1957, Rubidium-strontium ages of the mineral glauconite and their application to the construction of a post-Precambrian time scale, *in* Variations in isotopic abundances of strontium, calcium, and argon and related topics: Massachusetts Inst. Technology, Dept. of Geology and Geophysics, unpublished report and Table III.

a succession of relatively homogeneous marine sediments, and might have taken place much earlier than the first appearance of fossil shells in the Chilhowee group and its equivalents.

AGE OF CHILHOWEE GROUP

Determination of the age classification of the Chilhowee group is part of the broader problem of designation of the base of the Cambrian system. The Cambrian differs from all other systems that succeed it in that its base is undefined paleontologically. At the boundaries of all succeeding systems, the faunas of one give place to those of the next, and however much the precise boundary may be debated, it is debated with knowledge of the faunas which precede and succeed it. In the Cambrian system the lowest fossil zone is underlain by strata without fossils or with fossils of so ambiguous a nature as to be useless for precise paleontologic zonation.

Various solutions of the problem of the base of the Cambrian system have been proposed. Some geologists would restrict the Cambrian narrowly to the lowest formation which contains diagnostic fossils (Howell and others, 1942; Snyder, 1947, p. 152), to the lowest strata containing fossils, or even to the base of a specified zone, that of *Olenellus* (Wheeler, 1947, p. 157), even though some other fossils might occur beneath. Other geologists would extend the base of the Cambrian much lower to some pronounced unconformity, although great thicknesses of unfossiliferous strata might be included (Keith, 1907a, p. 3; Bloomer and Bloomer, 1947, p. 102–106). Still others would class greater or less thicknesses of strata beneath the lowest occurrence of diagnostic fossils as Cambrian(?), Cambrian or Precambrian, or age unknown (Rogers, 1956, p. 410; Neuman and Palmer, 1956, p. 433; Longwell, 1952, p. 212).

The Chilhowee group is here classed as of Cambrian(?) and Cambrian age. The Helenmode formation at the top is clearly part of the Cambrian, as it contains *Olenellus* and other fossil shells. The upper half of the group, including the Nichols shale, contains *Scolithus* and other trace fossils which resemble trace fossils in Cambrian and later Paleozoic systems, suggesting that the strata containing them are more closely related to those above than to those below. The barren lower half of the group, the Cochran formation and its equivalents, is conformable with the upper half, occurs beneath it throughout its extent, and lies on different kinds of rocks from one area to another. The formations of the Chilhowee group below the Helenmode formation, though less certainly part of the Cambrian, are so closely related to proved Cambrian rocks that they can justifiably be classed as Cambrian(?).[9]

SHADY DOLOMITE (LOWER CAMBRIAN)

The Shady dolomite is the lowest of the great carbonate formations of the southern Appalachian region and follows directly on the clastic rocks of the Chilhowee group. In the Knoxville folio Keith (1895a) interpreted the Shady of Miller Cove, its main occurrence in the Chilhowee Mountain block, as Knox dolomite lying with hiatus on the Chilhowee group; he did not at that time realize that there was another dolomite unit like the Knox much lower in the section. Keith (1903) only came to understand the true stratigraphic relations of the Shady when he later mapped areas farther northeast; he then named the unit for Shady Valley, Johnson County.

In Miller Cove the Shady dolomite lies in sequence between the Rome formation and Chilhowee group and is about 1,000 feet thick. In the report area itself, only parts of the formation are preserved; these lie out of sequence in slices along the Bogle Springs fault on the southeast slope of the mountain.

The widest outcrop area of the Shady is in a large slice southeast of Bench Mountain, but it is poorly exposed here and is mostly concealed by residual clay. A few small ledges of blue-gray dolomite occur in the first valley southwest of Compton Branch (Walden Creek quadrangle). Rocks of the slice are overturned, so that on the southeast side the Shady is overlain in reverse order by the Helenmode formation and Hesse sandstone.

The Shady reappears along the same fault farther east, in a smaller slice that projects as a low ridge west of Mountain View School, near the meridian between the Walden Creek and Pigeon Forge quadrangles. Here, the Shady is surrounded on all sides by shale of the Sandsuck formation, with which it is probably in tectonic contact. The Shady of the slice consists of light-blue-gray thick-bedded dolomite, which weathers to dark brown creased surfaces.

The contact between the Shady dolomite and higher formations is not exposed in the report area. In Miller Cove, farther southwest in the same structural block, it is overlain by red shale of the Rome formation, but here also the sequence is broken above the

[9] Because of the rediscovery of Cambrian fossils in the Murray shale by R. A. Laurence in 1962, the U.S. Geological Survey now classifies the Hesse sandstone and Murray shale as Cambrian.

Rome. However, the interval between the Shady and Rome formations, and the Ordovician formations of the report area, can be filled by strata exposed in nearby regions (Rodgers, 1953, p. 43–64; Cattermole, 1955).

The Rome formation is exposed again a short distance northwestward in the Appalachian Valley (Shooks Gap quadrangle), where it is succeeded conformably by the Conasauga group (Middle and Upper Cambrian), the Copper Ridge dolomite (Upper Cambrian), and the Lower Ordovician part of the Knox group, the latter forming the base of the exposed sequence in the northern part of the report area.

UPPER PART OF KNOX GROUP (LOWER ORDOVICIAN)[10]

GENERAL FEATURES

In the Appalachian Valley of Tennessee the Lower Ordovician series and most of the Upper Cambrian series is a mass of dolomite and limestone 2,500 to 3,100 feet thick which, following Safford (1869, p. 204–206), has long been known as the Knox dolomite, and more recently, when subdivisions were made, as the Knox group. The group varies across the valley from a dominant dolomitic facies on the northwest to a dominant limestone facies on the southeast, and the subdivisions of the two facies differ accordingly. Terminology of the Knox group is illustrated in table 19 below, introduced to facilitate reference in the discussion which follows to units outside the report area.

TABLE 19.—*Subdivisions of Knox group in Appalachian Valley of Tennessee*

[Modified from Rodgers, 1953, p. 56]

Series	Northwestern belts	Central belts	Southeastern belts
Lower Ordovician	Mascot dolomite Kingsport formation Longview dolomite Chepultepec dolomite	Newala limestone Longview dolomite Chepultepec dolomite	Jonesboro limestone
Upper Cambrian	Copper Ridge dolomite	Copper Ridge dolomite	Conococheague limestone

Within the report area the Upper Cambrian part of the Knox group does not emerge, and all of the group that is exposed belongs to the Lower Ordovician series. In the Appalachian Valley on the north the subdivisions of the central belts, listed in table 19, are applicable; but in Wear and Tuckaleechee Coves and in slices along the Great Smoky fault no subdivisions can be made, and all the Lower Ordovician is placed in the Jonesboro limestone (Ulrich, 1911, p. 671–672; Rodgers, 1953, p. 63–64).

[10] Discussion of the Ordovician rocks is based largely on observations by R. B. Neuman. Classification of the Middle Ordovician part of the section, in this area and to the west, has been published previously (Neuman, 1955). Includes some data from H. W. Ferguson and G. D. Swingle on the Wear Cove quadrangle, from P. B. King on the Gatlinburg quadrangle, and from J. G. Bumgarner on the Pigeon Forge quadrangle; data from Bumgarner were presented in a master's thesis at the University of Tennessee in 1956.

CHEPULTEPEC DOLOMITE, LONGVIEW DOLOMITE, AND NEWALA LIMESTONE

OCCURRENCE IN REPORT AREA

The Knox group emerges in the Appalachian Valley in an anticline in the northwest corner of the report area (Walden Creek quadrangle), and in the Fair Garden anticline and Rock Quarry dome in the eastern part of the report area (Pigeon Forge quadrangle). In these uplifts the subdivisions Chepultepec dolomite, Longview dolomite, and Newala limestone are mapped (pls. 2, 3). Bedrock is widely concealed, however, by red cherty residium, colluvium, and stream gravels, and the basis for the subdivisions made rests to some extent on exposures beyond the report area to the west, north, and east (Neuman, 1960; Cattermole, 1955; Bumgarner[11]).

FAIR GARDEN ANTICLINE

The most complete sequence in the area occurs in the Fair Garden anticline southeast of Sevierville, in the eastern part of the report area (Pigeon Forge quadrangle), where more than 2,000 feet of beds is exposed.

The oldest unit, or Chepultepec, consists of limestone with subordinate dolomite. The limestone is fine grained and dark gray and forms beds 1 to 6 feet thick, with some partings of green or black shale, and contains quartz grains, either dispersed or in seams parallel to the bedding. According to Bumgarner as much as 900 feet of the formation is exposed in the anticline east of the report area, the lowest beds that emerge being crossbedded sandstones which are probably near its base. The formation is only sparsely fossiliferous in the Fair Garden anticline.

The succeeding Longview dolomite, about 650 feet thick, consists of dolomite with subordinate limestone layers. About half the dolomite layers are fine grained and dark gray, with thin laminae, in part sandy, and form beds as much as 2 feet thick. The others

[11] Bumgarner, J. G., 1956, Stratigraphy and structure of the Knox dolomite in the Fair Garden area, Sevier and Jefferson Counties, Tennessee: Tennessee Univ., unpublished master's thesis.

are coarse grained, of the type called "recrystalline" by the local mining geologists (Bridge, 1956, p. 54), and form thicker more massive beds; most of the coarse-grained dolomite is light gray, but some is dark gray or black. Chert forms nodular or bedded layers 2 to 4 inches thick. Bumgarner reports the occurrence of *Lecanospira* in the unit.

The Newala limestone at the top consists of limestone with subordinate dolomite. Some of the limestone beds are very fine grained and dark gray and are marked by crenulated or wavy argillaceous laminae. Others are of clastic texture and are made up of limestone fragments, shell fragments, oolitic grains, and quartz sand grains. A few of the limestone beds contain irregular patches of dolomite, especially near their bases. Dolomite is interbedded throughout in beds a few feet thick and is light gray to white and fine grained. Quartz sand occurs in layers 1 inch to 4 feet thick, mainly in a dolomitic matrix; an especially conspicuous layer was observed in many places 220 feet below the top. Gray chert forms nodules and beds, one of which lies 40 feet above the sand layer noted above, and another not far below the top. According to Bumgarner the Newala limestone is 555 feet thick at Hodsden Bridge, 3 miles east of Sevierville (east edge of Pigeon Forge quadrangle).

Fossils have been observed or collected by Neuman at many localities in the Newala limestone of the Fair Garden anticiline. Fossils which indicate a correlation of the beds containing them with the Mascot dolomite of the northwestern belts (table 19) include opercula of the gastroped *Ceretopea*, and the brachiopods *Tritoechia* and *Diparelasma*. *Diparalasma typicum* Ulrich and Cooper was collected from limestone near the head of Cain Hollow south or Sevierville (PF–9). Occurrence of strata equivalent to the Kingsport formation in the Newala limestone is indicated by the sponge *Archaeoscyphia*, which was identified by W. J. Sando (oral communication, 1955) near Harrisburg.

ROCK QUARRY DOME

On the gently arched Rock Quarry dome probably no more than the uppermost few hundred feet of the Knox group come to the surface, all part of the Newala limestone. This is typically exposed in the Lambert Bros. quarry east of the West Prong of the Little Pigeon River, where 89 feet of the upper part of the Newala limestone is exposed, and has been opened along the strike for more than 1,000 feet. Here, the following section was observed (geologic section 6):

GEOLOGIC SECTION 6.—*Section of part of Newala limestone on face of Lambert Bros. quarry, 1.65 miles south-southeast of square in Sevierville*

[By R. B. Neuman, 1950, and R. A. Laurence and S. W. Maher, 1958]

	Thickness (feet)
Lenoir limestone:	
8. *Cobbly argillaceous limestone member:*	
Exposed in hills not far southeast of quarry, but straitigraphic interval between it and beds in quarry not determined	
7. *Douglas Lake member:*	
At west end of quarry, forms a channel filled with limestone and conglomerate, buff and red shale, and some crystalline limestone, which cuts at least 10 ft. downward into top unit of Newala limestone. Main face of quarry farther east extends straitigraphically higher, and is all Newala limestone	[1] 10
Newala limestone:	
6. Limestone, dove to very light gray, mostly aphanitic, with a few fine-grained dolomite beds and widely spaced, indistinctly sandy layers less than 6 in. thick. At east end of quarry, topmost bed is ribboned with much interstitial chert, and exhibits cross sections of low-spired gastropods	50
5. Limestone, very sandy, laminated and cross-bedded; may be the same as the sandstone bed 220 ft below the top in Fair Garden anticline	4
4. Limestone, dove, aphanitic with 2 in. of shaly limestone at bottom, lying with sharp contact on beds beneath	2
3. Limestone, fine-grained, coarser than unit 6 and somewhat darker, in 1- to 3-ft beds	15
2. Limestone, fine-grained, much darker than unit 3, in 3- to 6-in. beds	5
1. Limestone, like unit 3	13
Base of exposure in quarry; lowest beds quarried covered by water.	

[1] Approximate.

ANTICLINE IN NORTHWESTERN PART OF REPORT AREA

In the northwestern part of the report area the Knox group comes to the surface in an anticline crossed by U.S. Highway 411-441 south of Harrison-Chilhowee Academy (Walden Creek quadrangle). On the map (pl. 2) the Knox of this anticline is divided into its component formations, but mainly on the basis of observations to the west and northwest (Neuman, 1960; Cattermole, 1955). Most of the Knox group in the anticline within the report area is covered by residuum and other superficial deposits, although widely scattered ledges of limestone and dolomite occur along Boyds Creek and adjacent valleys.

JONESBORO LIMESTONE

OCCURRENCE IN REPORT AREA

The Knox group also comes to the surface south of the Appalachian Valley in Wear and Tuckaleechee Coves and Whiteoak Sink (Gatlinburg and Wear Cove quadrangles), where the subdivisions described above are less easily recognizable and cannot be mapped; the rocks of these areas are therefore classed as Jonesboro limestone. The name Jonesboro is also used for the Knox group in slices along the Great Smoky fault, because they are tectonically disordered, and in large part without distinctive fossils or lithologic features that would indicate their exact stratigraphic position.

TUCKALEECHEE AND WEAR COVES

Wide areas in the centers of Tuckaleechee and Wear Coves are underlain by Jonesboro limestone, which is in stratigraphic sequence beneath the Lenoir limestone and Blockhouse shale. Most extensive outcrops are in the more dissected Tuckaleechee Cove; in Wear Cove outcrops are much scattered and covered by residuum or wash, but the formation appears to be similar.

In Tuckaleechee Cove the Jonesboro is greatly disturbed and faulted, so that no clear stratigraphic section can be made out, but in places as much as 400 feet of beds occurs in unbroken sequence. The formation is dominantly limestone, dolomite forming only about a tenth of the observed thickness.

Several types of limestone are present, the first in the list below being dominant, the rest subordinate:

1. Light- to medium-gray fine-grained to aphanitic limestone, in 6-inch to 3-foot beds, containing crenulated clay partings.
2. Massive gray fine-grained limestone, fossiliferous in many places.
3. Dark-gray limestone with silty dolomite seams.
4. Platy limestone, much of which contains scattered well-rounded quartz grains.
5. Sandy limestone, consisting of well-rounded quartz grains embedded in a clastic limestone matrix.
6. Pink brecciated limestone.

The dolomite is dark gray and fine grained, and forms beds a foot or so thick which contain numerous closely spaced parallel laminae; some beds contain a few quartz grains. The dolomite weathers to brown dull creased surfaces, which contrast with the lighter gray surfaces of the limestone.

Chert forms sparse nodules throughout the formation, but has accumulated in considerable quantities in the residuum. Part of the chert is black and dense, part white and porcelaneous; the latter also forms tiny irregular bodies in some of the limestone.

Fossils are fairly abundant in the Jonesboro limestone of the central parts of Tuckaleechee and Wear Coves, especially in the massive fine-grained limestone (type 2, above). Most abundant are opercula of the gastropod *Ceratopea*, of which at least two species have been observed. One specimen from 0.8 mile northwest of Coker Hill Chapel has been identified by E. L. Yochelson as *Ceratopea subconica* Cullison. On the crest of Cedar Bluff near its western end the limestones contain *Ceratopea* sp. and numerous cross sections of gastropods resembling *Lecanospira*, but which Josiah Bridge has judged to be those of a stratigraphically younger genus. The following brachiopods have been identified by R. B. Neuman: *Tritoechia typica* (Ulrich) (WC 1, quarry 600 ft southwest of Wearwood School; WC 6, small quarry 0.3 mile southwest of the southwestern Wear Valley Church; 0.8 mile northwest of Coker Hill Chapel), *Diparelasma typicum* Ulrich and Cooper (west side of Walker Hollow 1 mile north of Little River), and *Diparelasma* sp., poorly preserved (WC 5A, half a mile west of Wearwood School and 12 ft below base of Douglas Lake member). All these fossils indicate correlation of the containing beds with the Mascot dolomite of belts farther northwest (table 19); no fossils indicating any older age have been discovered in the central area of the coves.

SLICES OF JONESBORO LIMESTONE ALONG GREAT SMOKY FAULT

Along the Great Smoky fault, both at the edge of the Appalachian Valley and in the coves, slices of Jonesboro limestone lie between the Blockhouse shale or Tellico formation and the overlying Ocoee series or Chilhowee group. Some slices are only a few feet thick and a hundred feet long; others are several hundred feet thick and have an exposed extent of a mile or more.

A typical well-exposed small slice of Jonesboro limestone underlies the Great Smoky fault in the cut on Tennessee Highway 73 at the Townsend entrance of Great Smoky Mountains National Park (pl. 11) (Wear Cove quadrangle). It is 5 to 25 feet thick and extends for at least 600 feet along the outcrop. Rock of the slice is gray or blue-gray limestone, so greatly broken, veined, and reconstituted that any original bedding or fossils have been lost.

Along the edge of the Appalachian Valley, small slices of Jonesboro limestone and dolomite are exposed northwest of Chilhowee Mountain on Coldspring Branch, South Fork of Ellijoy Creek, and Dry Branch (Walden Creek quadrangle); a larger slice occurs farther east along Guess Creek (Pigeon Forge quadrangle). A similar slice on the west side of the Little River to the southwest (Kinzel Springs quadrangle) contains *Diparelasma*, a brachiopod genus characteristic of the Mascot dolomite (Neuman, 1951, p. 747); it may be that all the slices in this belt were derived from the upper part of the Jonesboro limestone.

The limestone slices in Tuckaleechee and Wear Coves may be, in part at least, older than that part of the Jonesboro limestone exposed in the centers of the coves. In the southwestern part of Tuckaleechee Cove, west of the report area and a quarter of a mile southeast of Red Bank School (Kinzel Springs quadrangle), limestone of one of these slices contains *Lecanospira* sp. and *Diaphelasma pennsylvanicum* Ulrich and Cooper, identified by Neuman, which are of Longview age. The limestone of the slices in Wear Cove yielded no fossils, but it differs considerably from the limestone of the central area. On the northwestern lower slopes of Buckeye Knob (Gatlinburg quadrangle) are ledges and cliffs of gray fine-grained limestone in beds 3 to 5 feet thick, lacking any shaly laminae, sandy layers, or interbedded dolomite. On the slopes of Raven Den at the northeast end of the cove, scattered ledges cover an extensive area and include dark-gray limestone and limestone with closely spaced argillaceous and sandy seams that weather to ribs on the surface; residual chert in the vicinity is dark, crumbly, and partly oolitic. Rocks of the Raven Den area somewhat resemble those of the Chepultepec dolomite and Conococheague limestone in the lower part of the Knox group, as exposed elsewhere in the Appalachian Valley (table 19).

STRATIGRAPHIC RELATIONS OF KNOX GROUP

The Lower Ordovician part of the Knox group is overlain with erosional unconformity by the Lenoir limestone of the Middle Ordovician series, an unconformity of regional extent in the southern Appalachian region (Bridge, 1955; 1956, p. 57–59). Within the report area the unconformity is indicated by a sporadic occurrence of the basal clastic deposits of the Douglas Lake member of the Lenoir limestone which contain fragments derived from erosion of the underlying Knox group.

MIDDLE ORDOVICIAN FORMATIONS

LENOIR LIMESTONE

DEFINITION

The name Lenoir limestone was given by Safford and Killebrew (1876, p. 130–131) to dark-gray, argillaceous cobbly limestones exposed near Lenoir City, Loudon County; in the folio reports (Keith, 1895a, and others) approximately the same beds, there and elsewhere, were mapped as Chickamauga limestone. The name Mosheim limestone was given by Ulrich (1911, p. 413, pl. 27) to light-gray aphanitic limestone in similar stratigraphic position, but this and the Lenoir are now interpreted to be interfingering facies (Cooper and Cooper, 1946, p. 51–52). Basal clastic deposits of the Lenoir have been termed the Douglas Lake member (Bridge, 1955, p. 727).

GENERAL FEATURES

The Lenoir limestone of the southeastern part of the Appalachian Valley is divided into an unnamed unit of cobbly argillaceous limestone, similar to the limestone at the type locality; the Mosheim limestone member of light-gray aphanitic limestone; and the Douglas Lake member, or basal clastic deposits.

These members have an erratic development from place to place. The Douglas Lake member was deposited on an irregular erosion surface of the Knox group and thickens and thins along the outcrop, disappearing entirely in many places. Aphanitic limestone of Mosheim type commonly underlies the cobbly limestone, but in places overlies it, and in others constitutes the whole formation above the Douglas Lake member.

The Lenoir limestone is 90 feet thick at an outcrop on Boyds Creek near U.S. Highway 411–441 (W A 1) in the northwest corner of the report area (Walden Creek quadrangle). Elsewhere, it is probably thinner, and in places may be no more than 25 feet thick.

In the folio reports, Keith represented the Lenoir (his "Chickamauga") as discontinuous along the outcrop in the southeastern part of the Appalachian Valley; but he evidently mapped it only where outcrops of the cobbly facies were observed, omitting the formation where concealed by overburden, or including it in the Knox where it is represented by the aphanitic facies. The present investigation indicates that wherever the interval between the Blockhouse and Knox is well exposed, the Lenoir occurs; it evidently forms a continuous layer throughout the region, although in places masked at the surface by its own residuum or by colluvium derived from adjacent formations.

APPALACHIAN VALLEY

In the northwestern part of the report area, near Boyds Creek and south of Harrison-Chilhowee Academy (Walden Creek quadrangle), the Douglas Lake member is absent and the lower half of the formation is dove-gray aphanitic limestone of the Mosheim limestone member, which forms 6-inch to 2-foot beds without internal laminae, flecked by small calcite crystals. The upper half is dark gray, fine-grained, argillaceous, cobbly limestone.

Farther east (Pigeon Forge quadrangle), basal conglomerate of the Douglas Lake member was observed at several localities south and southeast of Sevierville, as in the Lambert Bros. quarry on the Rock Quarry dome (unit 7, geologic section 6) and on the northwest flank of the Fair Garden anticline, but it appears to be scantily developed or absent in nearby exposures. Most of the formation on the flanks of the

Fair Garden anticline and the nearby Rock Quarry dome is of cobbly facies. The aphanitic facies, or Mosheim member, is poorly developed, but it thickens eastward along the southeast flank of the Fair Garden anticline and occupies the whole of the formation a little beyond the report area.

TUCKALEECHEE AND WEAR COVES

The Lenoir limestone is exposed only sporadically in Tuckaleechee and Wear Coves (Wear Cove quadrangle). In Tuckaleechee Cove it has been removed widely by tectonic stripping along a "surface of movement" at the base of the Blockhouse shale. In Wear Cove there is little evidence of such removal, but outcrops are discontinuous because of deep weathering and extensive cover of wash.

The Douglas Lake member, or basal clastic deposit, forms lenses or pockets at several places, of which the following are typical:

1. Southeast side of Tuckaleechee Cove, cut on Tennessee Highway 73 at Townsend entrance of Great Smoky Mountains National Park. (pl. 11). An 8-foot bed of limestone conglomerate lies on Jonesboro limestone and is traceable 150 feet along the outcrop; it consists of angular fragments, as much as three-quarters of an inch across, of blue-gray limestone and gray dolomite in a fine-grained argillaceous limestone matrix.
2. North side of Tuckaleechee Cove, a short distance west of Walker Hollow, and about 1 mile north of the Little River. Several pockets of clastic rocks occur in different fault blocks, one of which is 3 feet thick and 15 feet long; in some pockets the rock is limestone and conglomerate, in others it is blue-gray limestone with scattered quartz grains and large angular blocks of dolomite.
3. Northwest side of Wear Cove half a miles west of Wearwood School (W C 5 B). Light-gray calcarenite with a few quartz sand grains and dolomite pebbles forms a bed 8 feet thick, lying on Jonesboro limestone and overlain by main body of Lenoir; it pinches out eastward along the outcrop.
4. Eastern part of Wear Cove, low anticline in valley, three-fourths mile southeast of Hatchertown on meridian between Wear Cove and Gatlinburg quadrangles. On the northwest flank of the anticline are poor exposures and much float of tan, vermillion, and brick-red dolomite, containing fragments of dolomite, limestone, and chert derived from Jonesboro. These beds pinch out southeastward across the anticline, as on the opposite flank aphanitic limestone of the Mosheim member lies directly on the Jonesboro.

The main body of Lenoir limestone in Tuckaleechee and Wear Coves is largely of gray aphanitic facies (Mosheim member) which forms massive beds 2 to 4 feet thick, without internal laminae, but containing a few spots of crystalline calcite. Fragmental layers are interbedded in places, made up of small rounded pellets in a gray granular partly recrystallized limestone matrix. Dark-gray argillaceous limestone of the facies of the typical Lenoir occurs at only a few places. On Tennessee Highway 73 at the Townsend entrance (loc. 1, above) a short lens 6 feet thick lies between the basal conglomerate and the aphanitic limestone above. In one outcrop west of Walker Hollow (loc. 2, above) such rock overlies the aphanitic limestone and contains fragmental brachiopods. West of Wearwood School (loc. 3 and WC–5, above) the Douglas Lake member is overlain by 12 feet of dark-gray fossiliferous argillaceous limestone which emits a strong petroliferous odor on fresh fracture. This intergrades eastward along the strike with aphanitic limestone of the Mosheim member.

FOSSILS

In outcrops of the Lenoir limestone in the Appalachian Valley some trace of fossils can generally be observed. In the northwestern part of the area (W A 1) according to Neuman the brachiopod *Valcourea strophomenoides* (Raymond) is plentiful in the upper cobbly part, and cross sections of the gastropods *Maclurites magnus* Lesueur and *Lophospira* sp. are visible in the aphanitic Mosheim limestone member below. *Valcourea* was also observed 5 feet above the base on Roberts Branch, on the west flank of the Rock Quarry dome south-southwest of Sevierville.

In Tuckaleechee and Wear Coves the aphanitic facies (Mosheim member) is poorly fossiliferous, but shows scattered cross sections of the characteristic gastropod genera *Maclurites* and *Lopospira*. The argillaceous cobbly facies (typical Lenoir) in exposures west of Walker Hollow contains *Rostricellula* sp., and half a mile west of Wearwood School (WC 5B) the following:

Onychoplecia longirostris (Billings)
Hesperorthis sp.
Macrocoelia champlainensis (Raymond)
Atelelasma cf. *A. multicostatus* (Hudson)

STRATIGRAPHIC RELATIONS

Fossil evidence and regional stratigraphy indicate that the Lenoir limestone is overlain with hiatus by the Blockhouse shale and its basal Whitesburg member, the hiatus representing a short period of nondeposition and erosion during early Middle Ordovician time (Neuman, 1955, p. 168). Physical indication of erosion at the contact was observed at a locality in Walker

Hollow, described below, but it is not evident elsewhere in the report area.

BLOCKHOUSE SHALE

DEFINITION

The Blockhouse shale was named by Neuman (1955, p. 148) for Blockhouse, Blount County (Blockhouse quadrangle), the unit corresponding approximately to the lower third of the Athens shale as mapped in the southeastern part of the Appalachian Valley in the folios (Keith, 1895a, 1896). The Blockhouse includes at its base the Whitesburg limestone member (Ulrich, 1929, p. 2), and above the Whitesburg, the Toqua sandstone member (Neuman, 1955, p. 150).

GENERAL FEATURES

The Blockhouse shale is exposed on the crests and flanks of various anticlinal uplifts in the Appalachian Valley in the northern part of the report area, on the higher of which it forms a band of outcrop around the Lenoir limestone and Knox group that emerge in the centers. In Tuckaleechee and Wear Coves it is the highest Ordovician formation and the youngest rock present.

The Blockhouse is mostly a dark-gray fissile finely laminated calcareous shale, characteristically containing graptolites, without much coarse silt or sand, and is 150 to 400 feet thick in the report area. Wherever good exposures are available, the Whitesburg limestone member, a few feet thick, is recognizable at the base; it is a cobbly argillaceous limestone in the northern part of the area and a calcarenite in Wear and Tuckaleechee Coves. The Toqua sandstone member, a gray medium-grained calcareous sandstone, is only locally present and is best developed southwest of the report area. Sandstone like the Toqua, occurs at many places in Tuckaleechee Cove, but is absent elsewhere, except for a thin tongue in the Appalachian Valley east of Sevierville.

APPALACHIAN VALLEY

The Blockhouse shale is about 400 feet thick along U.S. Highway 411–441 in the northwestern part of the report area (Walden Creek quadrangle), but it thins to about 300 feet on the northwest flank of the Fair Garden anticline farther east and to 150 feet on the southeast flank (Pigeon Forge quadrangle); the latter may have been thinned tectonically in proximity to the Great Smoky fault.

In the Appalachian Valley the Whitesburg limestone member is a gray nodular medium-grained very argillaceous limestone with a few lenticular layers of calcarenite. It is not easily distinguished from the cobbly limestone of the underlying Lenoir, but is generally lighter colored, more argillaceous, and more fossiliferous. At a roadcut six-tenths of a mile south-southeast of Harrison-Chilhowee Academy (W A 2) in the northwest corner of the area (Walden Creek quadrangle) the member is 20 feet thick and contains a bed of black chert 2 inches thick near the top. Farther east, at localities south of Sevierville (Pigeon Forge quadrangle), the Whitesburg is 3 to 9 feet thick and its characteristic limestone grades upward into, and is interbedded with, the shale of the main body of the formation.

Sandstone resembling the Toqua sandstone member occurs in the Appalachian Valley as a lens about a mile long on the southeast flank of the Fair Garden anticline near the east edge of the report area (Pigeon Forge quadrangle). This lens is as much as 35 feet thick and is separated by 40 feet of dark shale from the Whitesburg member beneath; it fingers out laterally into, and is overlain by, shale.

Most of the main body of the formation is dark-gray or black argillaceous laminated calcareous shale, containing some nodules of black dense limestone but no silt or sand. Where weathered, the shale becomes chocolate brown and thinly fissile. Near Knob Creek in the western part of the area (Walden Creek quadrangle) the lower two-thirds is all shale and contains many graptolites, whereas the upper third contains fewer fossils and contains nodules, lenses, and thin beds of limestone, many of which have conspicuous shrinkage cracks. Here, the top 60 feet is dark-gray shale without limestone, but with interbedded layers of gray silty shale that are a transition into the overlying Tellico formation.

TUCKALEECHEE AND WEAR COVES

In Tuckaleechee and Wear Coves (Wear Cove and Gatlinburg quadrangles) the Blockhouse shale is generally exposed around the edges, between the emerging anticlinal cores of Jonesboro limestone and the limestone slices associated with the bordering Great Smoky fault. Where the rocks are well exposed this general pattern is seen to be disrupted by minor faulting and crumpling, and in Tuckaleechee Cove the shale commonly lies directly on the Jonesboro along a "surface of movement" which in most places has removed the intervening Lenoir limestone and Whitesburg limestone member. The shale is much contorted and slickensided, but is not cleaved or metamorphosed in the manner of argillaceous rocks of the Ocoee series, which lie with tectonic contact above it. Thickness of the formation in the coves has not been determined because of complex structure, discontinuous exposures, and absence of any younger formation.

The basal Whitesburg limestone member is best exposed in Tuckaleechee Cove, although only at places where it and the underlying Lenoir limestone have escaped tectonic removal. An excellent outcrop of the member is on the west side of Walker Hollow 1 mile north of the Little River, where it is 3 to 5 feet thick and is a dark-gray to slightly reddish coarse-grained calcarenite with thin wavy clay partings, containing encrinal and bryozoan debris. At this locality the member lies with erosional contact on aphanatic limestone of the Mosheim member of the Lenoir, the surface being irregular, jagged, and coated by grains of well-rounded quartz sand; quartz sand also fills cracks a few inches deep in the underlying limestone.

Sandstone like that of the Toqua member occurs widely at the base of the shale around Tuckaleechee Cove, although it has been much disrupted tectonically. Best exposures are at the Walker Hollow locality and a quarter of a mile west of Caylor School, a little west of the edge of the mapped area (Kinzel Springs quadrangle); at the latter locality it is 12 feet thick. The sandstone is light gray, fine to coarse grained, feldspathic, and calcareous, in 2- to 6-inch beds, which weather to olive-brown blocks and slabs. It lies with sharp smooth contact on the Whitesburg member and passes into the shale above through a transition zone about 2 feet thick.

The main body of the Blockhouse in the coves differs somewhat from that in the Appalachian Valley. The fresh rock contains more silty layers and thin lenses of calcareous sandstone, and many bedding surfaces contain finely divided mica flakes. The rock weathers to an olive brown rather than to the more neutral brown of farther north, and fissility is notably weaker. An unusual phase of the formation is exposed in a roadside outcrop near Hatcher Cemetery in Wear Cove and consists of platy, gray, argillaceous, and finely sandy limestone, some of whose bedding surfaces contain elliptical shale chips 5 to 20 mm in diameter and 1 mm thick.

The shale is best exposed in Tuckaleechee Cove because of dissection by the Little River and its tributaries. In less dissected parts of this cove, and in most of Wear Cove, it has weathered at the surface to yellow or tan soil containing olive-brown chips of decomposed shale; these soils contrast with the reddish residuum derived from the associated Jonesboo limestone. In much of Wear Cove the shale beneath the soil has been leached of its carbonate content to form a punky tan residuum in which bedding laminae are still preserved, although much contorted.

FOSSILS

The Whitesburg limestone member contains abundant fragments of brachiopods, trilobites, and other fossils, of which the brachiopod *Christiana subquadrata* (Hall) is most characteristic. From a roadcut six-tenth of a mile south-southeast of Harrison-Chilhowee Academy (WA 2, Walden Creek quadrangle) the following have been collected (Neuman, 1955, p. 172):

Christiania subquadrata (Hall)
Orthambonites sp.
Oxoplecia sp.
Paleostrophomena superba Cooper
Skenidioides sp.
Titambonites amplus (Raymond)

No fossils were observed in the equivalent of the Toqua sandstone member in the Appalachian Valley, but at Walker Hollow and other localities in Tuckaleechee Cove it contains the graptolites *Glossograptus* sp. and *Diplograptus* sp.

Graptolites are common in the lower part of the overlying shale in the Appalachian Valley, especially near Knob Creek in the western part of the report area, from which the following have been collected: *Diplograptus* sp., *Dicellopgraptus* sp., *Cryptograptus* sp. (WA 27 and 29, Walden Creek quadrangle), and *Nemagraptus gracilis* (Hall) (Wildwood quadrangle, a little west of report area). Fossils are less abundant in the shale of Tuckaleechee and Wear Coves, but *Diplograptus* sp. and other graptolites have been collected from black calcareous shale in a roadsite outcrop in Wear Cove a quarter of a mile north of Hatcher Cemetery (Wear Cove quadrangle).

STRATIGRAPHIC RELATIONS

The Blockhouse shale is succeeded conformably by the Tellico formation. Where the contact is well exposed in the northwestern part of the area (Walden Creek quadrangle), rocks lithologically like the two formations are interbedded in a transitional unit which is assigned to the upper part of the Blockhouse. In the northeastern part of the area (Pigeon Forge quadrangle) the boundary between the formations is even more gradational and indefinite, and has been located only approximately on the map (pl. 3).

TELLICO FORMATION

DEFINITION

The name Tellico sandstone was applied by Willis (1893, pl. 59, p. 242) and Keith (1895a, 1896) to the middle part of the Middle Ordovician sequence in the southeastern part of the Appalachian Valley, the name being derived from exposures on the Tellico River, Monroe County. Limits of the unit were later revised by Neuman (1955, p. 154).

GENERAL FEATURES

The Tellico formation crops out over a wide area in the Appalachian Valley in the northern part of the report area and forms the greater part of the Slate Knobs west of Sevierville. It is a gray platy sandy or silty calcareous shale interbedded with blue-gray thinly and evenly bedded calcareous sandstone, in part feldspathic. Most of its sandstone units are thin, but a few in the western part are as much as a hundred feet thick, project in ridges higher than their surroundings, and are separately mapped. Within the report area the formation has been complexly folded and faulted, in contrast to its simple homoclinal structure along the same strike belt farther southwest. The sequence is thus difficult to make out, except in the extreme western part where the formation is probably about 4,000 feet thick from base to top. Only a smaller thickness is preserved farther east, where much of the upper part of the Tellico, as well as all the overlying formations, has been faulted out or eroded.

LOCAL FEATURES

In the western part of the report area (Walden Creek quadrangle), where the sequence is reasonably clear, three divisions can be recognized:

1. At the base is about 2,000 feet of gray platy calcareous shale, much of which is silty and sandy, interbedded with lenses of calcareous sandstone like those of the middle division, but too thin to be mapped separately.

2. This is followed by a middle sandstone division, about 1,850 feet thick, composed of as many as 3 calcareous sandstone units that are separately mapped, enclosed in shale like that of the divisions below and above. The sandstone is gray and blue gray, medium grained, in even beds 2 to 6 inches thick that are commonly separated by shaly partings less than an inch thick. Clastic grains are mainly quartz, but in a few beds feldspar grains are abundant.

The basal sandstone is 150 feet thick at the west edge of the area, but thins and disappears eastward. The middle sandstone is 200 feet thick and 1,000 feet higher. The top sandstone is 250 feet thick; in many places it is faulted against the middle one, but in less disturbed areas to the southwest they are separated by about 400 feet of shale.

Similar sandstone beds are also separately mapped in the extreme northern part of the area, but their correlation with particular beds in the middle division has not been established.

3. At the top, beneath the Chota formation, is several hundred feet of gray platy to irregularly bedded sandy and silty shale, in places containing limestone nodules. This division has yielded most of the fossils that have been collected from the formation in the area (see below).

East of the district in which this section is exposed, as far as the east edge of the report area (Pigeon Forge quadrangle), no subdivisions of the Tellico formation have been recognized. The rocks of most of this eastern area are not in sequence with those to the west, but lie southeast of the Guess Creek fault. Here the rocks are largely shale like those of the lower division of the Tellico to the northwest, but they are more sandy and contain more abundant thin beds of calcareous sandstone and thin layers of gray calcarenite. These rocks have been complexly deformed and, although individual units are not distinguishable, the beds are probably much repeated by minor folds and faults. Despite the width of the outcrop belt, the top of the Tellico is not preserved southeast of the Guess Creek fault in the Walden Creek or Pigeon Forge quadrangles, and none of the sandstone beds are as thick as those of the middle division. Probably no more than the lower half of the Tellico formation is preserved southeast of the Guess Creek fault.

FOSSILS

In the section in the western part of the area, fossils have been collected only from the upper unit, as follows (Neuman, 1955, p. 173):

(WA 42):
- *Bimuria superba* Ulrich and Cooper
- *Leptellina tennesseensis* Ulrich and Cooper
- *Paurorthis* sp.
- *Rhipidomena tennesseensis* (Willard)
- *Sowerbyites* sp.

(WA 45):
- *Sowerbyites lamellosus* Cooper?

(WA 61):
- *Atelelasma* sp.
- *Cyrtonotella* sp.
- *Paleostrophomena* sp.
- *Ptychoglyptus virginiensis* Willard
- *Titambonites amplus* (Willard)

(WA 60):
- *Echinosphaerites* sp.
- *Climacograptus* sp.
- *Dinorthis* sp.
- *Leptellina* sp.
- *Multicostella* sp.
- *Oxoplecia* cf. *O. holstonensis* (Willard)
- *Rhipidomena tennesseensis* (Willard)
- *Sowerbyites* sp.

STRATIGRAPHIC RELATIONS

The Tellico formation is overlain conformably by the Chota formation.

CHOTA FORMATION

The Chota formation was named by Neuman (1955, p. 157) for Chota School, Monroe County (Vonore quadrangle), and corresponds to the "sandstone lentil of the Sevier shale" of the Knoxville folio (Keith, 1895a).

Like the Sevier formation, the Chota formation crops out only in the western part of the report area, near the Sevier-Blount County line and on the northwestern side of the Guess Creek fault, where it forms a belt of outcrop 2 miles long that is faulted off northeastward (Walden Creek quadrangle).

Most of the unit is blue-gray calcarenite with much quartz sand. Near its middle on Walker Branch is a 20-foot bed of gray argillaceous limestone of a facies similar to that of the Lenoir limestone and Whitesburg limestone member lower in the section. The Chota differs from the calcareous sandstone of the underlying Tellico formation in containing fewer quartz grains and few or no grains of feldspar; it is also crossbedded in many places, rather than evenly bedded. The sandstone crops out in a prominent ridge or line of knobs which projects above the valleys and lower hills cut on more shaly rocks on either side. The Chota formation seems to be about 650 feet thick at a point 3 miles southwest of its truncation by the Guess Creek fault. The Chota formation contains few fossils throughout its extent, and no significant collections were made in the report area.

The Chota formation is overlain conformably by the Sevier formation.

SEVIER FORMATION

The Sevier shale was named by the folio geologists for Sevier County, in the region of the present report. In the Estillville and Bristol folios (Campbell, 1894, 1899) the term was used in a broad sense for most of the shaly part of the Middle Ordovician sequence, but in the later Knoxville folio (Keith 1895a) it was restricted to the upper part alone. Redefinition by Neuman (1955, p. 160) has further restricted its limits, so that only a small part of the Sevier formation as now defined is preserved in Sevier County, and is confined to a small area in the extreme western part, herein described. As now defined, standard sections of the unit are in an area 10 to 30 miles farther southwest along the strike, where its full thickness of 1,500 to 2,200 feet is preserved between the Chota and Bays formations.

Outcrops of the Sevier formation in the report area form a single narrow belt about 2 miles long at its western edge, near the Sevier-Blount County line (Walden Creek quadrangle). The formation as there exposed lies on the northwestern or downthrown side of the Guess Creek fault and is cut off northeastward by the fault. About 200 to 400 feet of beds are preserved, consisting of gray calcareous sandy shale.

Within the report area the highest beds exposed are part of the Sevier formation of Middle Ordovician age, whose top is cut off by the Guess Creek fault. Higher and younger beds are preserved farther west, west of the Little River, in the southeastern part of the Appalachian Valley near the foot of Chilhowee Mountain. Here, the Sevier formation is overlain by the Bays Formation, also of Middle Ordovician age, and this, in turn, by the Chattanooga shale (Devonian and Mississippian) and the Grainger and Greasy Cove formations (Mississippian) (Neuman and Wilson, 1960). The latter are the highest strata in the Great Smoky Mountains region.

IGNEOUS ROCKS

METADIORITE

A small outcrop of metadiorite occurs at the southeast edge of the report area, in a valley on the north slope of Clingmans Dome at an altitude of 4,350 feet (Silers Bald quadrangle). The metadiorite forms a sill in the Thunderhead sandstone about a thousand feet below the tongue of Anakeesta formation exposed higher on the mountain.

This is the westermost observed exposure of a metadiorite which forms a group of sills in the Thunderhead sandstone between Mount Collins and Clingmans Dome, best developed beyond the report area (Clingmans Dome quadrangle; Hadley and Goldsmith, 1963). The sills are on line of strike with metadiorite sills in the copper district between Hazel and Eagle Creeks 12 miles to the southwest (Fontana and Proctor quadrangles) (Espenshade, 1946), raising a question as to whether they might be continuous, or nearly so, in the intervening report area. West of the observed outcrop, within the report area, the belt in which the sills should occur was traversed on three trails without yielding traces of igneous rock and it seems unlikely that any thick sills exist. Thinner ones might, however, be concealed by weathering or be exposed in the unvisited intervening areas.

The age of the metadiorite is undetermined, but is probably Paleozoic. Its sills follow southeast-dipping foliation and bedding, but the smaller bodies are themselves considerably altered and foliated, suggesting that they were introduced during an intermediate stage in the deformation of the region (Hadley and Goldsmith, 1913).

TECTONICS

GENERAL FEATURES

The central Great Smoky Mountains area lies within the strongly deformed region of the southern Appalachians about 60 miles southeast of its edge and includes parts of two provinces of different structural style. It extends a few miles northward into the Appalachian Valley portion of the Valley and Ridge province and nearly 20 miles southward into the Great Smoky Mountains portion of the Unaka province.

The Valley and Ridge province is made up of sedimentary rocks of Paleozoic age which have been folded and faulted, but little metamorphosed; deformation is a relatively shallow feature, involving mainly the sedimentary rocks themselves.

The Unaka province is made up of older deeper lying rocks, partly of earliest Paleozoic, partly of Precambrian ages, which have likewise been folded and faulted, but metamorphosed also by amounts that increase progressively southeastward. The northwestern border of the province is marked by a wide zone of thrust faulting which extends many miles northeastward and southwestward along the strike, across Tennessee and into adjacent States (Rodgers, 1953, p. 139–147); this faulting is a manifestation of a deep-seated structural discontinuity between the Unaka and the Valley and Ridge provinces. Farther southeast in the Unaka and Blue Ridge provinces faulting diminishes, and deformation has been accomplished mainly by folding and shearing.

The local area is a representative segment of this zone of faulting (pl. 9). At its northwest edge the low-angle Great Smoky fault has moved the rocks of the Unaka province many miles northwestward over the rocks of the Valley and Ridge province; it is a late feature of the deformation, little disturbed since its emplacement and younger than the regional metamorphism. Some miles to the southeast, and wholly within the Unaka province, is another major low-angle fault, the Greenbrier, which has moved the rocks of the main Great Smoky Mountains northwestward over those of the foothills; it is older than the Great Smoky fault, was folded and faulted after its emplacement, and is older than much of the regional metamorphism.

Besides these major faults are a host of others of various magnitudes, which form a complex network in the northwestern parts of the Unaka province, branching and interlacing, some offsetting others, which have formed from time to time, partly as early as emplacement of the Greenbrier fault, partly as late as emplacement of the Great Smoky fault. Fault contacts are the rule between at least the larger stratigraphic units, and normal sedimentary contacts are less common.

Rocks of the Unaka province in the blocks between the faults have been folded in varying degree, according to their competence, some of those between the Great Smoky and Greenbrier faults being so minutely contorted that little idea can be gained of their gross structure, others above the Greenbrier fault forming great homoclinal sequences, miles in breadth.

In the detailed treatment of these structures which follows, successive areas and features will be described from north to south, after which their interpretation will be discussed.

APPALACHIAN VALLEY [12]

The part of the report area within the Appalachian Valley forms a strip 3 to 6 miles broad along its northern edge (Walden Creek and Pigeon Forge quadrangles), in which the surface rocks are mainly the Middle Ordovician series, the Lower Ordovician series emerging in anticlines toward the east and west. These rocks are mainly folded rather than faulted, in contrast to the part of the Valley and Ridge province farther northwest, which is split by many closely spaced thrust faults (Rodgers, 1953, p. 130–136). They are part of a major synclinal belt 8 to 20 miles broad which extends nearly across Tennessee, and whose northeastern part is known as the Bays Mountain synclinorium.

In the segment opposite the Great Smoky Mountains the syncline is bordered on the northwest by the Dumplin Valley fault, which emerges about 2½ miles beyond the northwest corner of the report area. Successively older formations come to the surface toward the fault, down to the Lower Cambrian Rome and Shady formations (Cattermole, 1955). In the report area is a culmination in the synclinal trough; on one side folds plunge northeastward toward the Bays Mountain synclinorium where higher Ordovician rocks are preserved, on the other they plunge southwestward toward a narrower syncline where Mississippian rocks are preserved.

ANTICLINAL AREAS

Part of the synclinal belt is framed on the northwest and southeast by anticlinal uplifts in which Lower Ordovician carbonate rocks lie at or near the surface; these rocks are more broadly folded than the less competent higher Ordovician rocks of the synclinal areas.

On the northwest a blunt-nosed faulted anticline brings up Lower Ordovician rocks along Boyds Creek and is flanked on the southeast by the lower Knob Creek anticline which brings up Blockhouse shale (Walden Creek quadrangle) (section *K–K′*, pl. 9). Both anticlines are open arches a mile or more across, which plunge northeastward beneath the Tellico

[12] Based largely on observations by R. B. Neuman, but includes data from J. G. Bumgarner on the Fair Garden anticline.

formation, in which arching of the beds is less apparent.

On the southeast, close to the Great Smoky fault, is the much larger and higher Fair Garden anticline (Pigeon Forge quadrangle) (section *A–A'*, pl. 9), which extends 14 miles northeastward from the report area. Throughout its course it brings up Lower Ordovician carbonate rocks down to the Chepultepec dolomite, so that its crest must be nearly horizontal; but at its southwestern end, south of Sevierville, it plunges abruptly at angles of 25° to 30° beneath the Tellico formation, in which there is little indication of anticlinal structure. On the broad southeastern flank beds dip 30° or less, but they are duplicated by the Middle Creek fault. On the narrow northwestern flank beds dip steeply or vertically and the Lower Ordovician section is abnormally thin; part of the sequence is perhaps cut out by one or more undetected faults. Curiously, the overlying Blockhouse shale is thicker on the northwestern flank than on the southeastern; on the latter side it may have been thinned tectonically my movements associated with the nearby Great Smoky fault.

South of Sevierville, northwest of the terminus of the Fair Garden anticline, Lower Ordovician carbonate rocks emerge again in the Rock Quarry dome (Pigeon Forge quadrangle) (section *C–C'*, pl. 9), lower structurally than the main anticline and separated from it by a shallow syncline. The dome is irregular, and has dips no steeper than 30° in any direction, but the main axis on the north side trends nearly east. Crude fracture cleavage in the cobbly Lenoir limestone of the south flank of the dome strikes northeast to east-northeast and dips 45° to 70° southeast.

SYNCLINAL AREA

Most of the surface of the synclinal area is formed of Tellico formation, although the higher Chota and Sevier formations are preserved in its deepest part, against the Guess Creek fault near the west edge of the report area (Walden Creek quadrangle). In this vicinity several thick sandstone beds are mappable in the Tellico formation and afford indications of the larger structure, although they are much folded and faulted in detail. In the rest of the synclinal area the Tellico is a homogeneous body of silty and sandy shale which exhibits the characteristic small-scale foldind and faulting of incompetent strata. These structures are disharmonic with those of the carbonate rocks beneath, and were probably detached from them along the still weaker intervening layer of Blockhouse shale.

The complex small-scale folding and faulting of the Tellico formation is visible in nearly every roadcut in the synclinal area, some of the largest and finest exposures being on U.S. Highway 411–441 (pl. 10 *A*.) Folds are overturned northwestward, the axial planes dipping 20° to 70° southeast. Weak fracture cleavage occurs in many places in the shales, and is also developed in the sandy and silty rocks near the axes of folds. Most of the cleavage planes dip steeply southeast. Folds are sharpest and tightest in the southeastern part of the area, where the rocks are also much sheared, slickensided, and veined.

GUESS CREEK FAULT

The synclinal area is crossed diagonally by the Guess Creek fault, on which lower parts of the Middle Ordovician are thrust over high parts on the northwest (Neuman, 1951, p. 746). In the western 5 miles of its trace in the report area (Walden Creek quadrangle), and thence southwestward, the Guess Creek fault lies within less than a mile of the Great Smoky fault and parallel to it, and can be located from the presence of Chota, Sevier, and higher formations on its downthrown side (section *M–M''*, pl. 9). Farther northeast it passes into the more uniform body of the Tellico formation and is less certainly traceable, but a prominent northwest-facing scarp along Guess Creek 2 to 7 miles west of Sevierville lies on its apparent prolongation (Pigeon Forge quadrangle); the scarp is recognizable for about 4 miles beyond the report area north of Sevierville (Kykers Ferry quadrangle), but it fades out in the Tellico formation. If the fault is correctly identified in this eastern segment it diverges from the Great Smoky fault, which here turns southeastward.

As the Guess Creek fault is poorly exposed for the most part, its structural relations are somewhat uncertain. Its close association with the Great Smoky fault in its western segment suggests that it may bound a slice beneath and related to the Great Smoky fault, but its apparent northeastward divergence from the latter implies that it is an independent feature. Neuman suggests that it dips more steeply than the Great Smoky fault, and that it developed as a break on the southeastern flank of the synclinal belt of Paleozoic rocks.

GREAT SMOKY FAULT [13]

The main trace of the Great Smoky fault crosses the northern part of the report area, where it forms the boundary between the Appalachian Valley on the north and Chilhowee Mountain and the foothills of the Great Smoky Mountains on the south. Undula-

[13] Data on the main trace of the fault are from observations by H. W. Ferguson and G. D. Swingle and by R. B. Neuman. Those on the fault and its substructure in the cove areas are largely from observations by Neuman (1951), with additions by King. Discussion of the configuration of the fault is based on a study of structure sections and structure contours by King.

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tions in the surface of the fault cause it to reappear around the edges of various windows farther south, such as those of Wear and Tuckaleechee Coves some of which are as much as 10 miles southeast of its main trace. These occurrences indicate the minimum possible displacement of the fault; actual displacement was certainly much greater.

During early work in the area (Safford, 1869; Keith, 1895a) the manifestations of the Great Smoky fault were not understood and were variously interpreted. Later, the fault was described and named by Keith (1927), although its existence had been inferred by other geologists some years before (Ulrich, 1911, p. 674; Gordon, 1920).

MAIN TRACE

To the west (Walden Creek quadrangle) the main trace of the Great Smoky fault trends northeastward along the base of Chilhowee Mountain, a course which it pursues for many miles farther southwest. Beyond the end of Chilhowee Mountain the trace is deflected more than 2 miles southeastward, and the fault is probably displaced by the Pigeon Forge transverse fault, beneath the alluvium of the valley of the West Prong of the Little Pigeon River. East of the river (east part of Pigeon Forge quadrangle) the trace resumes an east-northeastward course.

Along the main trace of the Great Smoky fault in the report area the Sandsuck and other formations of the Walden Creek group override the Tellico formation of the Middle Ordovician series; both overriding and overridden rocks are mainly sandy or silty shales, and both are nearly unaltered. For about a third of the distance along its trace, these relatively incompetent rocks are separated by thin to thick slices of more competent quartzite, sandstone, limestone, and dolomite, derived from other parts of the overriding and overridden rocks.

The outcrop pattern of the fault indicates that it dips about 30° to 40° southeast or south, which is confirmed by exposures of the fault surface. Several exposures or near-exposures of the fault were observed, and are described below. Many of them, when discovered, prove to be unimpressive for so large a feature. In some, one shale lies on another with slight lithologic contrast and structural discordance, and in all of them there is little breccia or gouge along the contact.

1. About 7 miles southwest of Sevierville, near head of Knob Creek, between Sugarloaf and Little Pine Mountains (Walden Creek quadrangle) (fig. 15*C*). In a cut on a secondary road the fault surface dips 40° east-southeast and is overlain by medium-bedded feldspathic quartzite of the lower part of the Cochran formation, fractured but not brecciated, which is succeeded a few feet higher by feldspathic sandy maroon shale of the same formation. The fault is underlain by shale of the Tellico formation (weathered yellow brown), which nearby contains thin layers of fossiliferous calcareous sandstone. Bedding both above and below is nearly paralled to the fault.
2. About 4½ miles southwest of Sevierville on east side of Yellow Spring Hollow (Walden Creek quadrangle). In a cut on a county road the fault surface dips 40° south, and is followed by a weathered layer a foot thick, made up of fragments of calcareous sandstone and white quartzite. The fault is overlain by brittle silty shale of the Sandsuck formation, containing detrital mica flakes, and is underlain by calcareous shale of the Tellico formation. Bedding both above and below is nearly parallel to the fault.
3. About 2½ miles southwest of Sevierville on west side of valley of West Prong of Little Pigeon River, north of Large Island (Pigeon Forge quadrangle). The river has undercut the slope in a cliff, 1,500 feet long and nearly 200 feet high, which exposes thinly fissile drab calcareous shale and silty shale of the Tellico formation, somewhat more indurated and foliated than elsewhere, whose bedding is much sliced and contorted. These rocks lie just beneath the fault, which occurs southwest of the end of the cliff, but is not exposed. Overriding rocks are sandy micaceous noncalcareous shale of the Sandsuck formation, which forms small outcrops south of the cliff and extends a short distance up the ridge above the cliff, demonstrating a low dip of the fault to the southwest.
4. About 4 miles south of Sevierville in Possum Hollow (Pigeon Forge quadrangle). In a cut on a county road the fault surface dips 50° southeast, and is followed by an 18-inch layer made up of fragments of shale of the Tellico formation in a fine-grained matrix. The fault is overlain by argillaceous rocks of the Wilhite formation, which are knotty and phyllitic, and contain pods of white calcite; bedding is not visible, but foliation dips 35° southeast. The fault is underlain by weathered fossiliferous shale of the Tellico formation, which dips 75° south-southeast.
5. Davids Knob, about 4½ miles southeast of Sevierville (Pigeon Forge quadrangle). The knob, which rises nearly 600 feet above the Appalachian Valley on the north, is a klippe of the Great Smoky thrust sheet and is capped by white quartzite of the Cochran formation, which crops out in discontinuous

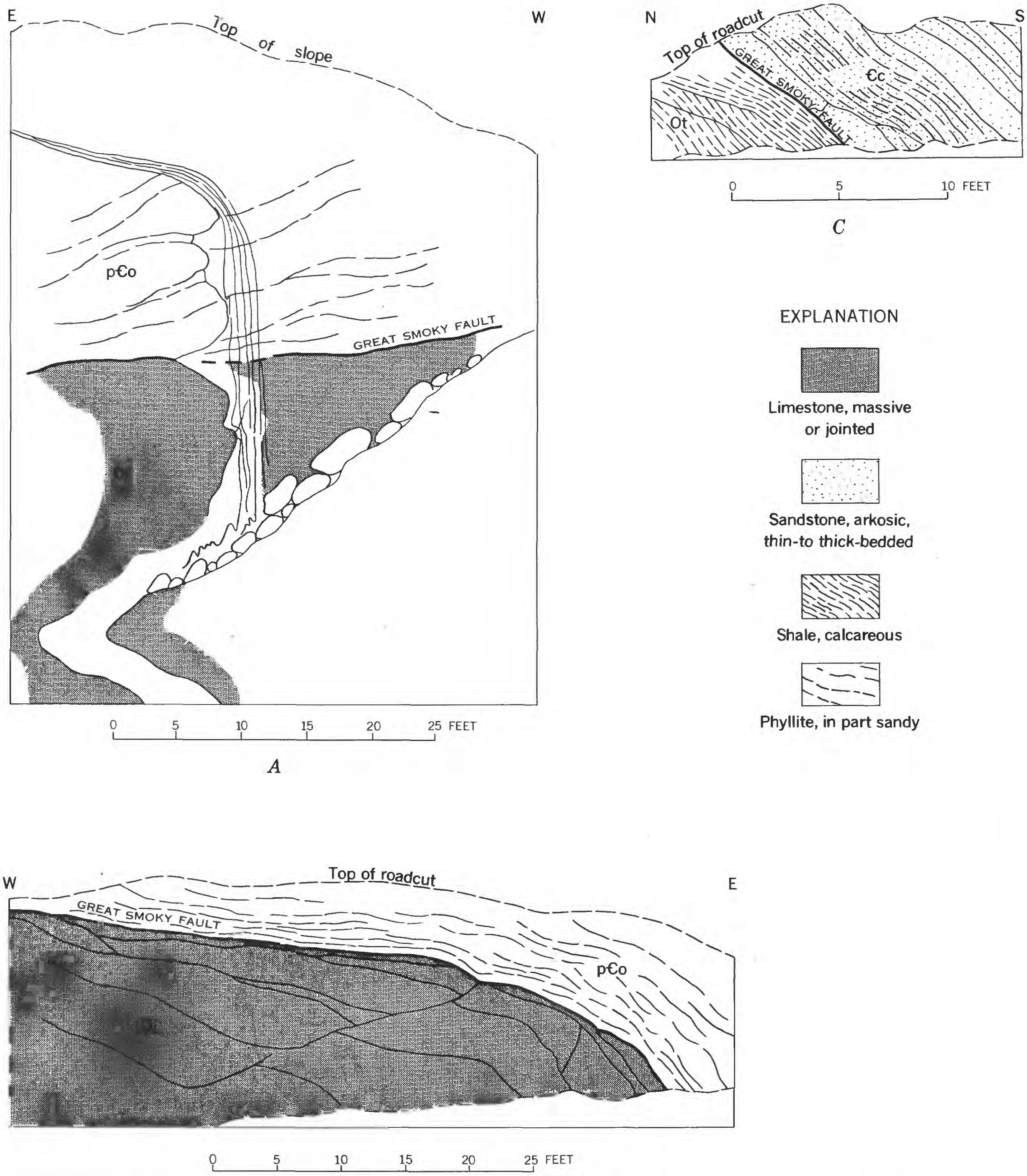

FIGURE 15.—Field sketches showing outcrops of Great Smoky fault in central Great Smoky Mountains. *A*, At waterfall and cave at east end of Whiteoak Sink, 3 miles south of Townsend (Wear Cove quadrangle); south end of Tuckaleechee Cove window. *B*, On Tuckaleechee Cove-Wear Cove road at foot of grade, 3¼ miles east of Townsend (Wear Cove quadrangle); east end of Tuckaleechee Cove window. *C*, On lumber road at northwest base of Chilhowee Mountain, one-half mile southwest of summit of Sugarloaf Mountain (Walden Creek quadrangle): on main trace of fault. Note that sections *A* and *B* are on the same scale, but that section *C* is on a larger scale. pCo, Phyllite of Ocoee series; Cc, Cochran formation; Oj, Jonesboro limestone; Ot, Tellico formation.

ledges and loose blocks. The faulted contact with the underlying Tellico formation is obscured by float, but apparently dips less than 10° south. Along the main trace of the fault to the south, on the slope north of Seaton Branch, obscure exposures suggest that the fault dips 60° to 80° south. Here, shale and thin beds of sandstone of the Walden Creek group override the Tellico formation.

The intermediate slices along the main trace of the Great Smoky fault are most extensively developed along the northwest slope of Chihowee Mountain (Walden Creek quadrangle), where they extend 4½ miles as a continuous body and form the prominent knobs of Sugarloaf, Little Pine, and Big Pine Mountains (fig. 2). These slices consist of Cochran formation, especially its arkosic maroon lower part, but include its upper gray quartzite on Sugarloaf Mountain and a fragment of the upper conglomerate of the Sandsuck formation near the South Fork of Ellijoy Creek (section *L–L'*, pl. 9). The Cochran and Sandsuck of the slices were derived from the higher parts of the Great Smoky thrust sheet.

The Cochran formation of Sugarloaf Mountain is overturned, with its beds dipping 50° southeast, away from the upper gray part and toward the lower maroon part (section *I–I'*, pl. 9). The upper gray quartzite on the northwest, nearest the Great Smoky fault, is much brecciated, jointed and veined. Sugarloaf Mountain evidently forms a separate slice, for it adjoins beds on the southwest which appear not to be overturned.

The Cochran of the slices is separated from the shale of the Sandsuck formation at the base of the main overriding block of Chilhowee Mountain by another fault, which dips steeply southeastward and probably branches from the Great Smoky fault at depth. Along it, southwest of Knob Creek, the arkosic sandstone is much sheared and dolomitized, and parts are replaced entirely by a medium-grained blue-gray dolomite, containing scattered relict quartz grains, and thin veinlets of pink dolomite. The replacement is comparable to the more extensive dolomitization of the Cochran equivalent along zones of structural weakness in the Del Rio district northeast of the Great Smoky Mountains (Ferguson and Jewell, 1951, p. 47, 86–87).

Between the slices of Cochran northwest of Chilhowee Mountain and the Tellico formation beneath the Great Smoky fault are a few shorter narrow slices of Jonesboro limestone (Lower Ordovician), derived from the overridden block. They were observed on the South Fork of Ellijoy Creek and on Coldspring Branch.

East of Sugarloaf Mountain the slices along the Great Smoky fault are smaller and are separated by wider gaps; they were either discontinuous originally, or were remnants of more continuous slices higher up, now largely destroyed by erosion. Quartzite of the Chilhowee group, probably mainly Cochran formation, forms Jackson Knob west of Guess Creek and Davids Knob southeast of Sevierville, as well as many lesser knobs and hills. One of the larger slices on Guess Creek is composite, being half quartzite and half dolomite of the Jonesboro.

The southeastward offset of the main trace of the Great Smoky fault in the valley of the West Prong of the Little Pigeon River is alined with the Pigeon Forge transverse fault, which is mapped for 6 miles southeastward through the overriding rocks to the vicinity of Gatlinburg. The northern half of the trace of the Pigeon Forge fault, near the Great Smoky fault, is covered by alluvium of the river valley, and even in its southern half its position in the bedrock can be located definitely only in places. Its existence is indicated, nevertheless, by discontinuities in rocks and structures across the valley; structures which can be correlated on the two sides are displaced left laterally by half a mile or more. Northwestward prolongation of the fault into the overridden rocks would carry it into a wide expanse of Tellico formation where it has not been mapped, and in which it could not be located readily in any event.

Offset of the surface trace of the Great Smoky fault across the Pigeon Forge fault is in a right-lateral sense, but this was probably not the actual displacement of the Pigeon Forge fault. Besides the dominant left-lateral strike-slip displacement on the Pigeon Forge fault, there may have been a minor component of dip-slip displacement, which dropped the rocks and structures on the southwestern side. This dip-slip component would have been less effective in offsetting the steeply dipping structures of the overriding block than in offsetting the low-dipping Great Smoky fault.

The Pigeon Forge fault thus apparently displaces the Great Smoky fault, the structures of the overriding block, and perhaps those of the overridden block. This does not indicate, necessarily, that the Pigeon Forge fault is a younger feature; considerable discontinuities in rocks and structures across it suggest that it was more likely developed as a flaw in the Great Smoky thrust sheet, during emplacement of that feature.

WEAR COVE

Southeast of its main trace, the Great Smoky fault emerges again around Wear Cove (Wear Cove and Gatlinburg quadrangles) (section *K'–K''*, pl. 9). The falt encloses an oval window 5 miles long and 2 miles wide, elongated northeastward, which forms the low ground of the cove that is excavated in the overriden

Lower and Middle Ordovician rocks (fig. 3). In Wear Cove the fault surface is nowhere exposed, and the Ordovician rocks are extensively masked by alluvium, washed mostly from the adjacent hills. Nevertheless, a convincing picture of the structure can be worked out from what outcrops there are, supplemented to some extent by water-well data in the intervening areas.

On the Knoxville geologic map Keith (1895a) showed five areas of Lower Ordovician carbonate rocks ("Knox dolomite") on the floor of the cove, surrounded by Ocoee series ("Wilhite slate"), which he later (1927) interpreted as separate windows in the thrust sheet. Areas thus mapped as Ocoee, however, are a combination of outcrops of Middle Ordovician shale with areas covered by wash from the Ocoee series of the overridden block. The cove is actually a single window.

As delimited by outcrops near it, the Great Smoky fault has a variable height around the edges of the cove, descending to the level of the floor in places and rising high on adjacent hills in others. It rises to an altitude of 2,000 feet on the west spur of Raven Den at the eastern end, and nearly as high on Buckeye Knob on the southeastern side, but it descends below 1,400 feet where Cove Creek leaves the cove on the north. The surface is somewhat irregular in detail, having differences in altitude of more than 100 feet within short distances. Southwestward toward Tuckaleechee Cove the fault must remain relatively high beneath the overriding rocks (section *N′–N″*, pl. 9). Between the two coves in the lower ends of Patterson and Lemon Hollows, the drainage descends into sinkholes—two in one hollow, three in the other—which stand at altitudes of 1,640 feet. The smaller sinks expose only the overriding phyllite, but several of the larger reveal overridden limestone in their bottoms.

Overriding rocks of the window are parts of the Ocoee series—Walden Creek group on the northwest and mainly Snowbird group on the southeast. They are complexly folded and faulted in a manner to be described below; at least part of the deformation is earlier than the thrusting. The overriding rocks were regionally metamorphosed before emplacement, in contrast to conditions along the main trace of the Great Smoky fault; their argillaceous rocks have been converted to chloritic slate and phyllite, whereas the overridden argillaceous rocks remain unaltered.

Overridden rocks of the window are Lower Ordovician and basal Middle Ordovician limestone (Jonesboro and Lenoir limestones) and Middle Ordovician shale (Blockhouse shale). These form two structural elements—an underlying core, emerging in the central part of the cove, and a series of overlying slices, exposed around the edges, which partly separate the core from the Great Smoky fault.

The core of the window is an irregular double-crested dome, which brings up Jonesboro limestone, surrounded by Blockhouse shale. Observed dips in the limestone are from 10° to 55°, but the gross structure is a gentle arch. The thin Lenoir limestone is only sporadically exposed but is probably continuous around the northern and eastern sides of the dome; it is missing in a minor uplift toward the southwest, where it may have been removed by tectonic stripping in the same manner as in Tuckaleechee Cove (p. 95). The surrounding Blockhouse shale is deeply weathered on the outcrop and has much steeper and more erratic dips than the limestones. Its structure may have resulted from deformation of the incomplete rock, although part may have been produced by slumping, resulting from loss of volume during weathering.

The slices above the core of the window separate it from the Great Smoky fault through about half the circumference of the cove. They are composed almost wholly of Jonesboro limestone, but two small higher slices on the slope of Buckeye Knob are formed of quartzite of the Chilhowee group; no Blockhouse shale is present. The limestone of the slices appears to have been derived from stratigraphic levels beneath the limestone exposed in the core. It is lithologically distinct from the limestone of the core, and in the slice in the Raven Den area is like limestone in the lower part of the Lower Ordovician exposed in other areas.

The largest slice is in the northeastern part of the window, where limestone is exposed in scattered outcrops over an area half a mile wide and more than 2 miles long; outcrops are most extensive on the west spur of Raven Den where the slice must be about 250 feet thick. The slice on Buckeye Knob on the southeast side of the window does not extend as far, but it is at least 350 feet thick. Slices farther southwest are thinner and shorter and are missing altogether on the northwest side of the window.

TUCKALEECHEE COVE

Southwest of Wear Cove the Great Smoky fault emerges again in Tuckaleechee Cove, a larger window 7 miles long and 2 to 3 miles wide, only the eastern half of which lies in the report area (Wear Cove and Kinzel Springs quadrangles) (section *P-P′*, pl. 9). Many of the same structural features occur here as in Wear Cove; also some others. Relations are better exposed as a result of dissection by the through-flowing Little River.

On the Knoxville geologic map the contact shown in Tuckaleechee Cove by Keith (1895a) between Ordovician carbonate rocks ("Knox dolomite") and Ocoee series ("Wilhite slate") is mostly the stratigraphic contact between the Lower and Middle Ordovician series. The Great Smoky fault actually lies higher on the slopes surrounding the cove. It stands between 1,400 and 1,600 feet in most of the report area, but it rises to more than 2,000 feet farther west and descends to valley level where the Little River enters and leaves the cove on the southeast and northwest.

The trace of the fault is sinuous because of its low dip. On the north side of the window its sinuosities indicate that it dips 5° to 10° north. On the south side the dip is even lower to the south or southeast, so that parts of the overlying thrust sheet have been detached by erosion from the rest and cap outlying hills within the cove; they are klippen within the window. One of these lies above Cedar Bluff northeast of the Little River; another forms Little Mountain southwest of the river, only the eastern spurs of which extend into the report area.

Because of plentiful outcrops in the cove, the position of the Great Smoky fault can be located closely in most places, and several exposures or near exposures of the fault surface were observed, two of which merit special description:

1. East end of window, along county road from Tuckaleechee to Wear Coves (Wear Cove quadrangle). The Great Smoky fault, dipping at a low angle southward, crosses the road several times as it ascends the grade to the divide between the two coves. The surface of the fault has been exposed from time to time at some of these crossings, although part of the exposures have been obliterated by later realinement of the road. In all exposures, phyllite and sandstone of the Walden Creek group lie on limestone of the Lower Ordovician. The best exposures when the area was last visited (1954) were at the foot of the grade, at an altitude of about 1,240 feet (fig. 15*B*). Here, the fault surface dips irregularly 10° southeast, and there is no gouge or breccia. Bedding of adjacent rocks is approximately parallel to it, but is much disturbed. The phyllite above is scaled and sliced, and the limestone beneath is strongly jointed. A former excellent exposure, now obliterated, was higher up the grade at an altitude of 1,400 feet; it showed a smooth fault surface on the underlying limestone, which dipped 20° south, and had no gouge or breccia. Still higher on the road, limestone projects through the phyllite in several places and is much silicified.
2. On Tennessee Highway 73, just north of the Townsend entrance of Great Smoky Mountains National Park (Wear Cove quadrangle) (pl. 11). Here, a cut 1,000 feet long and nearly 100 feet high exposes rocks both above and below the Great Smoky fault; the fault itself is poorly exposed, except in a few small outcrops, and is mostly covered by wash. Its position can be determined closely by limited outcrops; its dip is less than 10° south. The overlying Metcalf phyllite (Snowbird group) is smoothly and regularly foliated for the most part, but in one outcrop close to the fault on the north it is strongly contorted and has a polymetamorphic fabric.

Beneath the Great Smoky fault is an intermediate slice of blue-gray limestone 5 to 25 feet thick, probably derived from the Jonesboro limestone, but so broken, veined, and reconstituted that not trace of original bedding or fossils remains. The slice lies on drab-gray calcareous Blockhouse shale which is slickensided but otherwise unaltered, thus being of markedly lower metamorphic rank than the argillaceous rocks of the overriding Metcalf phyllite. The Blockhouse lies discordantly on the Lenoir limestone along a "surface of movement" (p. 5).

At this locality the Ordovician rocks below the Great Smoky fault have been broken by many normal faults, mostly downthrown on the south and dipping 60° toward the downthrow, with displacements of a few feet to more than 50 feet. One of these faults near the middle of the cut, which drops Blockhouse shale down against Lenoir limestone, has previously been identified as the main Great Smoky fault (Wilson, 1935, fig. 3, p. 62). Small normal faults near the south end of the exposure offset the intermediate limestone slice and the Great Smoky fault; it is inferred that the larger ones farther north do also.

Overriding rocks of the Tuckaleechee Cove window, like those of the Wear Cove window, are part of the Ocoee series—Walden Creek group on the north and Snowbird group on the south—and possess a similar complex structure. Contrast in grade of metamorphism between the overriding and overridden rocks is general around the cove. At many localities, as much as 2 miles north of the window, foliation of the overriding rocks departs from its usual southeastward inclination and dips aberrantly eastward, northeastward, or northwestward, as though it had been rotated after formation, during or after emplacement of the Great Smoky fault.

Overridden rocks of the Tuckaleechee Cove window, like those of the Wear Cove window, are Lower Ordovician and basal Middle Ordovician limestone (Jonesboro and Lenoir limestone) and Middle Ordovician shale (Blockhouse shale); as in Wear Cove they form two structural units, a core and a set of intermediate slices, but the core is more extensively exposed and the slices are smaller.

The core is a highly irregular domical uplift which brings up Jonesboro limestone in a wide area in the center of the cove, with a narrow band of Blockhouse shale around the edges; the latter is missing at a few places on the southeast and east sides, so that the Great Smoky fault lies directly on the limestone. The dome seems to conform broadly to the arched configuration of the Great Smoky fault above it, although the local structure of the core rocks is steeper and more complex than that of the fault.

Single outcrops of Jonesboro limestone expose sections as much as 400 feet thick, and its total exposure in the cove may be several thousand feet, yet only fossils of Mascot age (upper part of Knox group) have been collected, suggesting that the sequence has been much repeated. Such repetition is indicated by a few favorable exposures as follows:

1. At Cedar Bluff, a cliff more than 300 feet high on the northeast bank of the Little River, on the southeast side of the cove (Wear Cove quadrangle). The cliff is Jonesboro limestone, but higher on the slope this is capped by Metcalf phyllite of the Great Smoky thrust sheet. Although the limestone dips generally at a low angle to the southeast, it is thrown into open folds and is cut by at least six low- to steep-angle thrusts, which variously duplicate the strata.
2. West of Walker Hollow, about a mile north of the Little River, at the contact between the Jonesboro limestone and overlying Middle Ordovician rocks on the north (Wear Cover quadrangle). Detailed mapping indicates that the Jonesboro and Lenoir limestones are repeated by two or three low-angle thrusts, which are truncated, in turn, by a fault at the base of the Blockhouse shale.

The Blockhouse shale succeeds the limestones of the core in normal stratigraphic order, but through much or all of the window it overlies them with tectonic discontinuity; evidently it was detached from its foundation and moved across it during emplacement of the overlying Great Smoky thrust sheet. The contact, here termed a "surface of movement," is shown by a separate symbol on the geologic map. Thin units at the contact—the Lenoir limestone and the Whitesburg and Toqua members of the Blockhouse shale—were originally deposited in continuous layers across the area, but they are now preserved only along short segments of outcrop. Elsewhere, Blockhouse shale lies directly on Jonesboro limestone, in some places, as at High Top, with much angular discordance. Amount of movement of the Blockhouse over the rocks beneath is undetermined, but on the northwest side of the cove, mostly west of the report area (Kinzel Springs quadrangle), long slices of Jonesboro and Lenoir limestones are embedded in the Blockhouse shale; they may represent fragments which were peeled from the crest of the dome farther southeast.

Intermediate slices between the Blockhouse shale and Great Smoky fault extend continuously around most of the circumference of the window. Some are a mile or more long, but most are only a few feet to a hundred feet thick; the slice described at the Townsend entrance is typical of the smaller. The largest and thickest slice is in the southwestern part of the window, mostly west of the report area, although its feather edge extends into Mitchell Hollow; it probably also includes the overridden rocks in Whiteoak Sink (see below).

Most of the slices consist of Jonesboro limestone, except for a small body of *Scolithus*-bearing quartzite of the Chilhowee group west of the report area (Kinzel Springs quadrangle). In the thinner slices, as at the Townsend entrance locality, the limestone has been so shattered and reconstituted that its original nature is not apparent and its position in the sequence therefore cannot be determined. One of the slices northeast of Cedar Bluff, which includes a fragment of overlying Blockhouse shale, must have come from top of the Jonesboro; but the large slice in the southwestern part of the cove, which has yielded fossils of Longview (early Early Ordovician) age, must have been derived from lower in the sequence than any rocks exposed in the core area.

WHITEOAK SINK

South of Tuckaleechee Cove is Whiteoak Sink, whose eastern part extends into the report area (Wear Cove and Kinzel Springs quadrangles) (section *S–S′*, pl. 9). It is a separate deep topographic depression half a mile across, floored by limestone and nearly surrounded by Metcalf phyllite. Limestone is continuous over the divide from Whiteoak Sink into Tuckaleechee Cove (Kinzel Springs quadrangle), so that, strictly speaking, the area is part of the Tuckaleechee Cove window.

Around most of the circumference of the sink, the Great Smoky fault can be located closely from outcrops of adjacent rocks, except on the south where it is heavily covered by mountain wash. It stands at altitudies of 1,800 to 2,000 feet, or higher than in the eastern part of Tuckaleechee Cove.

The fault surface is exposed only at the eastern end, where a stream from the nearby hills plunges over a cliff and disappears into an underground channel (fig. 15*A*). The fault lies about halfway up the side of the cliff and dips 10° east-southeast, forming a clean-cut surface with no more than a few inches of gouge at the contact. Overlying rock is foliated sandstone, probably part of the Cades. Underlying rock is Jonesboro limestone, which is greatly sheared for 3 or 4 feet below the contact. Microscopic examination of a specimen of the sheared limestone (WC 9) by J. B. Hadley indicates that it is much deformed, crushed, and recrystallized, and has a foliation of subparallel lenses of carbonate of contrasting grain size, which produce light and dark laminae in hand specimen.

BIG SPRING COVE

Another window of the Great Smoky fault underlies Big Spring Cove 1½ miles south of Whiteoak Sink on the road to Cades Cove (Thunderhead quadrangle.) The window is entirely covered by wash from nearby mountains, but its presence is indicated by four shallow sinkholes in the alluvium. The alluvial basin is about half a mile in diameter and is surrounded on all sides but the south by hills of Metcalf phyllite; on the south, beyond the trace of a fault of the Gatlinburg family, ridges of Elkmont sandstone rise toward the heights of the main Great Smoky Mountains.

To verify the occurrence of limestone beneath the sinkholes, a boring was made by the U.S. Bureau of Mines in 1951, under geologic direction of R. B. Neuman. Limestone, probably Jonesboro, was penetrated at a depth of 45 feet, under an overburden of bouldery alluvium; the lower part of the boring, to a total depth of 70 feet, was in a mud-filled crevice, probably in the weathered surface of the limestone.

The window at Big Spring Cove lies farthest back from the main trace of the Great Smoky fault, and is 10 miles southeast of the latter on the farther side of Chilhowee Mountain. The overriding rocks also lie farther back in the metamorphic terrain than those of any other window; the adjacent Metcalf phyllite is in the incipient phase of the biotite zone, and contains not only dominant chlorite but minor biotite.

CONFIGURATION OF GREAT SMOKY FAULT

General configuration of the Great Smoky fault is apparent from its outcrops and the distribution of the overriding and overridden rocks; these indicate that it dips southeast from its main trace, but rises again in the windows farther southeast. Nevertheless, the only absolute facts on the configuration of the fault are its various dips and altitudes along the outcrop. Its subsurface position cannot be proved, as there are no drill data; but it can be inferred from the structures and the lay of rock formations above and below it.

These facts and inferences were used to prepare contours on the surface of the fault (pl. 12). Closely spaced structure sections were drawn along parallel lines across the area (some of which are reproduced on pl. 9); on these sections the position of the fault was sketched. The contours are based on altitudes of the fault surface that were scaled from these sections and plotted on a map.

In sketching the Great Smoky fault on the structure sections it was assumed that it conforms to other structures of the area, some of which were contemporaneous, others earlier or later. It conformed to contemporaneous structures, was shaped by later structures, and even conformed to some of the earlier structures, shearing around competent rock units, and following zones of weakness already created. It probably did not truncate indiscrimately the tops of structures in the overridden block or the bases of structures in the overriding block.

The assumptions made in sketching the Great Smoky fault can be illustrated by a few examples:

1. Faults which bound the lower sides of intermediate slices were formed at the same time as the main Great Smoky fault, and are roughly parallel to it (for example, section *H'-H''*, pl. 9). They provide information as to the former position of the Great Smoky fault above them.
2. Doming of the overridden rocks in the cores of Wear and Tuckaleechee Coves probably occurred at about the same time as doming of the fault, either during or after its emplacement, and provides information as to the former position of the Great Smoky fault above them. However, the structure of the cores conforms less to configuration of the fault than does that of the intermediate slices (for example, section *M'-M''*, pl. 9). The core rocks dip more steeply and irregularly than the observed surfaces of the fault, probably because of interposition of the incompetent Blockhouse shale.
3. In many areas configuration of the fault must conform broadly to that of the overlying bedding. Observed truncation of rocks and structures in the overriding block by the Great Smoky fault is generally at a low angle. Northeast of Wear Cove, the Shields formation is warped into a broad northeast-plunging arch which reflects the northeastward extension of the arching of the fault over the Wear Cove window (section *G'-G''-G'''*, pl. 9).
4. At several places in the overriding block, competent rocks, such as those of the Cochran formation on Chilhowee Mountain, are deeply downfolded into synclines. The Great Smoky fault probably does not truncate the bases of these competent rocks, but descends beneath them through less competent strata (section *J'-J''*, pl. 9).

5. The Great Smoky fault probably extends beneath the Greenbrier fault, whose roots are farther southeast, and whose upper plate consists of the competent rocks of the Great Smoky group. Southeast of Wear and Tuckaleechee Coves the Greenbrier fault dips 30° or steeper toward the southeast, and the Great Smoky fault probably descends beneath it (section *I′–I″*, pl. 9).

Contours on the surface of the Great Smoky fault, prepared in this manner, suggest that it slopes southeastward from its main trace at about the same angle as it does on the outcrop, as far as the trough of the Chilhowee Mountain syncline, where it lies more than 1,600 feet below sea level. It then rises in a distance of 5 or 6 miles to the crests of the Wear and Tuckaleechee Cove windows, where it stands at more than 2,400 feet above sea level. Southeast of the windows it descends again, steeply in the Wear Cove segment, gently in the Tuckaleechee Cove segment, where it remains near the surface as far south as Big Cove.

The last exposures of the fault to the southeast are in the coves, and no facts are available as to its position beyond, under the Great Smoky Mountains. If the Great Smoky fault extends beneath the Greenbrier fault, it must descend to great depths, for rocks above the Greenbrier fault are at least 25,000 feet thick along the State-line divide at the south edge of the report area.

SUMMARY

From this description of the Great Smoky fault, the following items of general significance can be derived:

1. The Great Smoky fault is a major low-angle thrust, which extends along the strike far beyond the report area, and is exposed across the strike for a known breadth of 10 miles. It probably plunges to great depth southeastward beyond its last exposure.
2. No rocks of the overriding block are duplicated by those of the overridden block within the observed breadth; so the actual displacement of the fault is greater than 10 miles.
3. Overriding rocks show an increasing grade of metamorphism southeastward. Those along the main trace are nearly unaltered; those farthest southeast are in the biotite zone. Metamorphism occurred before the thrusting, as the overridden rocks are unaltered. Metamorphism of the overriding rocks suggests that they were deformed before the thrusting.
4. The fault surface descends through the overridden rocks southeastward across its known breadth, from high in the Tellico formation on the northwest, through intervening formations down to the Jonesboro limestone on the southeast; slices of rocks of the Chilhowee group along the fault indicate that it extends as low as that unit beyond the last outcrops. Descent of the fault surface through the overridden formations occurs over so broad an area that these formations were probably only slightly deformed before the thrusting.
5. The Great Smoky fault mostly follows incompetent layers. Throughout the cove areas the fault or its intermediate slices overlies the Blockhouse shale. Along much of its course farther northwest, shale of the Walden Creek group overlies shale of the Middle Ordovician series, although more competent overriding rocks occur a short distance above or behind it.
6. Intermediate slices are common along the Great Smoky fault between the overriding and overridden rocks. The slices of the Chilhowee group along the main trace of the fault were derived from higher parts of the overriding block. The rest of the slices are from the overridden block: those in the north from the upper part of the Jonesboro limestone, those farther southeast from its lower part and from the still lower Chilhowee group.
7. The Great Smoky fault is a clean-cut surface, which is nearly parallel to, or cuts across, the bedding or foliation. Fault breccia and gouge are thin or absent. Overlying and underlying rocks in most places show few effects that can be attributed to movement of the fault, although in some places adjacent quartzite and limestone beds have been finely crushed and reconstituted, and in others the overriding phyllite has a polymetamorphic fabric.

CHILHOWEE MOUNTAIN BLOCK[14]

Chilhowee Mountain, the northeastern 7 miles of which extends into the report area (Walden Creek quadrangle), is the highest part topographically of a structural block just southeast of and above the Great Smoky fault (fig. 2), which is separated from the main body of overriding rocks of the Great Smoky thrust sheet on the southeast by the Miller Cove fault family. In the western half of the report area, the block is about 3 miles wide, but it terminates eastward near the West Prong of the Little Pigeon River by convergence of the Great Smoky and Miller Cove faults (Pigeon Forge quadrangle).

The Chilhowee Mountain block differs from the rest of the Great Smoky thrust sheet both stratigraphically and structurally, and was probably not transported as far northwestward on the thrust sheet from its place

[14] Based largely on observations by H. W. Ferguson and G. D. Swingle.

of origin as the blocks southeast of it. It includes Cambrian(?) and Cambrian formations, mainly Chilhowee group in the report area, but including Shady dolomite and Rome formation in the area farther southwest. These formations lie on the Sandsuck formation of the Walden Creek group, not represented in the block to the southeast within the report area. In contrast to the rocks farther southeast, those of the Chilhowee Mountain block are for the most part openly folded, even in the relatively incompetent Sandsuck formation, and show little contortion or shearing except near the Great Smoky and other faults. They are also virtually unmetamorphosed; shales of the Sandsuck possess only a faint dull cleavage at most, and pebbles in its conglomerates retain their detrital shapes and are not crushed or flattened.

SUBDIVISIONS

Within the report area, the Chilhowee Mountain block is split longitudinally by the Bogle Spring fault, a member of the Miller Cove fault family described below. The part to the northwest forms the main crest of Chilhowee Mountain and preserves a full section of the Chilhowee group with Sandsuck formation beneath; the part to the southeast forms rugged foothills and exposes mainly the upper sandstone and conglomerate of the Sandsuck formation and some remnants of Cochran formation (basal Chilhowee) on the higher ridges. East of the end of Chilhowee Mountain the Bogle Spring fault passes into the lower shale of the Sandsuck formation, and distinctions between the northwestern and southeastern parts of the Chilhowee Mountain block are no longer apparent.

STRUCTURE OF NORTHWESTERN PART OF BLOCK

The Chilhowee group of the northwestern part of the block, between the Great Smoky and Bogle Spring faults, is folded into a syncline whose axis lies near its southeastern side (for example, section *J–J′*, pl. 9). On the wide northwestern flank beds dip southeast at angles of 20° to 35°; on the narrower opposite flank they are in part steep or overturned. The syncline plunges southwest at the northeast end of the mountain, but the plunge is reversed between The Wolfhook and Doyle Springs, creating a basin beneath Bench Mountain, and another farther west which plunges southwestward toward Miller Cove.

STRUCTURE OF SOUTHEASTERN PART OF BLOCK

The southeastern part of the block, between the Bogle Spring and Miller Cove faults, is broadly anticlinal (for example, section *J–J′*, pl. 9). The lower shale of the Sandsuck formation emerges on the arches as inliers in the overlying sandstone and conglomerate, notably on Sandsuck Branch and in the cove in the headwaters of Walden Creek northeast of Hornet; outliers of the basal part of the Cochran formation occur on ridge tops mainly on the northwest and southeast sides of the anticline. In detail, angle and direction of dip in the Sandsuck formation is more varied than in the northwestern part of the block and a few minor faults have been mapped; but the beds retain their continuity, and the structure nowhere attains the complexity of that in the Walden Creek group southeast of the Miller Cove fault.

MILLER COVE FAULT FAMILY[15]

In the western part of the report area the main trace of the Great Smoky fault is paralleled by another set of major faults 2 or 3 miles to the southeast, on the opposite side of Chilhowee Mountain (Walden Creek quadrangle). These are termed the "Miller Cove fault family" after its longest member; two others, the Bogle Spring and Walden Creek faults, lie northwest and southeast of it.

BOGLE SPRING FAULT

The Bogle Spring fault branches northeastward from the Miller Cove fault about 2 miles west of the report area (Kinzel Springs quadrangle); in the report area it splits the Chilhowee Mountain block longitudinally into two parts. Through much of its course the fault raises sandstone and conglomerate of the upper part of the Sandsuck formation on the southeast against Chilhowee group on the northwest, but east of the end of Chilhowee Mountain it passes into the shale of the lower part of the Sandsuck and its course is difficult to trace; it probably rejoins the Miller Cove fault a little west of the West Prong of the Little Pigeon River.

The Bogle Spring fault, which dips southeastward at an angle of 45° or less, is only scantily exposed in the report area, but it can be located closely by quartzite slices which occur along it. These slices are most abundant for about 4 miles along the flank of Chilhowee Mountain near its northeastern end (Walden Creek quadrangle), where many minor faults also branch northeastward and southwestward into the country rock. The largest slice, southeast of Bench Mountain, is 2 miles long and ½ mile wide, and is formed at the surface by Hesse sandstone, Helenmode formation, and Shady dolomite, all dipping southeastward at low angles, in inverted order (section *J–J′*, pl. 9). Smaller slices farther southwest are sheared quartzite, variously identified as Hesse, Cochran, or Nebo formations; another to the east, near Mountain View School, is Shady dolomite.

[15] Based on observations by H. W. Ferguson and G. D. Swingle and by Warren Hamilton.

Origin of the slicing along the Bogle Spring fault is suggested in part by relations on Blue Rock Mountain, where the fault is adjoined on the northwest by highly sheared steeply dipping quartzite of the Cochran formation, which is thrust northwestward, in turn, over Nichols shale (section *M–M′*, pl. 9). The latter thrust dies out southwestward, so that the steeply dipping Cochran merges with the southeast flank of the syncline on Chilhowee Mountain.

Many of the slices along the Bogle Spring fault cannot be explained so readily, for they are made of formations higher stratigraphically than those adjoining them on either side. The original structure from which these slices were broken is undetermined, but it must have been more complex than a mere steep limb of the Chilhowee Mountain syncline.

MILLER COVE FAULT

The Miller Cove fault proper lies wholly in the Walden Creek group and separates the openly folded shale, sandstone, and conglomerate of the Sandsuck formation on the northwest from the more contorted similar rocks of the Whilhite and Shields formations on the southeast (for example, section *J–J′*, pl. 9).

It enters the report area from the west along the north side of Long Ridge, thence follows the edge of the hills northwest of the valley of Walden Creek (Walden Creek quadrangle); but east of the end of Chilhowee Mountain it passes into shale so that its course is difficult to trace. The fault apparently reaches the valley of the West Prong of the Little Pigeon River half a mile north of Henderson Springs (Pigeon Forge quadrangle), where a lithologic contrast in shales on the two sides was observed by Hamilton, and it may join the Great Smoky fault beneath the valley alluvium on the east.

The Miller Cove fault was located closely by Ferguson between Patty Branch and Nichols Branch, where topographic and lithologic contrasts on the two sides are greatest; at a point about a mile east of Patty Branch an outcrop of its surface dips 25° southeast. Here and elsewhere, the Miller Cove fault is a single break, separating sharply the Sandsuck formation from the rest of the Walden Creek group on the southeast, without the slicing or branching which occurs along the Bogle Spring fault. Within half a mile to the northwest, however, the shales, sandstones, and conglomerates are repeated by minor thrusts, probably related to the main fault.

WALDEN CREEK FAULT

The southeasternmost fault of the family, the Walden Creek, branches eastward from the Miller Cove fault a little west of Sandsuck Branch (Walden Creek quadrangle) and follows the south side of the valley of Walden Creek to within a mile of the West Prong of the Little Pigeon River (for example, section *H-H′*, pl. 9). Here it seemingly turns southeast past Pigeon Forge, is offset by the Pigeon Forge fault, reappears east of the river, and joins the Great Smoky fault south of Davids Knob (Pigeon Forge quadrangle).

The Walden Creek fault can be located less closely than the other two members of the family, as it lies within poorly differentiated rocks of the Walden Creek group. Nevertheless, presence of a major break in this position is suggested, not only by subtle lithologic differences between the upper division of the Wilhite formation on the northwest and the Shields formation on the southeast, but by contrasts in metamorphism on the two sides. Argillaceous rocks of the Wilhite are shale or argillite, and those of the Shields are thinly fissile slate. Hamilton concludes that the fault probably developed later than the metamorphism, for in several places north of Pine Mountain nearby cleavage dips in aberrant directions, as though subsequently deformed. Repetition of slate and conglomerate beds on Valley Ridge, southeast of Walden Creek, may result from imbrication above the fault (section *I–I′*, pl. 9).

BROADER RELATIONS

Faults of the Miller Cove family bound a major discontinuity in the Great Smoky thrust sheet, between the Chilhowee Mountain block on the northwest, which moved many miles over the rocks beneath, and the main mass of the thrust sheet on the southeast, which moved even farther. Faults of the family undoubtedly branch from the main Great Smoky fault at depth, but no evidence is available as to whether they moved at the same time as the main fault or at a slightly different time.

In a segment about 7 miles long in Miller Cove (Kinzel Springs quadrangle) the Miller Cove fault has the maximum stratigraphic throw of the family; the Shady dolomite and Rome formation (Cambrian) are downthrown on the northwest against the Walden Creek group. Northeast of Miller Cove, displacement is distributed between the three branches of the family. The Bogle Spring fault has many intermediate slices—a characteristic of major thrusts in the Appalachian region—but it lies within the Chilhowee group and Sandsuck formation, which are mildly folded and metamorphosed on each side; its stratigraphic offset is small. The Miller Cove fault proper separates openly folded Sandsuck formation from complexly deformed lower formations of the Walden Creek group; its stratigraphic throw is greater, and perhaps also its actual displacement. The Walden Creek fault lies wholly within the lower formations of the Walden Creek group, but forms a metamorphic discontinuity; its displacement, relative to that of the others, is undetermined.

The great stratigraphic displacement of the Miller Cove fault in Miller Cove has led some geologists (Wilson, 1935; Stose and Stose, 1949, p. 296, fig. 4, p. 301) to interpret it as the main Great Smoky fault and to assign an independent and minor role to the fault on the opposite side of Chilhowee Mountain to the northwest. Evidence presented herein demonstrates that the two faults are parts of the same system of displacement, the one to the northwest being the sole fault, as the rocks above it on Chilhowee Mountain are themselves a far-traveled mass.

That these distinctions are relative is illustrated by relations east of the report area. From English Mountain northeastward the frontal fault is again bordered on the southeast by Chilhowee group, Shady dolomite, and Rome formation, which are overridden, in turn, on the southeast by Ocoee series along faults analogous to the Miller Cove family (Hamilton 1961). In this area, however, these and the frontal fault interlace, some faults overriding others, so that distinctions between a sole fault and its lesser branches disappear; here, no single fault can properly be termed the "main Great Smoky fault."

NORTHERN FOOTHILL BLOCK [16]

The northern foothill block comprises the body of rocks which form the outermost part of the main Great Smoky thrust sheet. Where the thrust sheet is most completely preserved, the block lies behind and southeast of the Chilhowee Mountain block and Miller fault family and extends southeastward to the Dunn Creek and Line Springs faults, which separate it from the southern foothill block. However, breaching of the thrust sheet by erosion causes the block to terminate northward on the Great Smoky fault in the eastern part of the report area and southward against the Wear and Tuckaleechee Cove windows in the western part of the report area. Toward the west the block is 4 or 5 miles wide, but it is less than 2 miles wide east of the Pigeon Forge fault.

The northern foothill block is formed of rocks of the Walden Creek group, a heterogeneous body of slightly metamorphosed sedimentary rocks, mainly argillaceous or silty, but with discontinuous layers of conglomerate, sandstone, quartzite, and limestone. The block is underlain by the Great Smoky fault at relatively shallow depth, so that, although the Walden Creek group probably exceeds 8,000 feet in thickness, no more than a few thousand feet is preserved at any one place.

The rocks are affected only by low-grade metamorphism—the argillaceous rocks are mainly slate, and in exceptional areas merely shale or argillite. The more competent rocks are generally little altered, except for shearing and elongation of the conglomerate on the south, near the Line Springs fault.

Nevertheless, the rocks have an extraordinary structural complexity, with so much small-scale folding and faulting that it is difficult to decipher the gross structure. Small-scale deformation is especially marked in the less competent argillaceous and silty rocks. The more competent sandstone, conglomerate, quartzite, and limestone beds are more broadly folded; but their outcrops are discontinuous, probably due partly to original lenticularity and partly to disruption during deformation. Difficulties of interpretation of the gross structure are compounded by uncertainty as to the original sequence in the Walden Creek group; the structure as here interpreted is based on an apparent sequence in the report area and on a better displayed sequence in the Richardson Cove and Jones Cove quadrangles to the east (Hamilton, 1961).

This structural complexity doubtless results from the general incompetence of the rocks of the Walden Creek group and their position no more than a few hundred or thousand feet above the sole of the Great Smoky fault. Perhaps, however, the rocks were already somewhat deformed before the Great Smoky thrusting.

In describing the structures of the northern foothill block it will be convenient to divide it into: The part west of the Pigeon Forge fault, consisting of (a) a narrow northern belt between the Miller Cove and Walden Creek faults; (b) a wide central belt between the Walden Creek and Happy Hollow faults; (c) southern belt between the Happy Hollow fault and the Line Springs and Dunn Creek faults at the south edge of the northern foothill block; (d) the part east of the Pigeon Forge fault.

NORTHERN BELT

The northern belt west of the Pigeon Forge fault is formed of the upper unit of the Wilhite formation—mainly argillaceous rocks with minor sandstone and limestone, and one larger limestone body, or rocks dominantly incompetent. These dip mainly to the southeast, but with local reversal and overturning, and their thickness and gross structure are indeterminable. Metamorphism in the belt is slight—most of the argillaceous rocks are shale or argillite, the cleavage is weak and differs from place to place, and this differ-

[16] Based largely on observations by King, but includes data from H. W. Ferguson and G. D. Swingle, J. K. Lydecker, and Warren Hamilton.

ence depends as much on degree of weathering as on original structure.

CENTRAL BELT

The wide central belt appears to be a synclinorium, and throughout its extent consists mainly of siltstone of the lower unit of the Wilhite formation, with sandstone, conglomerate, and argillaceous rocks of the Shields formation appearing along the edges, especially on the north flank and at the eastern end.

Synclinorial structure is plainest toward the west, in the area of the Bates Mountain and Little Rocky synclines (Wear Cove quadrangle).

The Bates Mountain syncline is rimmed by quartzite, sandstone, and conglomerate beds of the lower unit of the Whilhite formation in Bates Mountain and Long Ridge, which enclose an oval downfold 2 miles broad and 4 miles long (section *O–O*", pl. 9). The rocks along the rim are interbedded with, and underlain and overlain by, dominant silstone. On the north flank beds dip southward toward the basin at angles of 10° to 20° and on the south flank somewhat more steeply northward—the most extensive belt of north-dipping strata in the Great Smoky thrust sheet of the report area. Metamorphism of the rocks in the syncline is weak, the argillaceous and silty rocks being argillite and siltstone with only fracture cleavage at most and with well-preserved sedimentary structures. The gently deformed little metamorphosed rocks of the Bates Mountain syncline seem to be downfaulted along the Carr Creek fault against the more deformed, more metamorphosed rocks of the rest of the central belt on the southeast. The Carr Creek fault can be located closely at many places by contrasting structures on the two sides, but outcrops of the fault itself have not been observed.

The Little Rocky syncline farther east is similarly composed of quartzite beds in dominant siltstone, but the structure is more complex and obscure. On the north flank, in Little Rocky and adjacent ridges, as many as 6 quartzite units 50 to 150 feet thick dip 45° south (section *L′–L″*, pl. 9); these pinch out laterally and probably represent only a few original beds, which have been repeated by imbrication. The south flank of the syncline is less evident, although north-dipping quartzite beds occur on The Hogback and for a mile or two eastward (section *N′–N″*, pl. 9). The less competent siltstone which forms the main body of rocks in the syncline gives less indication of gross structure, for it exhibits highly variable dips from outcrop to outcrop, and weak to strong cleavage. Where good outcrops are available, as on the Cove Creek road to the east (Pigeon Forge quadrangle) the silststone is thrown into a succession of open to tight folds 10 to 50 feet across, slightly to strongly asymmetrical northward; the folds are crossed by a coarse axial-plane cleavage, movement on which has produced pseudoripple marks on many of the bedding surfaces (fig. 11).

The Shields formation emerges along Walden Creek on the north side of the synclinorium and also in an anticline in Happy Hollow on the south side. Structure of the Shields on the north is confused, observed strikes and dips in neither the argillaceous rocks nor the conglomerates appearing to have any gross meaning, but it is reasonable to believe that the formation passes beneath the siltstone body on the south (section *K–K′*, pl. 9). On Valley Ridge, just south of Walden Creek, conglomerate beds form four or five bands in the argillaceous rocks (Walden Creek quadrangle) and were perhaps repeated by imbrication above the Walden Creek fault.

East of Cove Creek (Pigeon Forge quadrangle), apparently up the plunge of the synclinorium, outcrops of Shields formation dominate the central belt; at the north end of Pine Mountain are large outcrops of its sandstone and conglomerate, but elsewhere the formation is represented mainly by the upper argillaceous beds. Quartzite of the Wilhite formation forms a mass within them in the southeastern part of Pine Mountain and on Sugar Camp Knob, and is probably a narrow slice of younger rocks, somehow embedded in the Shields, with thrusts on either side (section *F′–F″* pl. 9).

In this eastern area, all the outcrop belts (and probably the thrust slices) strike southeastward—a trend unique in the region—perhaps as a result of movements related to those on the Pigeon Forge fault, adjacent on the east. Curiously, both bedding and cleavage in the argillaceous rocks of the Shields in this area maintain a northeastward strike and southeastward dip, across the southeastward grain of the larger structures.

HAPPY HOLLOW FAULT

The central belt of the northern foothill block is separated from the southern belt by a well-marked easily mapped lithologic discontinuity, which in many places is provable as a fault, although its surface is nowhere exposed. The break is plain, for example, on the Cove Creek road a quarter of a mile south of Cove Creeks Cascades (Pigeon Forge quadrangle), where gently dipping sandstone and conglomerate of the Shields formation on the south closely adjoin folded siltstone of the Wilhite formation on the north.

This fault, termed the "Happy Hollow fault," for the most part probably dips southward, mainly at a steep angle, but gently near Happy Hollow as noted below. For a short distance near Headrick Top (Walden Creek quadrangle), however, relations of adjacent formations suggest a steep north dip. (section *I–I'*, pl. 9). As the sole of the Great Smoky fault underlies the area at shallow depth, the Happy Hollow fault undoubtedly joins it; but whether it branches from the Great Smoky fault, or is truncated by it, is undetermined.

East of Little Cove (Pigeon Forge quadrangle) the Happy Hollow fault apparently turns southeastward, parallel with the thrusts on Pine Mountain and Sugar Camp Knob nearby, and it may converge with the Dunn Creek fault on Caney Creek, although it would here lie within argillaceous rocks of the Shields formation where it cannot be traced.

At Happy Hollow to the west (Wear Cove quadrangle), the continuity of the fault line is broken by a deep reentrant, bordered on each side by hills capped with conglomerate of the Shields formation. In the intervening low ground of the hollow, conglomerate of the Shields, with a carapace of its argillaceous rocks, emerges anticlinally in the overridden block; in this area the fault must dip at a low angle (section *M'–M''*, pl. 9).

West of the reentrant, on the north side of Rocky Mountain, conglomerate of the Shields and sandstone of the Licklog(?) formation are intensely sheared and broken, the only rocks which are strongly deformed near the fault.

SOUTHERN BELT

Rocks of the southern belt are mainly Shields formation, but with Licklog(?) formation preserved in places beneath it, especially along the north side of Tuckaleechee Cove; rocks of the belt have been upthrust from a lower level along the Happy Hollow fault against the Wilhite formation on the north.

West of Happy Hollow the rocks of the southern belt are synclinally downfolded. The syncline plunges northeast, as shown by looped outcrops of sandstone of the Licklog(?) formation on Alie Mountain west of the report area (Kinzel Springs quadrangle). On the south flank of the syncline the Licklog(?) dips very gently in places, its sandstone beds forming mesalike benches overlooking Tuckaleechee Cove, on Hicks Lead, Bordon Top, and Listening Top (Wear Cove quadrangle) (section *O'-O''*, pl. 9). Above the Licklog(?) about 1,000 feet of conglomerate of the Shields formation, preserved in Grassy and Rocky Mountains, dips more steeply and erratically, although its gross synclinal structure is relatively plain. Rocks of the eastern end of the syncline are greatly sheared, evidently by movements related to the Happy Hollow fault on the north and the Line Springs fault on the south.

In the central segment of the southern belt, on Davis and Hatcher Mountains (Wear Cove quadrangle), conglomerate and associated rocks of the Shields formation are poorly exposed, and the rocks in available outcrops have such variable dips that their gross structure is indeterminable.

East of Cove Creek, however, this complex structure gives place to a broad dome whose crest is near Little Cove (Pigeon Forge and Gatlinburg quadrangle) (section *G'-G''-G'''*, pl. 9). The doming involves about 1,500 feet of Shields formation, dominantly argillaceous, but with interbedded sandstone and conglomerate layers which can be traced along the hillsides, very much as in a region of plateau structure. The dome has formed in the overriding rocks above the Great Smoky fault, and evidently conforms to an arch in the latter, over the northeastward prolongation of its structure in the Wear Cove window.

In many places in the southern belt, grains and pebbles in the sandstone and conglomerate beds of the Shields formation have been strained and crushed, to the accompaniment of much quartz veining, but for the most part their sedimentary structures are well preserved. Internal deformation reaches a maximum on the south side of the belt, in outcrops between Wear and Tuckaleechee Coves, and in their extension south of the coves (Wear Cove quadrangle). On ridges near Pawpaw and Lemon Hollows, pebbles in the conglomerate beds are flattened in the plane of the foliation and elongated down the dip, some being reduced to flakes or wafers, warped against adjacent pebbles (fig. 10). In places on the south side of the coves similar rocks are further reduced to thinly foliated schist, knotted around relicts of the more resistant pebbles. The extreme internal deformation of the rocks in this area appears to be related to movements on the Line Springs fault, which crops out nearby to the south and doubtless overrode them; it seems not to be related to the Great Smoky fault just beneath, along which associated deformational effects are rather minor.

At a few places near the Great Smoky fault phyllite of the Licklog(?) formation has a polymetamorphic fabric, but in most places the maximum effect of this faulting is a distortion of the foliation, especially north of Tuckaleechee Cove (p. 94), where the foliation dips aberrantly eastward, northeastward, or northwestward.

PART EAST OF PIGEON FORGE FAULT

The part of the northern foothill area east of the Pigeon Forge fault and the West Prong of the Little

Pigeon River forms a belt no more than 2 miles between the Great Smoky and Dunn Creek faults. At the eastern edge of the report area (Pigion Forge quadrangle) most of the block is formed of the lower conglomerate and sandstone of the Shields formation. The block has a homoclinal structure dipping moderately southward or southeastward away from the underlying argillaceous rocks of the Licklog formation on the north and toward the overlying slaty argillaceous rocks of the Shields on the south (section *B-B′*, pl. 9). These overlying rocks are displaced against the conglomerate beds along a minor fault which dies out east of the report area (Richardson Cove quadrangle).

The conglomerate body that forms Shields Mountain pinches out westward in the argillaceous rocks, which form all the block west of Middle Creek; these rocks apparently belong to a number of stratigraphic units, faulted together, and distinguishable with difficulty. From relations farther east it would seem that argillaceous rocks of both Shields and Licklog occur, and to the northwest there is probably a body of the upper division of the Wilhite formation, separated from the rest by an extension of the Walden Creek fault.

The upper unit of the Wilhite formation northwest of the Walden Creek fault must correspond to the northern belt west of the Pigeon Forge fault, but the structural analogue of the rocks further southeast is not entirely clear. They may correspond to the central belt to the west, the southern belt being cut out before reaching the Pigeon Forge fault, but they lack the thick bodies of the lower unit of the Wilhite formation which occur just across the fault to the west. Evidently the rocks of the northern foothill block were deformed and faulted somewhat differently on the two sides of the Pigeon Forge fault as though, as suggested above, the latter developed during emplacement of the Great Smoky thrust sheet, rather than afterwards.

DUNN CREEK AND LINE SPRINGS FAULTS

The northern and southern foothill blocks are separated by a major line of faulting which places the Walden Creek group on the north against the Snowbird group on the south. The zone is continuous and well displayed to the east (Richardson Cove and Jones Cove quadrangles; Hamilton, 1961), where it is traceable for more than 25 miles, but in the report area it is preserved only in fragments.

The Dunn Creek fault, or eastern representative of the fault line, enters the report area on Middle Creek (Pigeon Forge quadrangle), but at the West Prong of the Little Pigeon River it is offset three-quarters of a mile southward to Caney Creek by left-lateral movement on the Pigeon Forge fault. Toward the head of Caney Creek it becomes entangled in the complex structures of the Raven Den area (p. 111–112), where varied formations are juxtaposed by faulting, apparently of several different ages. Here it is impossible to identify any specific fault as the Dunn Creek, but the latter almost certainly ends southwestward against the Great Smoky fault at the edge of the Wear Cove window.

Beyond, the fault line is cut off for 2½ miles by erosion of the cover of the window. It reappears near Wear Cove Gap as the Line Springs fault (Wear Cove quadrangle), which extends thence westward for 4 miles along the south side of the coves, until it ends likewise against the Great Smoky fault at the edge of the Tuckaleechee Cove window.

The Dunn Creek fault is expressed topographically by a north-facing scarp, resulting from more rapid erosion of the slate of the Shields formation on one side than of the Pigeon siltstone and Metcalf phyllite on the other. Near Middle and Caney Creeks, the trace of the fault is so straight that it probably dips steeply, but south of Middle Creek a long, narrow sliver of slate of the Shields formation emerges a short distance behind the front and evidently represents rocks overridden by the Dunn Creek block that were raised by later thrusting (section *B–B′*, pl. 9).

The Line Springs fault can be located closely on the slopes south of the coves by adjacent outcrops of conglomerate and slate of the Shields formation on the north and of Metcalf phyllite on the south. Bedding and foliation in both formations dip 30° to 60° south, and the fault surface probably parallels them closely (section *N′–N″*, pl. 9).

Evidence available in the report area is not conclusive as to age relations of the Dunn Creek and Line Springs faults to adjacent structures. From the map pattern it might appear that they were formed by upward branching from the Great Smoky fault, like the Miller Cove fault family. Other evidence suggests that they might be earlier, and be truncated below by the Great Smoky fault. Repetition of the Dunn Creek fault block south of Middle Creek indicates that it was deformed by later faulting. East of the report area there is also some indication that the fault was emplaced before or during the metamorphism, as it runs through various meamorphic zones without offsetting them (Hamilton, 1961); this is not conclusive, for all the zones are subdivisions of the low-grade chlorite zone. As noted above, conglomerate of the Shields formation beneath the Line Springs fault is strongly distorted and foliated, apparently by movements related to its emplacement, but not to emplacement of the Great Smoky fault, which may therefore be younger.

SOUTHERN FOOTHILL BLOCK

The southern foothill block, made up of rocks of the Snowbird group, lies between the Dunn Creek and Line Springs faults on the north and the Greenbrier fault on the south. Its character is plainest east of the report area, where it forms a belt 4 to 8 miles wide. Although it extends entirely across the report area, it is broken into two or three strips, separated by outliers of the Greenbrier thrust sheet and its kindred, the whole being repeated by faults of the Gatlinburg family, and others.

East of the report area, Roaring Fork sandstone and Pigeon siltstone are folded on the south into the broad Copeland Creek and Cartertown anticlines (Cartertown quadrangle), which are flanked on the north by a homocline in the Pigeon siltstone, with various minor superposed folds (Richardson Cove quadrangle). Within the report area (Gatlinburg quadrangle) these folds are represented only by (a) a fragment of the south flank of the Copeland Creek anticline south of Gatlinburg and (b) a fragment of the homocline north of Gatlinburg. Farther west, the southern foothill block consists of (c) the complexly deformed and metamorphosed Metcalf phyllite, with uncertain gross structure, which is faulted between fragments of the Greenbrier thrust sheet (Gatlinburg and Wear Cove quadrangles).

Rocks of the southern foothill block are of more uniform lithology than those of the northern foothill block, and are somewhat more competent. In the east, structure of the block is thus broader, plainer, and less erratic; it is only obscured in the Metcalf farther west, which has been involved to a greater extent in faulting and shearing.

AREA SOUTH OF GATLINBURG

The southern foothill block is exposed south of Gatlinburg in a triangular area about 3 miles across (Gatlinburg quadrangle), bordered by rocks of the Greenbrier thrust sheet to the southeast in the main Great Smoky Mountains and to the northwest, in Cove Mountain, from which it is separated by the Greenbrier and Gatlinburg faults (section *G''–G'''*, pl. 9).

This part of the southern foothill block is formed entirely of southeastward-dipping Roaring Fork sandstone, evidently representing the southeastern flank of the Copeland Creek anticline, with the opposite flank faulted off. The strata are inclined mainly between 20° and 40°, and show little folding or warping; some faults may occur, trending either along or across the strike, but exposures are generally not sufficient to map them.

The thicker, more competent sandstone beds exhibit the most consistent and gentlest structures. Many are cut by high-angle clean-cut joints, some parallel to the dip, others to the strike, the latter commonly followed by quartz veins. The weaker, thinner bedded units of sandstone, siltstone, and argillaceous rocks dip more steeply and irregularly, and locally are much contorted and filled by pods of vein quartz. They contain a pervasive slaty cleavage which dips southeastward at an angle steeper than the bedding, and the more argillaceous parts are converted to phyllite containing metamorphic chlorite and minor biotite. The cleavage has been further deformed by slip cleavage which crosses it at wide angles; the slip cleavage was observed mainly in float blocks so that information is not sufficient to indicate its pattern.

AREA NORTH OF GATLINBURG

An irregularly shaped area of the southern foothill block extends north from Gatlinburg for 3½ miles along the West Prong of the Little Pigeon River, but persists only a short distance west of the river, where it is largely cut off by other structures (Gatlinburg and Pigeon Forge quadrangles).

This part of the block is formed of Pigeon siltstone and is the western end of the homoclinal belt referred to above. In its southern two-thirds along the river, beds strike eastward and stand nearly vertically, with only minor flattenings, their tops being consistently toward the north (section *D–D''*, pl. 9). In the northern third, probably in the upper part of the formation, the beds are thrown into numerous folds, mostly with amplitudes of less than 50 feet, generally asymmetrical toward the north (pl. 10*C*). Some of these folds are well displayed at the "Rock Fold" quarry on U.S. Highway 441 just south of the mouth of Caney Creek. Various high-angle transverse faults, such as the Pigeon Forge, extend into the area of the Pigeon and probably cross it, but they cannot be traced in the homogeneous siltstone; they undoubtedly disorder the homocline and the folds, but by amounts which cannot be determined.

Bedding and other sedimentary structures are well preserved in the siltstone, but the siltstone is thoroughly recrystallized throughout; its finer constituents have been altered to chlorite, and contain a faint but pervasive slaty cleavage. In the folded area to the north, cleavage is geometrically related to the minor folds (pl. 10*C*), but in the homocline to the south it dips southward across the nearly vertical beds, its strike curiously diverging northeastward from the strike of the beds. A similar consistent divergence between strike of cleavage and bedding is general throughout the outcrop area of the Pigeon siltstone farther east (Richardson Cove and Jones Cove quadrangles; Hamilton, 1961), but it is not apparent elsewhere in the foliated rocks of the central Great Smoky Mountains (pl. 13).

The divergence between the strike of the cleavage and bedding in this area suggests that the former was imposed on the siltstone by differently alined forces after it had been folded (Hamilton, 1961). The regional metamorphism and the cleavage related to it is known to be younger than the Greenbrier thrusting. Perhaps the folds in the siltstone transected by this cleavage formed in the rocks overridden by the Greenbrier thrust sheet, during or immediately before its emplacement. The consistency of the divergence between cleavage and bedding has certainly been enhanced by the uniform lithology and competence of the great mass of siltstone.

In some of the exposures along the river near McCookville in the northern part of the area, the deformed and foliated siltstone is further disrupted by gashes, fractures, and minor thrusts, most of which dip at low angles southward (pl. 10*C*). In places, these have sliced the rock to such an extent that it is reduced to lenses and scales, separated by gouge zones several inches thick containing scattered quartz stringers, so that the original structure is no longer apparent. The rocks are gashed and fractured over small to large areas, between which they remain firm and unbroken, but these areas have no obvious relation to known faults or other larger features. The gashes and fractures are clearly the youngest structures in the siltstone; similar ones occur in parts of the Metcalf phyllite, as described below.

BELT OF METCALF PHYLLITE

The western part of the southern foothill block, 14 miles in length within the report area, is formed of Metcalf phyllite, and extends southwestward along the lower slope of Cove Mountain into the basin of the Little River and its tributaries. The Metcalf has been tectonically intercalated in places with Thunderhead and Cades sandstones of the Greenbrier thrust sheet, which form many small slices near Raven Den (Gatlinburg quadrangle) and a much thicker and longer slice near the Little River (Wear Cove quadrangle). The Metcalf belt has been split longitudinally into two strips, on each side of the Little River, in which the structures are somewhat different.

The rocks of the Metcalf belt are notable for their thorough physical metamorphism, which is greater than that in the Roaring Fork sandstone or Pigeon siltstone of the southern foothill block farther east. The rocks are, however, of no higher mineralogic rank; like those to the east they are in the chlorite zone or the incipient phase of the biotite zone.

Metamorphism of the argillaceous and silty rocks of the Metcalf has produced an all-pervasive foliation, or slaty cleavage, which everywhere dips southeast, mainly at angles of 30° or steeper. Over wide areas it is nearly parallel to the bedding laminae, but these areas are probably on the southeast flanks of major and minor folds; where the laminae are folded, cleavage crosses them at all angles but is probably geometically related to axial planes of the folds. Many cleavage surfaces in the phyllite are marked by lineation produced by mineral segregations; this mainly extends down the dip, although a few aberrant trends in other directions were observed (pl. 13). In many places, lenses of vein quartz have been introduced parallel to the foliation. Because of the uniformity of the body of phyllite, and obliteration of its bedding by cleavage over wide areas, gross structure of the Metcalf is indeterminable.

Slaty cleavage is best preserved in the strip of Metcalf southeast of the slice of Thunderhead and Cades sandstones along the Little River. Even here, however, it is crossed erratically by narrow to wide zones of steeply dipping slip cleavage, which has offset and crimped the primary cleavage and bent it into sharp-crested chevron folds an inch or so across (fig. 16). Slip cleavage and chevron folds are well displayed in cuts on the Cades Cove road along the West Prong of the Little River and Laurel Creek.

Deformation of the slaty cleavage is much greater in the strip of Metcalf phyllite northwest of the slice of Thunderhead and Cades sandstones along the Little River. Here, much of the phyllite is cut by planes of low-dipping shear cleavage spaced a few inches apart, which so bend and offset the slaty cleavage that each higher slice is carried northwestward over the slice beneath (fig. 17); quartz lenses that had formed parallel with the slaty cleavage are reduced to knots and eyes. Each offset amounts to only a few inches, but total differential movement within the mass is probably large. The shear cleavage grades into, and in places is overwhelmed by, less regular low-dipping shears and gashes, which in extreme phases have reduced the foliated rock to a mass of scales and knots (fig. 18); many of the shears and gashes have been filled by vein quartz, apparently of a later generation than that which follows the slaty cleavage. These shears and gashes resemble those in the northern part of Pigeon siltstone.

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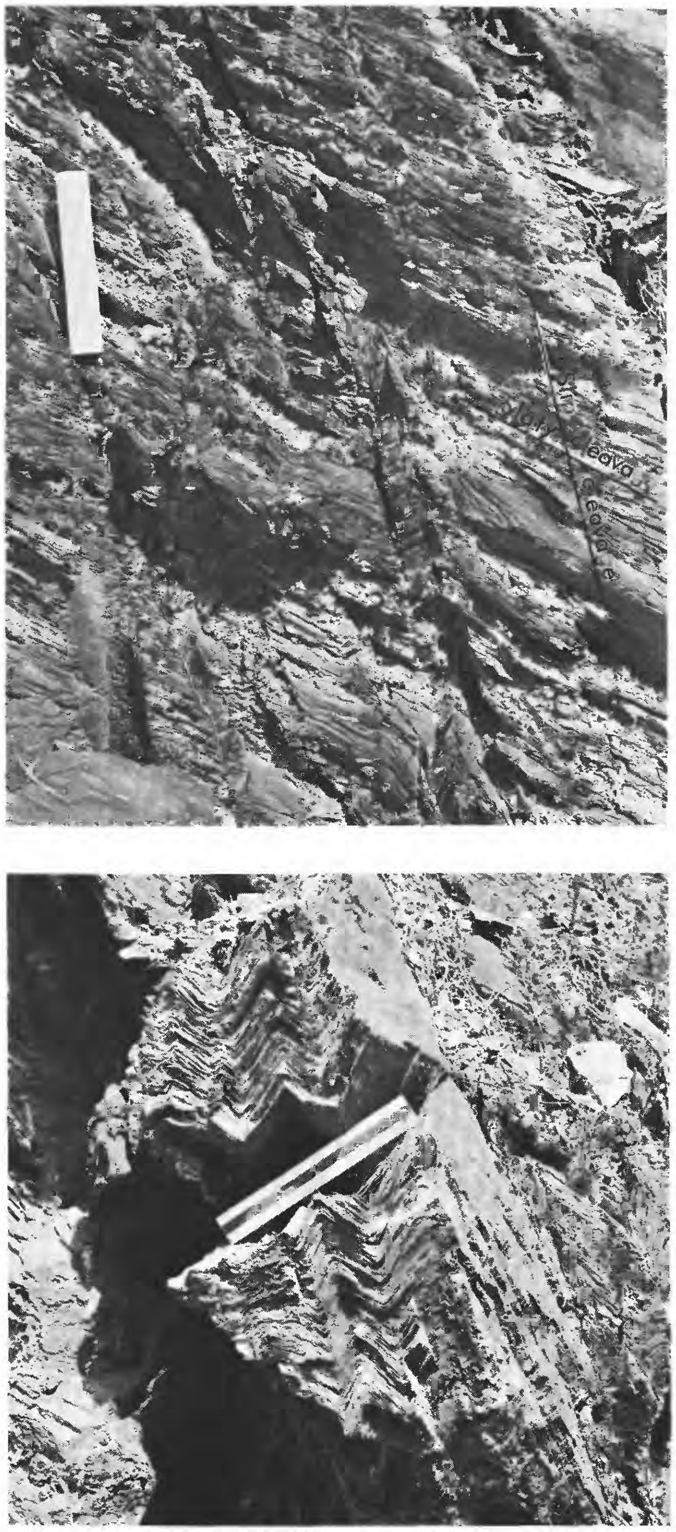

FIGURE 16.—Slip cleavage and chevron folds in Metcalf phyllite in cut on Cades Cove road, on Laurel Creek immediately above junction with West Prong of Little River (Wear Cove quadrangle). Upper, General view showing low-dipping slaty cleavage crossed by steeply dipping slip cleavage and small chevron folds produced by deformation of slaty cleavage between planes of slip cleavage. Photograph by H. E. Malde. Lower, Detail, showing chevron folds. Photograph by Warren Hamilton. Scales are 6 inches long.

Both the shear cleavage and the shears and gashes are probably younger than the slip cleavage, broken remnants of which were observed in the same area, and they appear to be the youngest structures in the phyllite. Their occurrence in the northwesetrn strip of the Metcalf belt may be related to the great thrusts which bound it on each side; they are best developed directly under the Greenbrier fault, and somewhat more sporadically above the Great Smoky and Line Springs faults from the Little River northeastward to Cove Mountain (pl. 13).

GREENBRIER FAULT

The Greenbrier fault, as indicated above, is one of the major low-angle faults of the Great Smoky Mountains. It separates the Snowbird group of the southern foothill block from the Great Smoky group of the mountain block south of it, crossing the report area near its center and extending well to the east and west (fig. 6). It was named for Greenbrier Pinnacle east of the report area, where it is well exposed (Mount Guyot 7½-minute quadrangle; King and others, 1952; Hadley and Goldsmith, 1963). Younger rocks have been carried over older rocks along the fault; these rocks were supposed by earlier geologists (Keith, 1895a and 1952) to represent an unbroken stratigraphic sequence.

The Greenbrier fault is older than the other major low-angle fault of the region, the Great Smoky, and has been considerably deformed and faulted since its emplacement. Its trace is thus preserved only in fragments in the report area, the overriding and overridden rocks elsewhere being juxtaposed along younger faults. The fault trace enters the report area from the east at the foot of the main Great Smoky Mountains south of Gatlinburg (Gatlinburg quadrangle), but this segment is cut off westward at Fighting Creek Gap by the Gatlinburg fault, which drops the Greenbrier thrust sheet northwestward in Cove Mountain. Another segment of the fault trace extends along the northwest side of Cove Mountain, from Gatlinburg to the West Prong of the Little River (Wear Cove quadrangle). There, it is cut off again by faults of the Gatlinburg family, but it reappears on the south a short distance west of the report area (Cades Cove quadrangle). Outliers of the Greenbrier thrust sheet occur northwest of the main body, in the drainage basin of the Little River and near Raven Den, and are bounded on their northwest sides by other segments of the trace of the Greenbrier fault.

SEGMENT SOUTH OF GATLINBURG

The trace of the Greenbrier fault south of Gatlinburg (Gatlinburg quadrangle) is one end of a seg-

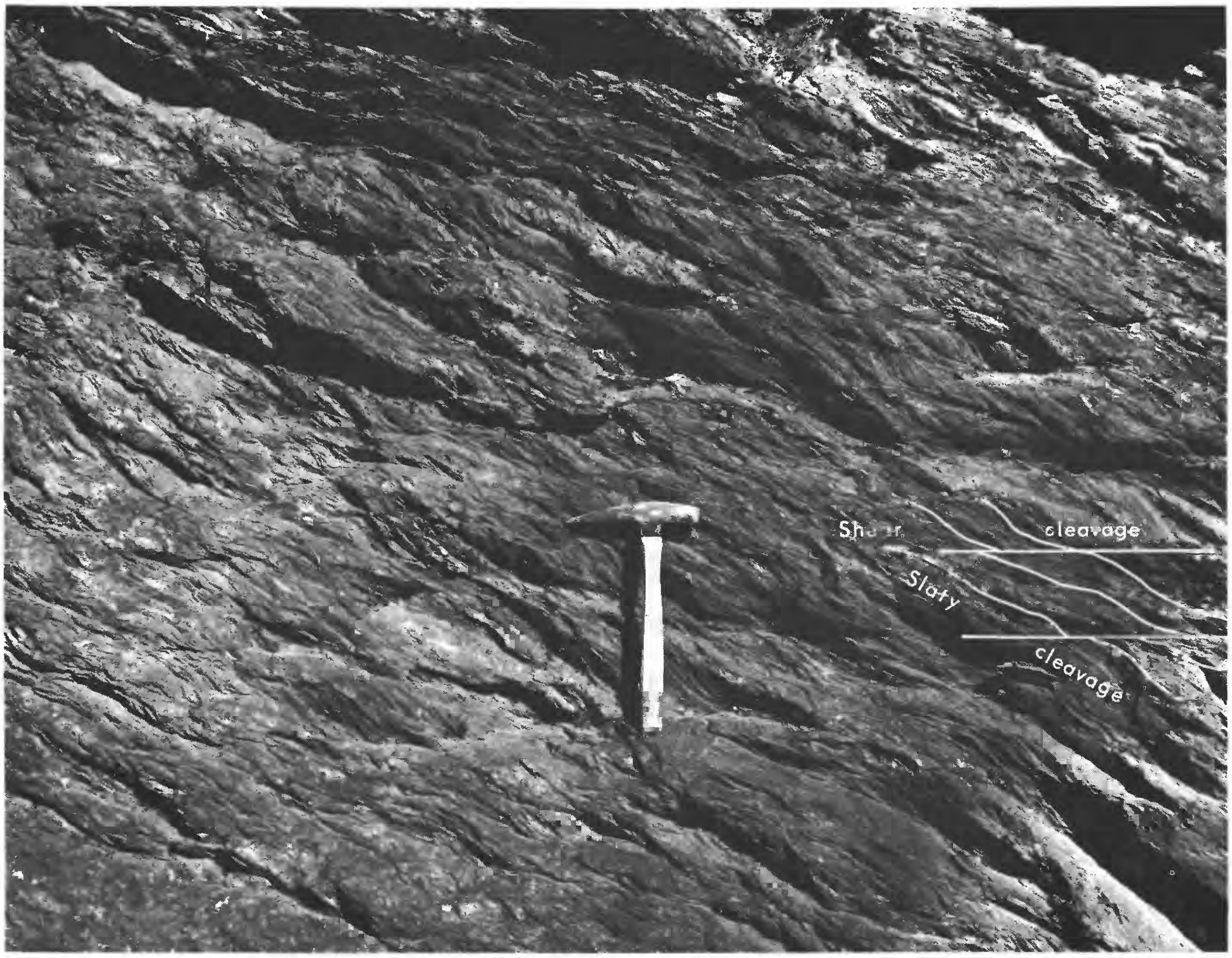

FIGURE 17.—Metcalf phyllite on Tennessee Highway 73 in Little River Gorge a mile east of Tremont Junction (Wear Cove quadrangle). Shows inclined slaty cleavage deformed by nearly horizonal shear cleavage. Movement on shear cleavage has offset each rock slice to the left (north), relative to the slice beneath. Photograph by Warren Hamilton.

ment which extends far eastward along the north slope of the Great Smoky Mountains (fig. 6; Hadley and Goldsmith, 1963). Exposures within the report area are not sufficient to demonstrate the fault structure, and interpretations must be based on analogy with better demonstrated relations farther east. The fault trace must lie down the slope below ledges of Thunderhead sandstone on Bull Head and Sugarland Mountain and below ledges of the upper part of the Elkmont sandstone between Huskey Gap and Fighting Creek Gap; it must lie up the slope above areas of identifiable Roaring Fork sandstone. Between these outcrops, however, is a wide band, extensively masked by wash from above, in which it is difficult to determine whether available exposures belong to Roaring Fork sandstone below the fault or to Elkmont sandstone above the fault.

Relations are further complicated toward the west. Cuts on Tennessee Highway 73, where it descends eastward from Fighting Creek Gap to the valley of Fighting Creek, expose a thick mass of steeply dipping siltstone, unlike either the Roaring Fork on which it rests, or the lower part of the Elkmont which lies along its strike to the west. A possible explanation, which is adopted tentatively on the geologic map, is that the siltstone is part of the Pigeon which lies in a subsidiary slice beneath the Greenbrier fault.

Representation of the trace of the Greenbrier fault on the basis of identifiable outcrops some distance on either side suggests that it has been displaced by the Huskey Gap and Mids Gap faults, which extend northeastward across part of the area (section H''–H''', pl. 9). At Fighting Creek Gap the Greenbrier fault of this segment terminates westward against the Gatlin-

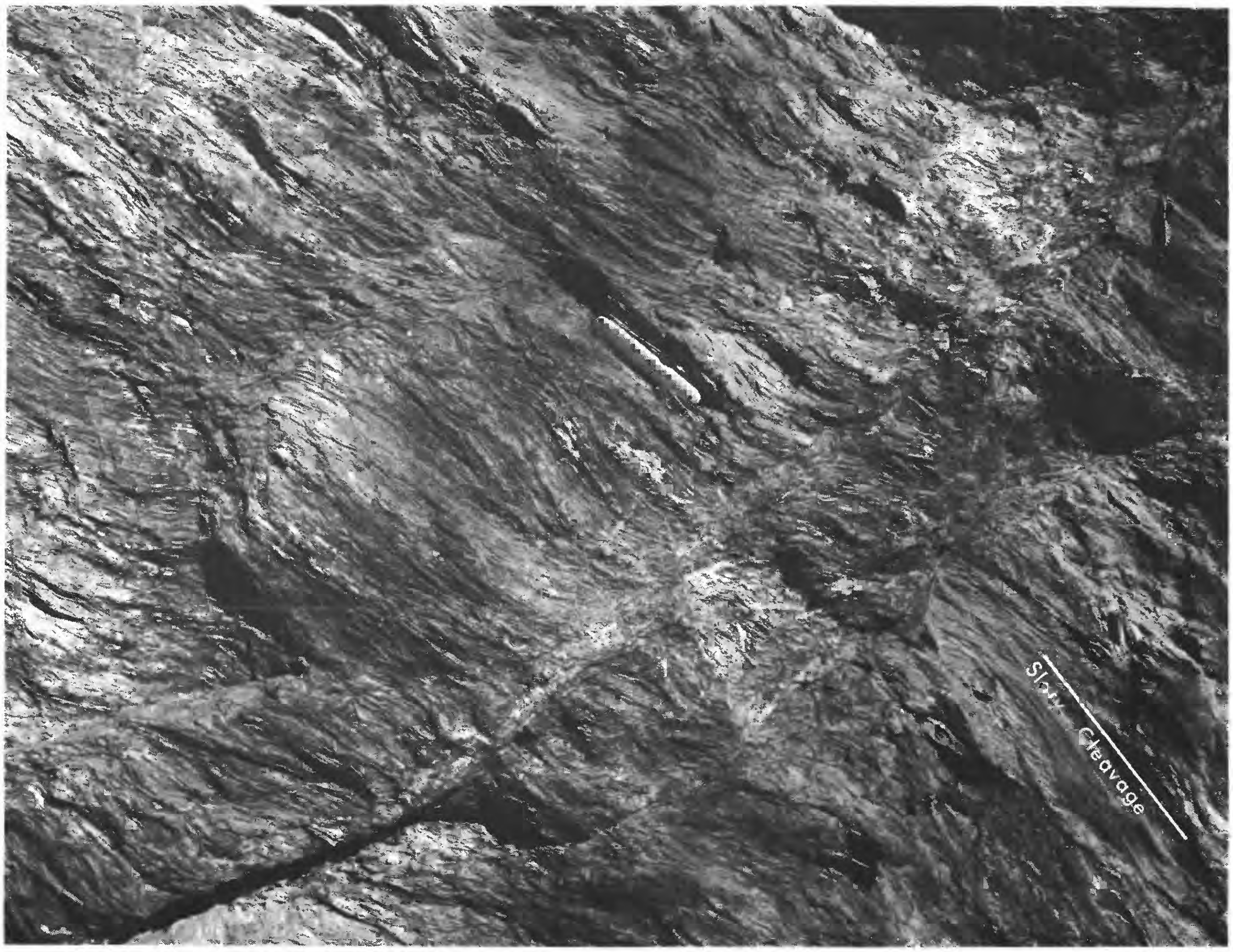

FIGURE 18.—Metcalf phyllite on Tennessee Highway 73 in Little River Gorge a mile east of Tremont Junction (Wear Cove quadrangle). Shows slaty cleavage broken and distorted by irregular shears and gashes. Photograph by Warren Hamilton.

burg fault, which throws down the Great Smoky group in the Cove Mountain area to the northwest.

SEGMENT BETWEEN GATLINBURG AND NORTON CREEK

The longest segment of the trace of the Greenbrier fault in the report area lies northwest of the Gatlinburg fault, on the northwest side of Cove Mountain, and extends 13 miles southwestward to the West Prong of the Little River. In the eastern few miles of this segment, between Gatlinburg and Norton Creek, it has been offset northward by several later northeast-trending faults (Gatlinburg quadrangle).

In this segment the Greenbrier fault and those which offset it can be located closely from nearby outcrops in the strongly dissected country near the West Prong of the Little Pigeon River and near Norton Creek, but relations are not so clear in the deeply weathered upland between.

The Greenbrier fault is exposed in the northern part of the town of Gatlinburg, in an excavation on the east side of U.S. Highway 441 a short distance north of the mouth of Roaring Fork (fig. 19). The fault surface, laid bare in the northern part of the excavation, dips irregularly 30° to 50° southward, and has a wide zone of shearing and slicing in the overriding and overridden rocks. The Pigeon siltstone just beneath the fault has been converted to dark greenish-gray mylonite, which is recrystallized and schistose and contains embedded angular silty fragments, as well as a few larger lenses of overriding Thunderhead sandstone. The mylonite is also slickensided, but evidently by movements later than the recrystallization. Normal Pigeon siltstone, steeply tilted but not sheared, is exposed 75 feet to the north. The Thunderhead sandstone just above the fault is greatly sliced and jointed and is traversed by low to high-angle thrusts, developed mainly on argillaceous partings. About 150 feet to the south the sandstone is little altered and gently tilted, although offset by minor normal faults.

North of Gatlinburg the Greenbrier fault is bordered by a steeply tilted sequence of 3,500 feet of carbonate-bearing siltstone of the upper part of the Pigeon, topped by 1,500 feet of Rich Butt sandstone on Dudley Bluff. These rocks are isolated from their neighbors; they terminate against transverse faults on the east and west, and the Rich Butt adjoins the lower part of the Pigeon on the north, hence must be faulted against it. Stratigraphic relations, suggest, implausibly, that the block is downthrown against the adja-Pigeon and Roaring Fork to the north and east. More likely, the block is an intermediate slice beneath the Greenbrier fault, whose sole is the presumed fault between the Rich Butt and the Pigeon on the north (section *D′–D″*, pl. 9).

SEGMENT NORTHWEST OF COVE MOUNTAIN

From Norton Creek to the West Prong of the Little River the trace of the Greenbrier fault on the northwest side of Cove Mountain is unbroken. Thunderhead sandstone overrides Metcalf phyllite throughout, its ledges crowning the Cove Mountain escarpment and the ridges on its southwestward extension. The Thunderhead dips southeastward away from the fault at low to steep angles, and graded bedding, where visible, indicates that it is not inverted. Superposition of Thunderhead on Metcalf is certainly tectonic rather than stratigraphic, for to the east near Norton Creek, the Thunderhead lies conformably on Elkmont sandstone rather than on Metcalf (section *F″–F‴*, pl. 9). In most places, rocks of the Thunderhead next above the Metcalf are massive sandstone, but on Mill Ridge, northeast of the Middle Prong of the Little River, they are blue-gray slate; these overridding argillaceous rocks are readily distinguishable from the overridden ones by their color and texture.

Throughout the segment the position of the Greenbrier fault can be located closely from outcrops of the adjacent formations, and configuration of its trace indicates that it dips between 30° and 45° southeast. Many near-exposures of the fault and a few outcrops of its surface were observed, of which the two most notable are along the main east prong and the Middle Prong of the Little River (Wear Cove quadrangle). At none of them is there disturbance of the adjacent rocks comparable to that in the exposure in the northern part of the town of Gatlinburg.

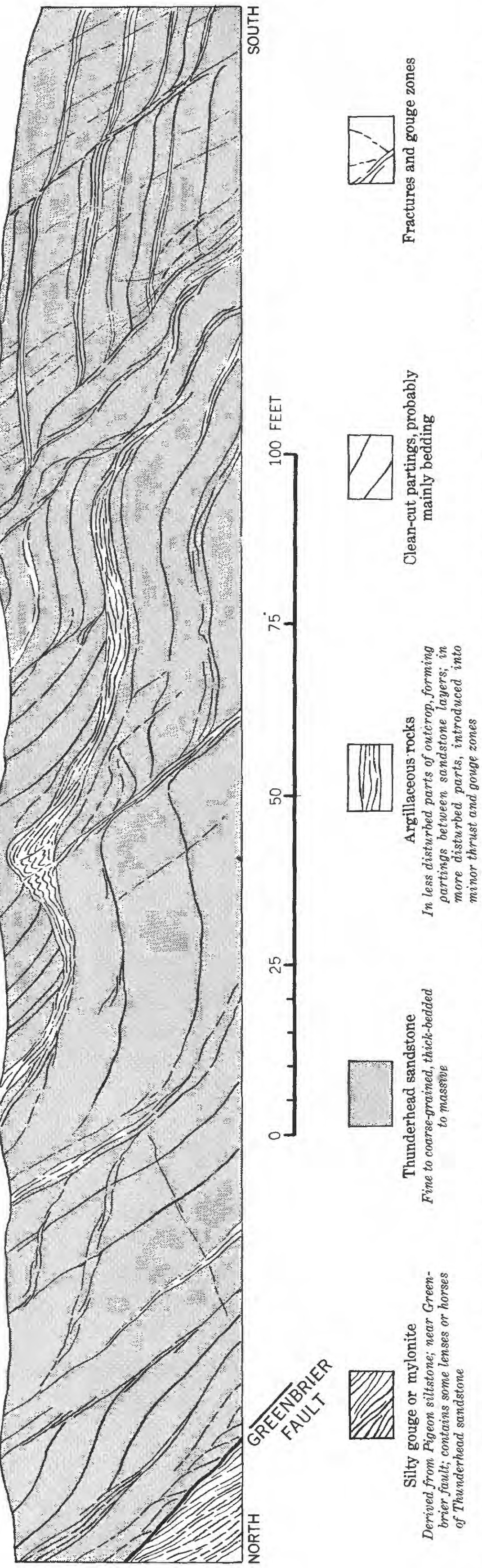

FIGURE 19.—Section showing outcrop of Greenbrier fault and associated structures in town of Gatlinburg, in excavation on east side of U.S. Highway 441, north of bridge over Roaring Fork. By P. B. King, 1954.

Where the fault trace crosses the main east prong of the Little River southeast of Metcalf Bottoms, the fault surface itself is concealed in a ravine, on one side of which are thick ledges of Thunderhead sandstone, and on the other, outcrops of Metcalf phyllite. Both sandstone and phyllite dip regularly about 35° southeastward, probably parallel to the fault, and are not sheared or crumpled. On the Middle Prong at Walker Fields the fault surface is exposed in the lower course of Fodderstack Branch, and dips about 60° southeast. A bed of gray slate of the Thunderhead 10 feet thick lies with clean-cut contact on Metcalf phyllite, and is overlain by a thick bed of massive sandstone. Except for an apparent truncation of the foliation of the Metcalf at the contact, there is little evidence of disturbance.

Subtle mineralogic differences between the Elkmont and Thunderhead sandstones of the Cove Mountain area, and across the Gatlinburg fault zone in the Great Smoky Mountains to the south, suggest, as noted above (p. 37), that extensive movements may have occurred along this zone of which there is little other indication. These may have been strike-slip movements on the Gatlinburg zone itself, as indicated below (p. 123–124), but there is a possibility that the Gatlinburg faulting is superposed on an earlier fault that is a branch of the Greenbrier fault; if so, all the rocks of the Greenbrier thrust sheet in the Cove Mountain area represent an intermediate slice of the Greenbrier thrust sheet, comparable to, but much larger than, the intermediate slices whose existence has been suggested near Fightiog Creek Gap and Dudley Bluff.

SEGMENT ALONG LITTLE RIVER

In the drainage basin of the Little River and its tributaries, between Metcalf Bottoms and Whiteoak Sink, a belt of coarse sandstone is intercalated between two belts of Metcalf phyllite (Wear Cove quadrangle) (for example, section N′–N″, pl. 9). The coarse rocks of this belt apparently represent an outlier of the Greenbrier thrust sheet, detached from the main body by later deformation. This inference is especially plausible near The Sinks, where only a narrow band of Metcalf phyllite separates Thunderhead sandstone of the Greenbrier thrust sheet on the southeast from sandstone of identical lithology in the outlier on the northwest (fig. 20). Farther west in the outlier, however, the rocks more closely resemble the Cades sandstone west of the report area than they do the Thunderhead sandstone; regional considerations suggest that the Cades lies in a thrust slice which is below, but related to the Greenbrier thrust sheet. The fault which underlies the outlier is therefore indicated on the map

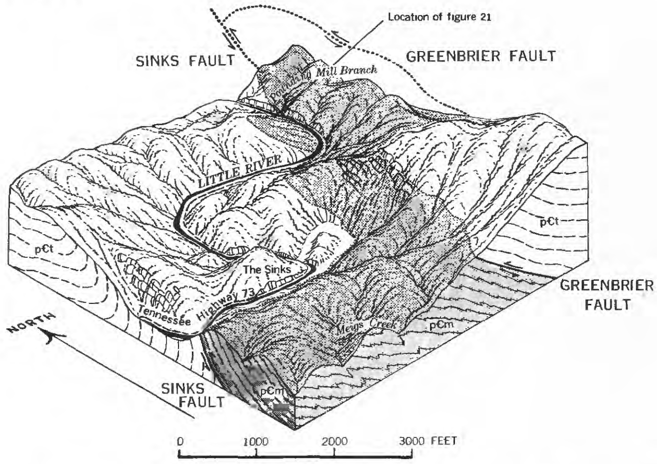

FIGURE 20.—Block diagram showing topography and bedrock structure in the vicinity of The Sinks. The "Sinks" are a point on the Little River where there is an abrupt steepening of gradient and are not a feature of limestone solution, as the name suggests; this steepening of gradient is caused by cutting through a former meander neck; the previous channel around it is evident in the diagram. Thunderhead sandstone (p€t) is part of Greenbrier thrust sheet which has been downdropped on the north along the Sinks fault; the two parts of the thrust sheet are separated by a band of outcrop of Metcalf phyllite (p€m).

as a segment of the Greenbrier fault in its eastern half and as another related low-angle fault in its western half. The junction of the two faults is placed a short distance southwest of the lower bridge on the Little River where the change from Thunderhead to Cades lithology occurs; exposures are not sufficient, however, to substantiate the assumed relation.

The fault northwest of the outlier can be located closely throughout its course by adjacent outcrops and float of the Thunderhead and Cades sandstones above and of Metcalf phyllite below. It is exposed at several places on Tennessee Highway 73 along the main east prong of the Little River between Tremont Junction and the lower bridge, 1½ miles to the east. At these places, it dips 20° to 35° southeast. Elsewhere, configuration of its trace suggests a similar low dip; moreover, windows of the overridden Metcalf phyllite appear in the southeastern part of the outlier near Strickler Branch. At the exposures of the fault east of Tremont Junction a specific contact is difficult to locate, as slate of the Cades generally lies next above the Metcalf phyllite, both of which are highly sheared and pyritized and are traversed by many subparallel thrust planes.

The Thunderhead and Cades of the outlier dip generally southeastward, probably broadly parallel to the fault beneath, but locally they are considerably folded; they are overturned at The Sinks, close to the southeastern edge (fig. 20), as indicated by reversed graded bedding. They are much more deformed internally than the rocks of the main body of the Greenbrier thrust sheet to the southeast. The finer grained sandstones have been widely converted to quartz-mica schists, and at a quarry just east of the lower bridge on the Little River even the coarser sandstones are foliated. At the quarry, quartz grains have been elongated and feldspar grains broken and strung out, producing a well-marked alineation which extends down the dip of the foliation.

The outlier is also separated by a fault from the Metcalf phyllite on the southeast. This fault is believed not to be a repetition of the Greenbrier fault, but to be distinct and later; hence it is termed the "Sinks fault." Faulting of the contact is clearly demonstrated at The Sinks, where the Thunderhead sandstone of the outlier is overturned near it. The Sinks fault is exposed in a cut on Tennessee Highway 73 half a mile northeast of The Sinks, just north of Pounding Mill Branch, where it forms a clean-cut surface that dips 35° southeast, discordant to the foliation of the overriding Metcalf phyllite and the bedding of the overridden Thunderhead sandstone (fig. 21). Graded bedding in the Thunderhead sandstone nearby indicates that it is not overturned, as at The Sinks. The trace of the Sinks fault, as mapped, indicates that it dips southeastward elsewhere, except near the tunnel on the Cades Cove road on the West Prong of the Little River, where a steep north dip is suggested by adajacent outcrops; exposures at the locality are insufficient, however, to determine the details.

Rocks of the outlier are also broken in its eastern part by two northwest-trending transverse faults, one of which terminates the outlier on the east. The transverse faults were located closely by Ferguson from outcrops of adjacent rocks and appear to stand nearly vertical, although no exposures of the faults themselves are visible.

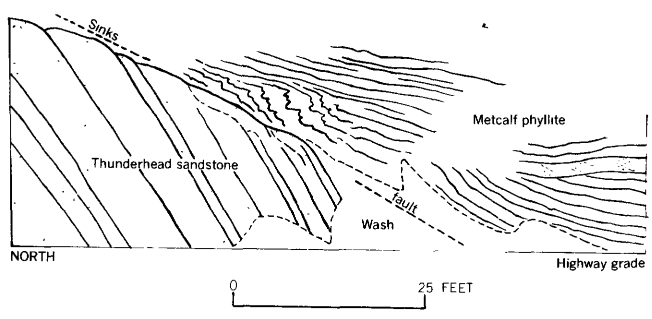

FIGURE 21.—Field sketch of outcrop of Sinks fault in cut on Tennessee Highway 73, in Little River Gorge three-quarters of a mile northeast of The Sinks. Graded bedding in Thunderhead sandstone 75 feet north of the fault indicates that its layers are not overturned. By P. B. King, 1953.

South of Whiteoak Sink, near the western end of the outlier, Cades sandstone reappears in another outlier on Turkeypen Ridge, again bordered by Metcalf phyllite on the northwest and southeast. This outlier is the eastern end of the main area of Cades sandstone, which expands westward, north of Cades Cove and beyond the report area (Neuman and Nelson, 1964). Within the report area the extent of the Cades can be determined accurately from float and scattered outcrops, but these are not sufficient to indicate the nature of its contact with the Metcalf. Presumably the structure of the Cades in this area is analogous to that of the outlier farther northeast, and it is probably faulted against the Metcalf on one or both sides (section *S–S′–S″*, pl. 9).

RAVEN DEN SLICES

Raven Den, the little peak which overlooks Wear Cove on the east, is formed of coarse sandstone, highly sheared and foliated, which lies on argillaceous slate of the Shields formation on the northwest and is intercalated with Metcalf phyllite on the southeast (Gatlinburg quadrangle) (section *H″–H‴*, pl. 9). The sandstone body is more than half a mile wide, but wedges out into Metcalf phyllite at the ends so that it is no more than 2 miles long. Southeast of it, many other elongated sandstone bodies, some as thin as 25 or 50 feet, are intercalated in the Metcalf (section *I′–I″*, pl. 9). These sandstone bodies line the northwest slope of Cove Mountain south of Raven Den, some continuing more than 2 miles southwestward.

As a result of the shearing, the sandstone of these bodies is pervaded throughout by a southeast-dipping foliation which has nearly obliterated the bedding, has shattered and stretched the quartz and feldspar grains, and has flattened and made schistose the argillaceous fragments. Large quartz grains have resisted deformation more than the smaller, and stand out as hard knots in the sheared rock. This extreme alteration was not accompanied by any increase in mineralogic rank, as the metamorphic minerals are largely sericite and minor chlorite.

The sandstone of the bodies near Raven Den is foreign to the Metcalf and Shields formations with which it is in contact; it is identical, except for its foliate structure, with the Thunderhead sandstone standing at a higher altitude less than a mile to the southeast. The writer interprets it as a set of outliers of the Greenbrier thrust sheet, detached from the main body by later deformation, like the outlier in the same position along the Little River a few miles to the southwest. This interpretation is most plausible for the large sandstone body on Raven Den, and rather less so for the thinner bodies to the south which, with the intervening Metcalf, have the superficial aspect of an interbedded sedimentary sequence. No such sequence occurs elsewhere in the Metcalf, however, and the pervasive shearing implies that the intercalation is tectonic rather than stratigraphic.

The Raven Den slices lie in an area of unusual structural complexity; the Dunn Creek fault strikes into the area from the northeast, and the area is underlain at shallow depth by the Great Smoky fault. The Great Smoky fault is younger than the Greenbrier fault, and probably also younger than the Dunn Creek fault, so that structures in the area were probably formed by several superposed deformations. The role of Dunn Creek faulting is difficult to evaluate; this fault or its branches may extend through the Raven Den area or may bound its northwestern edge where the Thunderhead sandstone is in contact with the Shields formation. During Great Smoky faulting, minor faults may have branched upward from the sole fault, fragmenting the earlier and higher Greenbrier thrust sheet and dragging the fragments into the Metcalf phyllite. Under this interpretation, which is adopted on the structure sections (pl. 9), the northwestern edge of each slice is a segment of the Greenbrier fault and the southeastern edge a later fault—analogous to the Sinks fault on the southeast side of the outlier along the Little River.

SUMMARY

From this description of the Greenbrier fault, the following items of general significance can be derived:

1. The Greenbrier fault, like the Greaty Smoky fault, is a major low-angle thrust, on which the overriding rocks have been carried northwestward across the overriden rocks. Like the Great Smoky fault, it forms an important discontinuity between different rock sequences, but here the discontinuitý is within the Ocoee series, rather than between the Ocoee and the Paleozoic.
2. Unlike the Great Smoky fault, the Greenbrier fault has carried younger rocks over older, a relation which can be proved by the stratigraphic sequence exposed farther southeast (Hadley and Goldsmith, 1963).
3. Like the Great Smoky fault, the Greenbrier fault is exposed for many miles across its strike. Within the report area the greatest breadth exposed from Raven Den to Sugarland Mountain, is 7 miles; east of the report area it emerges at greater distances to the southeast.
4. As younger rocks are thrust over older along the Greenbrier fault, the breadth of the fault does not provide a measure of its displacement, which might be less or greater.
5. Overridden rocks are truncated by the fault. In the segment south of Gatlinburg it lies on Roaring Fork sandstone, in the segment between Gatlinburg and Norton Creek on Pigeon siltstone, and in the segment northwest of Cove Mountain on Metcalf phyllite. Northwest of Raven Den, rocks of its thrust sheet are in contact with Shields formation, although this might be the result of faulting younger than the Greenbrier. Different formations also overlie the fault—in the south the Elkmont sandstone and farther north the Thunderhead sandstone—although the truncation is apparently not as great as in the overridden rocks. Truncation of both overriding and overridden rocks also occurs east of the report area (Hadley and Goldsmith, 1963).
6. The Greenbrier fault, like the Great Smoky fault, also appears to be underlain in places by intermediate slices, although these are less easy to identify. A possible intermediate slice of Pigeon siltstone occurs near Fighting Creek Gap, one of Pigeon siltstone and Rich Butt sandstone north of Gatlinburg and one of Cades sandstone farther west.
7. For the most part, rocks near the Greenbrier fault are less well exposed than those near the Great Smoky fault, and exposures of the fault surface itself are rare. Little information is thus available as to details of deformation related to the faulting. Some outcrops of the fault (in northern part of town of Gatlinburg and east of Tremont Junction) show extensive shearing of the rocks near it; others (on east and Middle Prongs of Little River) show little accompanying deformation of these rocks. The latter outcrops are comparable to many of those of the Great Smoky fault, already described, where the rocks adjacent to the fault are little truncated or affected by it.
8. The Greenbrier fault was emplaced before the Great Smoky fault. It is earlier rather than later than the regional metamorphism. Within the report area the northwestern part of its trace lies in the chlorite zone and the southeastern part in the biotite zone; these zones are not offset by it (pl. 13). East of the report area its trace extends into metamorphic zones of higher rank (Hadley and Goldsmith, 1963).
9. The Greenbrier fault and its thrust sheet have been displaced by later faults and have been folded, perhaps partly by movements related to the Great Smoky thrusting. Within the report area the fault is displaced by faults of the Gatlinburg family, by the Sinks fault, by faults near Raven Den, and by others. This faulting has broken the thrust sheet

into many parts, some of which, to the northwest, are entirely detached from the rest.

GATLINBURG FAULT FAMILY

Extending across the south-central part of the report area is a great system of faults which, from their similar habit and apparent kinship are termed the "Gatlinburg fault family." The major faults of the family are notable for their marked topographic expression; they rather consistently give rise to trenches or valleys and to notches on intervening ridges, the whole extending with relatively straight courses across country. Trenches, valleys, and notches suggest that the major faults are accompanied by wide zones of crushing and slicing, the straight courses suggest that they dip at steep angles. The lesser faults of the family, as mapped, pursue similar straight courses, but their topographic expression is less marked.

The principal trend of the faults of the family is east-northeast, broadly parallel to the structural grain of the region. A continuous break along this trend extends the entire length of the Great Smoky Mountains, and although this may be composite in detail, it is convenient to refer to it as the Gatlinburg fault proper from its exposures in the town of Gatlinburg. West of the report area it seems to be a single fault, but east of the report area it is paralleled on the south by numerous lesser faults (Hadley and Goldsmith, 1963). Within the report area the Gatlinburg fault proper is joined from the southeast by another member of the fault family, the Oconaluftee, also parallel to the structural grain near its point of convergence, but curving across the grain farther east. Convergence of the two faults has resulted in more fracturing than elsewhere in the region, so that most of the tract between them in the report area, and a considerable tract on the north, is split into a mosaic of fault blocks.

Displacement of the faults of the Gatlinburg family is seemingly diverse, although it is not wholly susceptible of analysis. Field relations suggest dominant reverse dip-slip displacement on some of the faults and dominant right-lateral or left-lateral strike-slip displacement on some of the others. At a few favorable localities, noted below, striae on some of the faults indicate diagonal movements, with both dip-slip and strike-slip components. Faults of the Gatlinburg family are thus either high-angle thrusts, transcurrent faults, or a combination of both.

Within the report area the high-angle faults of the Gatlinburg family pass, by chance, through the same general area as the low-angle Greenbrier fault. They extensively displace this fault and disorder the rocks of its thrust sheet, hence are younger features. Age relations of the Gatlinburg fault family to other major features, such as the Great Smoky fault, cannot be determined in the report area, but like the latter, the family is clearly a late feature in the orogenic cycle.

GATLINBURG FAULT PROPER

The Gatlinburg fault proper extends east-northeast across the south-central part of the report area. In its eastern segment (Gatlinburg quadrangle) it is followed by a chain of deep topographic depressions in the foothills, drained successively by Roaring Fork, the West Prong of the Little Pigeon River, Fighting Creek, Laurel Branch, and the Little River. In its western segment (Wear Cove and Thunderhead quadrangles) the depressions are shallower and are followed by tributary streams rather than major drainage, yet they are still conspicuous, as shown by air photographs. In the extereme eastern and western parts of the report area, where the Snowbird and Great Smoky groups lie in contact along the fault, it can be located closely by outcrops of contrasting rocks on the two sides; toward the east, where dissection is greatest, several outcrops of the fault itself have been observed. In the central part, where it lies within formations of the Great Smoky group, the contrast between rocks on the two sides is less pronounced, and more reliance for its location must be placed on attendant topographic features.

As thus mapped, the fault pursues a nearly straight or gently curved course, with an average trend of N. 60°–70°E. The only conspicuous deviation is between the town of Gatlinburg and the National Park Service Headquarters where, for 1½ miles it trends N. 20°E., in apparent alinement with the lesser Huskey Gap fault on the south, described below (p. 116). A similar offset of about half a mile occurs just east of the report area (Cartertown quadrangle; Hadley and Goldsmith, 1963).

In the eastern half of the report area and beyond, the Gatlinburg fault throws down the rocks on the northwest, relative to those on the southeast, suggesting a dominant dip-slip displacement. From the town of Gatlinburg eastward the downthrow can be proved stratigraphically by offset of formations of the Snowbird group. Farther west it transects the Greenbrier thrust sheet, so that between Gatlinburg and Fighting Creek Gap the Great Smoky group of the thrust sheet is downthrown on the northwest against Snowbird group on the southeast (for example, section *G''–G'''*, pl. 9). In this segment, downthrow on the north is probably about 5,000 feet.

From the Middle Prong of the Little River westward, the apparent displacement changes. The Greenbrier fault and its thrust sheet are cut off by the fault

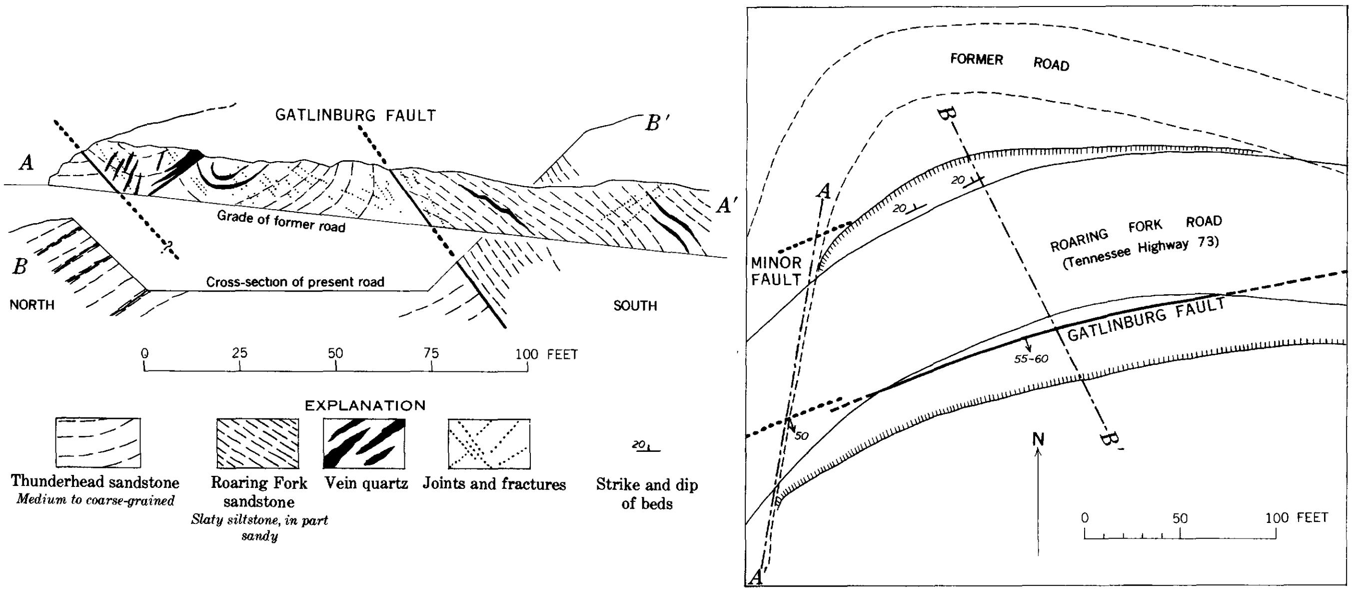

Figure 22.—Map and sections showing outcrop of Gatlinburg fault in town of Gatlinburg, at curve on Roaring Fork Road 300 feet north of Mountain View Hotel. Most informative exposures were in cuts of former road, which was destroyed when present road was constructed in 1955. In the figure the section of the former road (*A–A′*) is superposed on that across the present road (*B–B′*). Section *A–A′* by P. B. King, 1947; section *B–B′* and map by J. B. Hadley, 1955.

on the north near the West Prong, the Greenbrier fault reappearing on the south side 3 miles to the west, beyond Big Spring Cove and the report area (Cades Cove quadrangle). Along the Gatlinburg fault in the intervening area, the Great Smoky group of the Greenbrier thrust sheet on the south adjoins Snowbird group beneath the thrust sheet on the north (section *R′–R″*, pl. 9). The apparent displacement on the Gatlinburg fault is thus downward on the south, but this might be accounted for by a large component of right-lateral strike-slip displacement.

At several places, as indicated above, the Gatlinburg fault can be located closely; of these, the following merit further description:

1. East of the report area (Cartertown quadrangle) the Gatlinburg fault follows the valley of Dudley Creek, and the main fault or faults closely related to it are exposed in several places in cuts on Tennessee Highway 73, where they involve Roaring Fork sandstone and Pigeon siltstone (Hadley and Goldsmith, 1963). Their surfaces dip from 50° to 80° SE. and some of them are crossed by striae that plunge 20° to 80° E. The striae suggest both a reverse dip-slip and a right-lateral strike-slip component of movement, the latter being perhaps about half the amount of the dip-slip component.
2. The surface of the Gatlinburg fault can be identiged at several places within the town of Gatlinburg (Gatlinburg quadrangle), especially on Tennessee Highway 73 (Roaring Fork Road) half a block north of the Mountain View Hotel (fig. 22). The outcrops first observed were destroyed by realinement of the highway in 1955, and present outcrops are not so clear. In both earlier and later outcrops the fault is a clean-cut surface, dipping 50° to 60° S., separating phyllitic siltstone of the Roaring Fork sandstone on the south from thick-bedded coarse Thunderhead sandstone on the north. In the earlier exposures the fault is bordered on the north by a zone of crushed, fractured, and distorted sandstone 75 feet wide, followed on the north by a minor fault with the same attitude as the main one, beyond which the sandstone is less broken and dips more gently.

   Other outcrops occur about half a mile to the west, along the West Prong of the Little Pigeon River near the New Gatlinburg Inn. At several places, the north bank of the river is formed by a wall-like face of Thunderhead sandstone dipping 60° S., which is probably the footwall of the fault. Phyllite of the Roaring Fork in the hanking wall has been removed by erosion of the river, but it is exposed nearby.

   At these localities, no striae or other special structures were observed on the fault surface, so that the components of dip-slip and strike-slip movement could not be determined.
3. Near the National Park Service Headquarters 2 miles southwest of the town of Gatlinburg (Gatlinburg quadrangle), no outcrops of the fault were observed and the valley flat of the West Prong of

the Little Pigeon River is wider than elsewhere. Bedrock structure must be unusually complex, as the area seemingly lies near the junction of the Gatlinburg fault with the Huskey Gap and Mids Gap faults on the south. This complexity is attested by available outcrops, whose rocks are extensively disturbed, fractured, and crushed. The largest outcrop is in the old State highway quarry east of the river, where sandstones and siltstones of the Roaring Fork dip southeast at a low angle, and are broken by numerous fractures and minor faults, some dipping southeast, others northwest, with later faults offsetting the earlier ones. The most prominent feature is a bedding-plane thrust dipping irregularly 20° SE., which is offset by minor clean-cut veined faults that dip 40° in the same direction.

4. The Gatlinburg fault crosses a meander of the main east prong of the Little River 1¾ miles west of Fighting Creek Gap (Gatlinburg quadrangle), but it lies in a covered interval several hundred feet wide. Elkmont sandstone of the hanging wall is exposed on Tennessee Highway 73 at the south tip of the meander and Thunderhead sandstone of the footwall on its eastern side. The rocks of the Thunderhead, where nearest the fault, are crossed by closely spaced fractures and small faults which dip 40° SE., probably subsidiary to, and parallel with, the main fault.
5. The Gatlinburg fault crosses the Middle Prong of the Little River south of Walker Fields (Wear Cove quadrangle), but it is not exposed, although its position can be located by outcrops of contrasting facies of the Thunderhead sandstone on the two sides—on the south, coarse thick-bedded sandstone with common blue quartz grains; on the north, dark siltstone with scattered interbedded sandstone layers, in which blue quartz is rare or absent.
6. In Big Spring Cove, at the west edge of the report area (Thunderhead quadrangle), the Gatlinburg fault is covered by alluvium of the cove, although its position can be located just to the east by contrasting float and small outcrops of the Metcalf phyllite and Great Smoky group on the opposite sides. South of the cove, spurs of the main Great Smoky Mountains rise steeply and are formed of rocks south of the fault; Elkmont sandstone is exposed at their bases at the lower end of Sugar Cove Prong. These exposures are significant, for a short distance west of Big Spring Cove, Metcalf phyllite forms the lower mountain slopes (Cades Cover quadrangle), indicating that the low-angle Greenbrier fault has emerged on the south side of the Gatlinburg fault.

OCONALUFTEE FAULT

The Oconaluftee fault lies south of the Gatlinburg fault in the south-central part of the report area and follows a course which curves from east-northeast on the west to east-southeast on the east, becoming progressively more transverse to the structural grain in this direction. Near the west edge of the report area it converges with the Gatlinburg fault. East of the report area it crosses the mountain crest at Indian Gap and extends down the Oconaluftee River, for which it is named, dying out in highly deformed rocks north of Cherokee (Clingmans Dome and Ravensford quadrangles; fig. 6).

Like the Gatlinburg fault, the Oconaluftee fault is prominently expressed in the topography. Throughout most of the report area, high mountains rise south of it, and lower foothills north of it. Instead of being followed by drainage lines, streams from the mountains generally cross it, but nearly every valley widens into an alluvial basin near the fault, filled by wash from higher up, and each intervening ridge is nicked at the fault by a saddle. Alinement of saddles and other topographic features indicates that the course of the fault is nearly straight; hence it dips at a steep angle.

Unlike the Gatlinburg, fault, the Oconaluftee fault lies wholly in rocks of the Great Smoky group, commonly with higher stratigraphic units thrown down on the south against lower stratigraphic units on the north (section *I′-I″*, pl. 9). Along the main east prong of the Little River above Elkmont the two tongues of the Anakeesta formation and the intervening tongue of Thunderhead sandstone on the south thus adjoin the lower part of the Thunderhead sandstone on the north (Gatlinburg and Silers Bald quadrangles). That this displacement is not primarily dip slip but strike slip is indicated by right-lateral offset of the outcrops of comparable beds from one side to the other—most convincingly where the beds are nearly vertical toward the east, and less so where the beds are tilted at lower angles toward the west. Offset of the outcrops suggests that displacement may increase in magnitude westward: (a) Vertical beds along the Oconaluftee River are offset half a mile. (b) The Mingus fault and upper tongue of the Anakeesta formation at the east edge of the report area are offset a mile. (c) The top of the Elkmont sandstone south of Elkmont is offset more than 1½ miles. (d) The Greenbrier fault at the west edge of the report area is offset 3 miles by combined movements on the Oconaluftee and Gatlinburg faults. Such a westward increase in displacement would account for the disappearance of the fault southeastward; if valid, it may have occurred by variations in tilting or folding of the rocks on the two sides, perhaps including increasing uplift westward of the rocks on the southwest.

In most places few outcrops occur near the fault trace. In the valleys, as noted, bedrock is covered by alluvium, and at the saddles on the ridges the bedrock is deeply weathered into red or brown residuum. This weathering may be due to the topographic situation of the saddles, high above modern drainage, although it may have been produced in part by greater susceptibility to decay of fractured and sliced bedrock near the fault. In some places, as along Jakes Creek and Shields Branch south of Elkmont (Gatlinburg quadrangle), small rounded knobs project from the alluvium and residuum near the fault, and may be formed of wedges of less disturbed rock, surrounded by interlacing fractures.

The only extensive outcrops near the Oconaluftee fault occur where it crosses the Middle Prong of the Little River south of Spruce Flats (Wear Cove quadrangle). These outcrops confirm the interference from other areas of extensive disturbance near the fault. On the east bank of the river the Elkmont sandstone south of the fault is medium grained and forms strong ledges, greatly sheared nearest the fault and much faulted and folded farther south, beyond which it forms a more regularly dipping sequence. The Elkmont just north of the fault is exposed along the road on the west bank of the river and is fine-grained silty sandstone and slate, so contorted and sheared that the attitude of its bedding can be discerned only in places.

LESSER FAULTS BETWEEN GATLINBURG AND OCONALUFTEE FAULTS

The triangle between the Gatlinburg and Oconaluftee faults is split into blocks by three lesser members of the Gatlinburg fault family, the Huskey Gap, Mids Gap, and Mannis Branch faults.

The Huskey Gap and Mids Gap faults to the east are well expressed topographically in the ridges adjoining the Little River near Elkmont, crossing the ridge on the northeast at Huskey Gap and Mids Gap, from which they are named (Gatlinburg quadrangle). The western, or Mannis Branch fault, is similarly well indicated by alined notches and small valleys. The apex of the triangle on the west (Wear Cove quadrangle), into which it extends, in fact displays a more pronounced topographic grain on air photographs than any other part of the region, suggesting much fracturing and slicing of the bedrock, partly on the Gatlinburg, Mannis Branch, and Oconalutee faults, partly on other faults or fractures not detectable on the ground.

The three faults extend diagonally northeastward across the triangle, each one to the east trending more northerly than those on the west. As mapped, the Mannis Branch fault converges with the Gatlinburg fault at each end, and the Mids Gap and Huskey Gap faults converge with it at their north ends; the last two however, meet the Oconalutee fault on the south at more obtuse angles. The Huskey Gap fault is apparently alined with the divergent segment of the Gatlinburg fault between the National Park Service Headquarters and Gatlinburg, referred to above.

Near Elkmont the Huskey Gap and Mids Gap faults displace recognizable subdivisions of the Elkmont and Thunderhead sandstones, throwing them and the underlying Greenbrier fault down on the northwest by perhaps a thousand feet or more (section *I′–I″*, pl. 9). Northward, they run out into the Roaring Fork sandstone, where their positions are conjectural. The Mannis Branch fault lies wholly in Elkmont and Thunderhead sandstones, and lithologic contrasts across it are less obvious. East of Mannis Branch its position is indicated by a change from east-dipping to north-dipping beds of Elkmont sandstone, but on the Middle Prong on the Little River farther west, thick-bedded coarse Thunderhead sandstone is thrown down northward against the finer grained Elkmont sandstone, (section *O′–O″*, pl. 9).

No outcrops of the Huskey Gap and Mids Gap faults were observed, but the Mannis Branch fault is exposed on an abandoned road east of the Middle Prong of the Little River at Spruce Flats. The fault is marked by a gouge zone 10 feet wide, made up of deeply weathered pulverized sandstone. Its southern border dips 50° S. and the Elkmont sandstone for 50 feet beyond is so jointed that bedding is not discernible. On the north, strong fractures ramify at various angles from the gouge zone into the massive Thunderhead sandstone. General attitude of the bedding of the formations on opposite sides of the fault is discordant.

LESSER FAULTS NORTH OF GATLINBURG FAULT

Northwest of the divergent segment of the Gatlinburg fault, in the eastern part of Cove Mountain, are half a dozen faults trending north-northeast, across the structural grain. They displace the Great Smoky group of the Greenbrier thrust sheet and the Greenbrier fault beneath and extend northward into the Pigeon siltstone, where they cannot be traced.

The faults are poorly expressed topographically, if at all, and in most places their positions on the geologic map are shown with a considerable degree of inference. Their existence is indicated by offsets of the contact between the Thunderhead sandstone and Pigeon siltstone along the Greenbrier fault and by offsets farther south of segments of the nearly vertical contact between the Thunderhead and Elkmont sandstones. One of the faults, the Norton Creek, can be located closely from adjacent outcrops along Norton Creek a mile above its mouth; another one to the east can be similarly located on lumber roads northeast of Piney Butt, and a third on Cliff Branch just above its mouth. Even at these places the fault surfaces are not visible, but the map pattern suggests that the faults dip at high angles.

Many of the faults offset steeply dipping or vertical beds, indicating a component of strike-slip displacement. Displacement on the Norton Creek fault and those to the east is right lateral, on those west of it left lateral. The Middle Ridge fault, postulated to account for a repetition of the Elkmont-Thunderhead contact, is aberrant, as it throws down Thunderhead sandstone on the southeast in a strip 2 miles long on Middle Ridge (section $G''-G'''$, pl. 9). The true nature of its displacement, as between dip-slip and strike-slip components, is undetermined.

Most of the faults of Cove Mountain are not known to be in contact with the Gatlinburg fault, so that their relations are uncertain. The westernmost, or Fighting Creek fault, joins the Gatlinburg fault on the south at an obtuse angle, but the easternmost fault prolongs northward the line of the Huskey Gap fault and the divergent segment of the Gatlinburg fault.

Possibly related to the Gatlinburg family is the Pigeon Forge fault, which lies about a mile east of those last described. Unlike them, however, it trends north-northwest, and has an observed left-lateral displacement. It meets the Gatlinburg fault on the south at Dudley Creek, about a quarter of a mile east of the report area (Cartertown quadrangle) in a tract of complex minor faulting that is not fully understood. If the Pigeon Forge fault is a strongly divergent branch of the Gatlinburg family, it provides a tenuous link between the family and the Great Smoky fault, for, as indicated above, movement on it seems to have taken place at the time of the Great Smoke thrusting.

MOUNTAIN BLOCK [17]

The mountain block comprises the rocks of the Greenbrier thrust sheet, which form the main Great Smoky Mountains and the high outlying ridge of Cove Mountain on the north.

Within the report area the mountain block consists of a great mass of rocks of the Great Smoky group, dominantly of competent sandstone more than 25,000 feet thick. For the most part the gross structure of these rocks is less complex than that of the rocks of the foothill area on the north, although they generally possess a higher grade of metamorphism. Except at the forward edge of the block, in Cove Mountain, the rocks merely have been tilted at low to steep angles, and are cut by few thrust faults (pl. 9). Parts of the mountain block, however, have been broken by faults of the Gatlinburg family, younger than the deformation.

In describing the structures of the mountain block, it is convenient to divide it into (a) the Cove Mountain area, in parts of which the rocks are much folded, and which is separated from the remainder by the Gatlinburg fault; (b) the northern mountain spurs, between the Gatlinburg and Mingus faults, where the rocks are largely homoclinal, but have been somewhat disrupted by the Oconaluftee and related faults; and (c) the mountain crest farther southeast where the rocks are also homoclinal, but have strongly developed metamorphic structures.

COVE MOUNTAIN AREA

Cove Mountain, and its structural continuation to the southwest, forms a tract of rough mountain country, 13 miles long and as much as 3 miles broad, which extends across most of the central part of the report area (Gatlinburg and Wear Cove quadrangles). On the northwest it overlooks Wear Cove and the surrounding foothills in a high escarpment, followed by the Greenbrier fault, but on the southeast it slopes more gradually toward the topographic trench along the Gatlinburg fault.

The Cove Mountain area poses more problems of interpretation than the rest of the Greenbrier thrust sheet. As Keith (1895a) originally indicated, it is formed by a projection of the coarse rocks of the mountains (Great Smoky group) into the finer grained rocks of the foothills (Snowbird group), on which they lie. The coarse rocks do not, however, have the synclinal structure which he supposed, as the formations are not repeated nor are the dips reversed on the southeastern flank. Although the Great Smoky group of Cove Mountain adjoins that on the south through two-thirds of its length, the contact between them is the Gatlinburg fault. The Thunderhead sandstone just north of the fault differs slightly from that on the south, and these differences increase northeastward. Both Thunderhead and Elkmont sandstones in parts of the area are much folded, yet show less physical metamorphism than the rocks of the main part of the thrust sheet.

Nevertheless, the Thunderhead and Elkmont sandstones of both areas lie discordantly on the Snowbird group, and the surface of discordance in both would appear to be the same feature—the Greenbrier fault—offset by later faults of the Gatlinburg family. Litho-

[17] Based on observations by King (Gatlinburg quadrangle), by King and R. B. Neuman (Silers Bald quadrangle), and by H. W. Ferguson and G. D. Swingle (Wear Cove and Thunderhead quadrangle).

logic differences between the Great Smoky group of the two areas are a stratigraphic problem, discussed above. The greater folding and lesser physical metamorphism of the rocks of the Cove Mountain area may be features of the forward edge of the Greenbrier thrust sheet; the possibility has been mentioned above (p. 110) that the rocks of the Cove Mountain area may be a large intermediate slice between two branches of the Greenbrier fault.

In the western part of the Cove Mountain area, and along much of its northwestern edge, the Thunderhead sandstone has a southeastward-dipping homoclinal structure similar to that farther south (section J''–J''', pl. 9). Toward the east, however, the structure becomes more complex, not only because of later disruption by faults of the Gatlinburg family, but because of earlier folding (section F''–F''', pl. 9).

The folds can be inferred from variable dips in individual road and stream traverses, but they cannot be traced directly on the ground, due to poor exposures in the intervening areas. Their map pattern (pl. 5) is obtained by matching the folds in successive traverses. They trend generally northeastward, parallel to the regional grain, and are highest and most extensive on the southeast, where the Elkmont sandstone emerges; they are lower and less continuous in the Thunderhead sandstone to the northwest and west. In places, beds on the northwest flanks of anticlines dip northwestward, but in others, especially near Norton Creek, they stand vertical for long distances.

In the northeastern part of the Cove Mountain area, foliation is very weak in both the Elkmont and Thunderhead sandstones, so that they appear virtually unmetamorphosed, in contrast to the pervasively foliated rocks of the Snowbird group which adjoin them. No cleavage is visible in the sandstone and conglomerate, and the argillaceous rocks show only a faint coarse fracture cleavage related to the axial planes of the local folds. This is reflected by absence of recorded cleavage in this area on the geologic map (pls. 5, 13). Microscopic study indicates, however, that the two formations, like the adjacent Snowbird group, lie in the chlorite zone and incipient phase of the biotite zone; hence metamorphism of the two sets of rocks is mineralogically comparable.

NORTHERN MOUNTAIN SPURS

The northern spurs of the main Great Smoky Mountains are formed of a southeast-dipping homoclinal sequence of Great Smoky group at least 5 miles broad. Its base on the Greenbrier fault emerges east of Fighting Creek Gap, but farther west it terminates northward against the Gatlinburg fault. The eastern part of the homocline is separated and offset from the western by the Oconaluftee fault near the main east prong of the Little River (Gatlinburg quadrangle).

Northeast of the Oconaluftee fault the Great Smoky group dips southeastward at angles of 15° to 30° (section H''–H''', pl. 9), and the structure is not reversed until farther southeast, outside the report area (Cartertown quadrangle) (Hadley and Goldsmith, 1963). The only variations in the regularity of the homocline are a succession of cross-warps which produce broad southeast-plunging arches and troughs. One of the troughs follows the crest of Sugarland Mountain in the report area (Gatlinburg quadrangle) and causes the strike to bend from east-northeast on the northeast side to north-northeast on the southwest side. Its northwestern part has been dropped down successively along the Husky Gap and Mids Gap faults, producing two sets of half saucers in the units of thick-bedded Elkmont and Thunderhead sandstones.

Southwest of the Oconaluftee fault the homocline steepens, until near the Middle and West Prongs of the Little River (Thunderhead quadrangle) the strata dip generally between 30° and 60° (for example, section Q'–Q'', pl. 9). For the most part the homocline is uninterrupted and involves all the formations of the Great Smoky group, in the west amounting to about 25,000 feet of strata, from the Oconaluftee fault at the base on the north to the State-line divide on the south. The only exceptions observed were on Edens Garden and Sams Creeks where dips are reversed on local folds and at the northeast end of Long Arm ridge where the strata are repeated, apparently by a thrust fault. A significant feature in this segment is the divergence of the homocline from the Oconaluftee fault, not only in the east where the fault crosses the regional structural grain, but farther west where it is more nearly parallel to the grain. In the west the fault trends east-northeast and the rocks of the homocline strike north-northeast. Each stratum thus diverges westward from the fault and extends toward the State-line divide, where it crosses into North Carolina. In this manner, at least 8,000 feet of Elkmont sandstone wedges in south of the fault between Meigs Mountain and the west edge of the report area (sections L to T, pl. 8).

Throughout much of this belt, physical effects of metamorphism of the rocks of the Great Smoky group are slight, even though they contain biotite as a metamorphic mineral and are medium-grade metamorphic rocks. Sedimentary structures are faithfully preserved in the thick competent sandstone beds, but greater effects of metamorphism are apparent in the incompetent argillaceous layers, especially where these form thin partings between the sandstone beds. They are converted to slate or phyllite, whose cleavage dips southeastward at steeper angles than the dip of the bedding in the homocline, as may be seen along U.S. Highway 441 at the east edge of the report area and elsewhere.

This cleavage differs from the pervasive cleavage in the relatively homogeneous rocks of the Snowbird group to the north and results from a somewhat different resolution of forces. It resembles the cleavage in slaty partings between quartzite layers in the classic example in the Baraboo area, Wisconsin (Steidtman, 1910, p. 264–268; Leith, 1923, p. 153–157). Like the cleavage in the Baraboo area, this cleavage is on the flank of a major synclinorium, whose axis is farther southeast. The competent sandstone beds accommodated themselves to the synclinorial structure by differential movement along the weaker argillaceous partings, each higher bed moving away from the axis relative to the bed next beneath, setting up a couple that created the inward-dipping cleavage in the partings.

MOUNTAIN CREST

Southwest of the Oconaluftee fault, the structure of the homocline becomes more complex down the dip, toward the mountain crest, and its interpretation is more difficult because of increasing effects of metamorphism.

In the head drainages of both the main east prong and the Middle Prong of the Little River the dominantly argillaceous rocks of the Anakeesta formation are succeeded downdip by sandstone beds which form the mountain crest and adjacent spurs, from near Thunderhead Mountain eastward past Mount Buckley. Toward the west the sandstone beds succeed the Anakeesta formation conformably, but farther east relations seem to be discordant. This difference and contrasts in gross lithology between the sandstone to the west and east suggest that two units are involved. The sandstone to the west is interpreted as an unnamed upper units of the Great Smoky group (section *N″–N‴*, pl. 9), whereas that farther east is thought to be Thunderhead sandstone raised by faulting from a level below the Anakeesta formation (section *J‴-J⁗*, pl. 9). The presumed fault at the contact is probably the same as the Mingus fault which lies in a comparable structural position east of the report area, across the Oconaluftee fault (Clingmans Dome and Cartertown quadrangles; Hadley and Goldsmith, 1963).

Existence of the Mingus fault in the basin of the main east prong of the Little River is suggested by an abnormally small thickness of the upper tongue of the Anakeesta formation and by failure of its structures to conform to the well-defined contact with the Thunderhead sandstone southeast of it. Moreover, the Thunderhead sandstone in a belt a mile wide to the southeast is traversed by zones of strong internal deformation, in which foliation is more conspicuous than bedding and in which detrital grains and concretions are strongly elongated. These features suggest that movement was distributed extensively through the lower few thousand feet of overriding rocks above the fault. The deformed zones are separated by other zones of surprisingly undeformed rocks and are overlain by sandstone and argillaceous rocks which dip regularly to the southeast. The Thunderhead sandstone at the top of the sequence, on the mountain crest near Mount Buckley and Clingmans Dome, shows little directional fabric, either on the outcrop or under the microscope, and its contained concretions retain their original spherical or irregular outlines.

Mineralogic grade of metamorphism increases southeastward; garnet porphyroblasts occur with the biotite porphyroblasts a short distance northwest of the Mingus fault and continue thence to the mountain crest (pl. 13). Physical effects of metamorphism increase erratically with the mineralogic effects. In places, even the coarse sandstone beds are thoroughly foliated; in others, the dark silty and argillaceous rocks, although garnetiferous, retain most of their original sedimentary structures. Metamorphic isograds extend west-southwest obliquely across the strike of the rocks. Near Thunderhead Mountain the Thunderhead sandstone is thoroughly foliated and contains coarse biotite, in contrast to its less altered condition along the strike to the northeast.

An impressive feature of the area is the development of foliation, not only in the fine-grained weak silty and argillaceous rocks, but in the coarser and stronger sandstone and conglomerate beds. Foliated coarse rocks are especially prominent in the zones of strong internal deformation southeast of the Mingus fault. Their foliation results from a combination of flattening and elongation of the quartz grains, of crushing of feldspar grains, and of growth of micaceous minerals. Microscopic study indicates that deformation of the detrital grains is accomplished mainly by shearing, with much comminution into finer cataclastic debris which has, in turn, been partly converted to mica. These foliate structures resemble those already described, which occur much more locally in the sandstone and conglomerate farther north in the report area, but they differ in a much greater development of the micaceous minerals.

In many outcrops, especially south of the Mingus fault, foliation is parallel to the bedding, or nearly so (as indicated by a special symbol on pl. 13), in contrast to the usual divergent relations farther north. Parallelism probably developed mainly along the southeastern gently dipping flanks of anticlines, for some of the outcrops referred to are interspersed with others in which the only visible structure is foliation, and bedding is not apparent; the latter may be on the northwestern steeply dipping limbs of anticlines.

Nearly all the well-foliated sandstones within a few miles of the mountain crest possess a linear structure, indicated especially by elongation of the quartz grains and concretions. The lineation is in the plane of the foliation, and most of that observed is either parallel to, or slightly divergent from, the direction of dip (pl. 13). Linear structure grows fainter northward, beyond the garnet-biotite isograd, where it can be detected with difficulty on the outcrop, although microscopic study indicates that it occurs in places.

INTERPRETATION OF MAJOR FAULTS

PROBLEMS OF GREAT SMOKY FAULT

The description of the great Smoky fault (p. 89–97) fails to elucidate some of its larger problems: What is the meaning of the present configuration of the fault? To what extent was this the result of subsequent deformation, and to what extent was it inherited from the form of the initial fracture? What was the form of the initial fracture, in the overriding and the overridden rocks? What was the absolute displacement of the thrust sheet, or of its several parts? Additional analysis and speculation regarding the Great Smoky fault is desirable.

The structure sections and structure contour map (pls. 9, 12) show the configuration of the Great Smoky fault and the rocks beneath it in a band as much as 10 miles wide, but within no more than a few thousand feet of the surface. Further inferences regarding the structure of the rocks at greater depths and farther toward the root zone of the fault are possible because the overridden Paleozoic strata possess a fairly regular predictable stratigraphy. A possible reconstruction, based on this stratigraphy, is indicated in figure 23*D*, which is an expansion of section *J–J''''*, plate 9, to a depth of about 4 miles below sea level. This reconstruction typifies a broad segment of the fault zone southeast of Chilhowee Mountain; farther east, beyond the Pigeon Forge fault, subsurface relations probably differ.

The reconstruction is based on an assumption that the Great Smoky fault, like other low-angle faults farther northwest in the Appalachians (Rich, 1934, p. 1589–1591), developed from an initial break which followed for long distances the incompetent layers in the sequence, ascending abruptly through the intervening more competent strata along inclined planes of shear (fig. 13*B*). One of the incompetent layers involved in the Great Smoky thrusting is the Blockhouse shale, which underlies the fault through much of Tuckaleechee and Wear Coves. Where the fault emerges along its main trace to the northwest, however, the fault overlies the Tellico formation which succeeds the Blockhouse; presence nearby of strata as high as the Mississippian suggests that these strata are involved in the faulting as well. It is suggested that the fault is underlain by Blockhouse shale throughout its long gentle slope northwest of the coves, and that it only begins its ascent into the Tellico and higher formations in its steeper slope northwest of Chilhowee Mountain.

Relations of the fault southeast of the coves are less certain, for it is nowhere exposed in that direction; but the fault probably descends steeply, at least near Wear Cove (pl. 12). A descent of the fault into deeper overridden formations is suggested by occurrence along it in the coves of intermediate slices of the lower part of the Knox group and of the Chilhowee group. The fault probably descended through these competent units on planes of shear, but it may have flattened between them in the intervening incompetent Rome formation and Conasauga group. Another flattening is possible at a still deeper level in the incompetent Sandsuck formation which underlies the Chilhowee group.

This reconstruction suggests a possible derivation of the intermediate slices of Paleozoic rocks which are a characteristic feature along the Great Smoky fault. These slices undoubtedly originated southeast of the present outcrops of the fault, and may have come from blocks of strata which were bounded above and below by incompetent layers and at the sides by planes of shear (fig. 23*B*). During emplacement of the overriding mass of Ocoee series, the slices were torn loose from the overriden block and carried forward for greater or less distances along the fault (fig. 23*C*).

The Chilhowee Mountain block, separated from the rest of the Great Smoky thrust sheet by the Miller Cove fault family, might be merely a very large intermediate slice, derived from a competent mass of Chilhowee group and adjacent formations that originated southeast of the present outcrops of the fault in Wear and Tuckaleechee Coves. According to the reconstruction in figure 23, the Chilhowee Mountain block moved little more than 12 miles northwestward from its original position.

This reconstruction, if valid, suggests that much of the observed configuration of the Great Smoky fault originated from the initial fracture in the overridden Paleozoic rocks and not from later deformation of the fault surface. The synclinal structure of the Chilhowee Mountain block would not be a result of ordinary folding, but of warping of the overriding strata to conform to the abrupt bend in the fault surface. The arching and small-scale deformation of the overridden Ordovician rocks in the cores of Tuckaleechee and Wear Coves would be a superficial effect, produced immediately before or during the time the Great Smoky thrust sheet passed over them.

The form of the initial fracture of the Great Smoky fault in the main overriding mass of the Ocoee series is not amenable to the sort of reconstruction herein proposed for the overridden Paleozoic rocks. The stratigraphy of the Ocoee is less orderly and less well understood than that of the Paleozoic rocks, and its structure was probably complex at the time of thrusting; it had already been metamorphosed, involved in the Greenbrier thrusting, and otherwise deformed.

For at least 10 miles southeastward the initial fracture in the overriding rocks was in the Ocoee series itself, as Ocoee lies on the Great Smoky fault across most of its observed breadth. Farther southeast the fault descends into basement rocks, probably to its root zone. In the eastern Great Smoky Mountains the fault is not exposed again southeast of its main trace, but about 15 miles southeast of the trace, basement rocks emerge beneath the Ocoee series; the fault, if present here, lies still deeper.

The absolute displacement of the main overridding mass of Ocoee series is uncertain, but speculative minimum and maximum figures can be suggested. The main mass moved much farther than the 12 miles inferred for the Chilhowee Mountain block, for it differs much from it in degree of deformation and metamorphism. On the other hand, the fault descends into a root zone in the basement farther southeast, instead of continuing in the stratified rocks, so that total displacement of the main overriding mass was probably no more than twice that of the Chilhowee Mountain block.

PROBLEMS OF GREENBRIER FAULT

The description of the Greenbrier fault, like that of the Great Smoky fault, fails to elucidate some of its larger problems, but this fault is not sufficiently exposed in the report area for adequate analysis; most of the critical exposures lie farther east (Hadley and Goldsmith, 1963). The remarks made here are therefore incomplete.

Through most of the extent of the Greenbrier fault, the younger Great Smoky group is thrust over older Snowbird group and related formations. The initial fracture, at least in the forward part of the structure, probably developed along the stratigraphic contact between the two groups, because the Great Smoky strata were highly competent, and the Snowbird strata somewhat less so. In the southeastern part of the Great Smoky Mountains the Greenbrier fault is believed to descend into the basement rocks, probably toward its root zone (Hadley and Goldsmith, 1963).

As younger rocks are thrust over older on the Greenbrier fault, many of the usual criteria which would indicate the displacement of a low-angle fault are not applicable, and the amount of its displacement is uncertain. An estimate of 20 miles of displacement has been made on the basis of differences in stratigraphy and thickness of the Snowbird group above and below the fault in the eastern Great Smoky Mountains (Hadley and Goldsmith, 1963), but the actual displacement may be less or greater.

Relative displacement between originally contiguous rocks above and below the fault may vary considerably from place to place. At some localities the strata above and below the fault seem nearly parallel to it, but truncations of both overriding and overridden rocks by varying amounts are apparent over wider areas. Although the base of the overriding rocks is truncated, they were probably emplaced as a little-deformed plate. The overriden rocks are truncated to a greater extent throughout, but especially toward the northwest along the front of the Great Smoky Mountains in the report area and eastward. Here, the fault lies from place to place on the Rich Butt sandstone and various formations of the Snowbird group and bevels large folds, such as the Copeland Creek anticline (Cartertown quadrangle). Emplacement of the Greenbrier thrust sheet was therefore accomplished not only by forward movement of the upper plate, but by shortening of the lower plate by folding, and faulting, either immediately before or during the time when it was overridden. Relative displacement along the fault may thus have increased northwestward from its root zone.

PROBLEMS OF GATLINBURG FAULT FAMILY

Interpretation of the Gatlinburg fault family is attended by more uncertainties than that of any of the other major features in the Great Smoky Mountains. This is due mostly to lack of exposures sufficient to indicate the critical features of the family. Nevertheless, these exposures are not inferior in quality or abundance to those along the Great Smoky, the Greenbrier, and other faults of the report area. The latter, however, are clearly thrust faults with dominant dip-slip components of displacement, and can be interpreted according to the laws governing their kind. For the

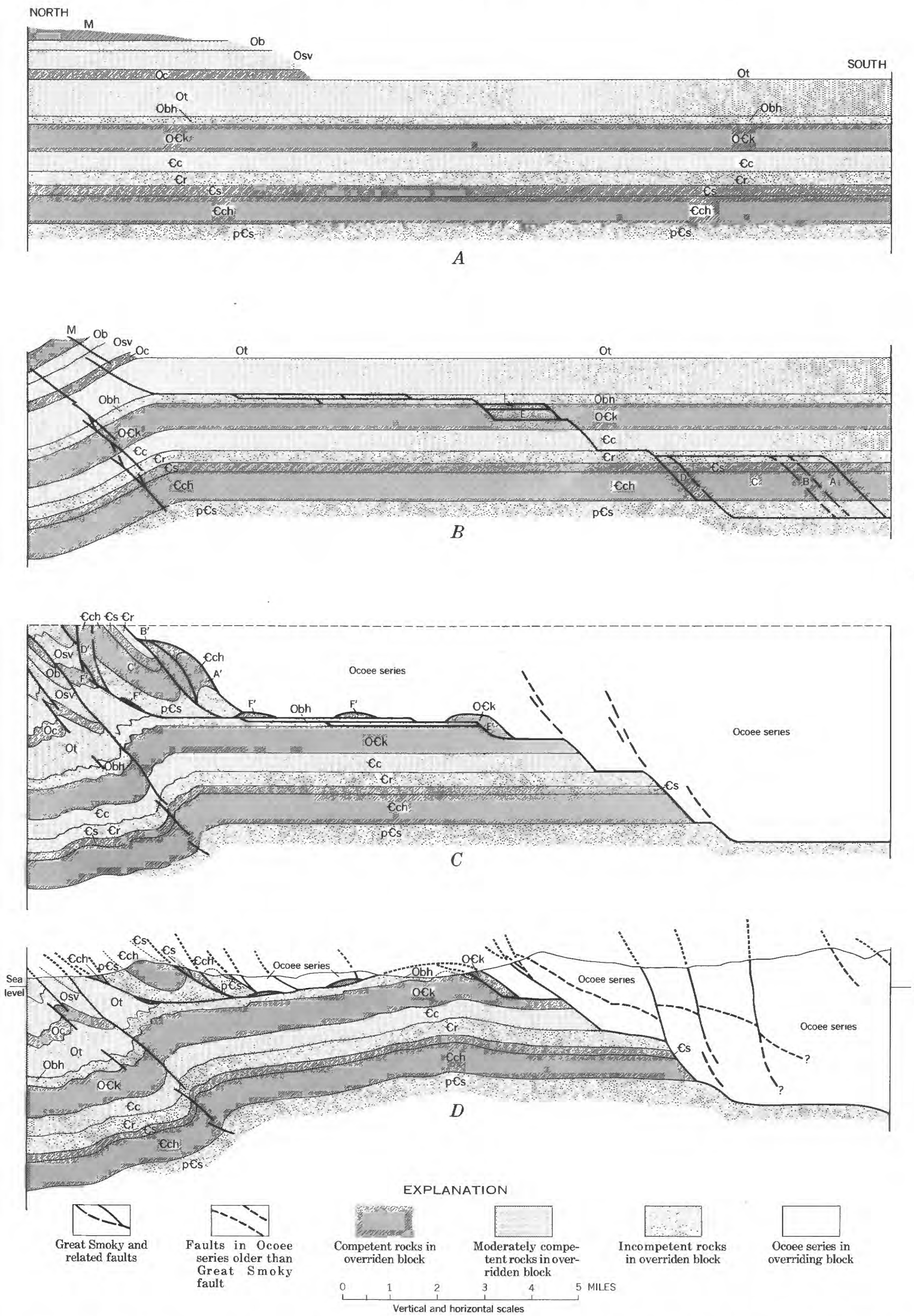

Figure 23.—Sequential sections showing inferred development of Great Smoky fault in relation to its overridden rocks. *A*, Before thrusting. *B*, Fractures in overridden rocks which determined course of fault. *C*, After thrusting. *D*, Present structure based on section J–J'''' of plate 9. Ꞓch, Chilhowee group. Ꞓs, Shady dolomite. Ꞓr, Rome formation. Ꞓc, Conasauga group. OꞒk, Knox group. Obh, Blockhouse shale. Ot, Tellico formation. Oc, Chota formation. Osv, Sevier formation. Ob, Bays formation. M, Rocks of Mississippian age.

faults of the Gatlinburg family, on the other hand, evidence as to the nature of the displacement is conflicting from one fault to another and from place to place along single faults, with indications of both dip-slip and strike-slip movements. More data than are available in the report area would be required to clarify their meaning.

Representation of the faults of the family on the geologic maps is that which seems most in accord with observed field relations, and the larger faults, at least, are mapped with much confidence on the basis of juxtaposed contrasting formations and strong topographic expression. Some anomalies in the fault pattern are thereby created which cannot be resolved on the basis of any theoretical assumptions as to the nature of the movements.

The nature of the movement on the Oconalutee fault is relatively plain, as offsets of the formations across it indicate a dominant right-lateral strike-slip displacement. East of the report area (Ravensford quadrangle) the fault fades out, and the formations beyond are not displaced by it (pl. 1). Progressively greater displacement along the fault apparently occurs farther west, not only in its transverse, west-northwest-trending segment but also in the segment where it curves west-southwest into the structural grain of the region. The fault seems to lack much dip-slip displacement. The block on the southwestern and southern side is known to have moved farther northwestward and westward than the block on the opposite side; the western segment of this block may have been raised somewhat relative to the block on the north.

Evidence as to the nature of movement on the Gatlinburg fault proper is more conflicting. Throughout much of the report area and farther east, offset of formations suggests a dominant dip-slip displacement with drawthrow on the north, amounting to as much as 5,000 feet. Nevertheless, in the western part of the report area, where the Gatlinburg fault approaches the Oconaluftee fault, it seems to share the dominant right-lateral strike-slip displacement of the latter; the trace of the Greenbrier fault is offset 3 miles across the 2 faults. More definite indications of right-lateral strike-slip displacement occur east of the report area (Cartertown quadrangle) where striae on the fault surface suggest a strike-slip component of about half the dip-slip component.

Right-lateral strike-slip movement on the Gatlinburg fault is seemingly impossible, because its trace is deflected north-northeast from its usual course for 1½ miles west of Gatlinburg and for half a mile east of Gatlinburg. If strike-slip movement on the Gatlinburg fault occurred, it could only have been when its course was straighter than now, suggesting a possibility that the deflections were imposed after the greater part of the movement on it had ceased. The deflection west of Gatlinburg is on the apparent prolongation of the Huskey Gap fault, which appears, in turn, to be truncated by the Oconaluftee fault at its south end.

One thus gains an inkling of a possible sequence of movements on the Gatlinburg fault family, although not all of it can be reconciled with known data, or is capable of analysis in detail: (1) The Gatlinburg fault proper developed, with east-northeast trend, and with both dip-slip and strike-slip components of displacement. (2) The Oconaluftee fault developed later toward the southwest, with dominant strike-slip displacement, in part following the southwestern prolongation of the Gatlinburg fault, but farther east diverging into a transverse course. (3) As a result of this later faulting, the area just east of the junction of the two faults was shattered into blocks which moved variously along minor faults, producing the complex mosaic of the eastern part of the report area (Gatlinburg quadrangle). Some of these minor faults deflected the Gatlinburg fault proper north-northeast from its original east-northeastward course, by a combination of strike-slip and dip-slip movements.

The problems of the Gatlinburg fault family would be understood more clearly if one knew its relation to the Great Smoky fault. Is the Gatlinburg fault family older, contemporaneous, or younger than the Great Smoky fault? Are the faults of the Gatlinburg family confined to the Great Smoky thrust sheet, or do they penetrate beneath it, offsetting the Great Smoky fault itself? What is the relation between the northwestward-directed force which caused the emplacement of the Great Smoky thrust sheet, and the probable strike-slip displacements on the faults of the Gatlinburg family which resulted in movements nearly at right angles to this direction?

Little evidence on these problems is available in the report area, as the two sets of faults are not in contact at the surface, but the following speculations can be listed:

1. Both the Gatlinburg fault family and the Great Smoky fault are late features in the orogenic history of the area, as both are younger than the metamorphism of the Ocoee series and much of its deformation. The apparently different resolution of forces which produced the two sets of faults suggests,

however, that they are not of the same age. The strong topographic expression of the larger faults of the Gatlinburg family indicates that they are followed by strong zones of unhealed slicing and gouge, which indicates further that they may be younger than the Great Smoky fault, on which such features are lacking. The difference may, however, be an expression of the contrasting attitudes and origins of the two sets of faults.

2. The Pigeon Forge transverse fault joins, or is truncated by, the Gatlinburg fault proper at the east edge of the report area. To the north it offsets the Great Smoky fault, and it is probably a flaw which developed during emplacement of the Great Smoky thrust sheet. The Pigeon Forge fault resembles those of the Gatlinburg family in possessing a strike-slip displacement; but this displacement is left-lateral rather than right lateral, and the fault trends north-northwest—a direction shared by none of the faults of the Gatlinburg family. The Great Smoky and Pigeon Forge faults therefore cannot be younger than the Gatlinburg fault family; they are either contemporaneous or older.
3. The windows of the Great Smoky fault are all north of the Gatlinburg fault proper, those at the west edge of the report area and beyond approaching it closely. South of the Gatlinburg fault the full thickness of the Great Smoky group is exposed, and the Great Smoky fault probably descends to great depth. The apparent relation between the Gatlinburg fault and the steep descent of the Great Smoky fault may be a coincidence, or it may have genetic implications. The Gatlinburg fault might have developed above an initial irregularity in the surface of the Great Smoky fault (as suggested in fig. 23*D*) or it may be younger and displace the Great Smoky fault downward on the south.

These speculations leave unanswered the questions raised above. Actual knowledge of the subsurface relations in the report area would contribute much to their solution, and so also would knowledge of the whole extent of the Gatlinburg faults east and west of the report area. The latter subject is beyond the scope of this account and is a field for future investigation.

SMALL-SCALE STRUCTURAL FEATURES

Various small-scale structural features and the physical and mineralogic effects of metamorphism have been mentioned in the descriptions of the rock formations and their structure; they will now be summarized and interpreted.

GENERAL FEATURES OF METAMORPHISM

As pointed out by Willis (1893, p. 229), the structure of the Great Smoky Mountains differs in style from that of the Valley and Ridge province on the northwest in that its rocks are not only deformed, but are regionally metamorphosed. Strength of metamorphism increases progressively southeastward, the physical effects variably, the mineralogical effects regularly. Rocks of the Appalachian Valley, although much deformed, show few or no metamorphic effects, whereas rocks near the State-line divide are medium-grade metamorphic rocks. Higher grade metamorphic rocks occur farther southeast, beyond the report area.

The metamorphism is not a mark of the Precambrian age of the rocks of the mountains. In the Chilhowee Mountain area no metamorphic discontinuity separates the Sandsuck formation of the Walden Creek group from the overlying Chilhowee group, and neither of these units is significantly more altered than the Paleozoic rocks of the Appalachin Valley. No metamorphic discontinuity can be found between the Sandsuck formation and the rest of the Walden Creek group, yet this group and the others of the Ocoee series become more metamorphosed southeastward. A truly Precambrian metamorphism occurs in the basement rocks southeast of the report area; but this metamorphism is older than deposition of the Ocoee series, and the metamorphism which affected the Ocoee is superposed on it (Hadley and Goldsmith, 1963).

Climax of the metamorphic period which altered the rocks of the Great Smoky Mountains occurred between the times of emplacement of the Greenbrier and Great Smoky thrust sheets. The metamorphic zones cross the Greenbrier fault, but they are displaced along the Great Smoky fault. Metamorphism of the Ocoee series occurred before its emplacement on the Great Smoky thrust sheet, and structures which formed at the time of the Great Smoky thrusting produced few additional metamorphic effects. The metamorphic climax must have occurred at some time between the earlier and later parts of the Paleozoic era.

METAMORPHIC ZONES

Position of the metamorphic zones in the central Great Smoky Mountains, which is summarized on plate 13, is based on results of thin-section study as reported above, supplemented by observations of other geologists in adjacent areas to the east and west (Hamilton, 1961; Hadley and Goldsmith, 1963; Neuman and Nelson, 1964).

In the northwestern part of the Great Smoky thrust sheet, large flakes of muscovite and biotite occur along the laminae in argillaceous rocks of the Walden Creek an Chilhowee groups, but these are of detrital origin and are not a metamorphic product. The argillaceous components of these rocks are, however, recrystallized into sericite and chlorite, at first in minute flakes without preferred orientation, but farther southeast in coarser flakes which produce a foliated metamorphic fabric. The argillaceous rocks thus pass in this direction from shale through argillites into slates. The passage from unaltered or little-altered rocks, to rocks which have a true metamorphic fabric, is difficult to locate closely in the field; but the boundary is tentatively placed near the southeastern edge of the Chilhowee Mountain block (pl. 13). An interesting feature of the rocks near the northwestern edge of the metamorphic belt is an alteration of detrital biotite to chlorite.

For 7 miles southeast of the edge of the metamorphic belt the rocks of the Ocoee series lie in the chlorite zone, and many of them are colored dull greenish or bluish by chlorite. The argillaceous rocks in the zone have been altered to argillite, slate, or phyllite, depending on formation or locality; siltstones are pervasively foliated, yet preserve their original sedimentary structures. The coarser sandstones and conglomerates show little sign of deformation, except in local areas where the foliation and lineation appears to be largely cataclastic.

About halfway southward across the report area, in Cove Mountain and near the prongs of the Little River, metamorphic biotite makes its appearance in the rocks, at first as stray porphyroblasts amongst the chlorite, but dominating altogether to the southeast (pl. 13). The north edge of the biotite zone lies in a much-disturbed area where the Greenbrier fault and Gatlinburg fault intersect. It is also close to the contact between the Snowbird and Great Smoky groups, and the metamorphic boundary is somewhat obscured by differing compositions of the rocks of the two groups. The characteristic green or blue of the rocks of the Snowbird group in the chlorite zone gives place to the prevailing somber grey of the Great Smoky group, which is caused in part by the presence of metamorphic biotite.

In most of the sandstones of the Great Smoky group in the report area, biotite forms minute unoriented porphyroblasts and produces little or no foliation, but the argillaceous and silty layers have been converted to slate, phyllite, or schist, in which muscovite dominates over biotite. At a few places near the north edge of the biotite zone unoriented porphyroblasts of chloritoid occur in the silty rocks; chloritoid was observed at about the same position farther east (Hadley and Goldsmith, 1963).

A short distance northwest of the Mingus fault small white garnet porphyroblasts make their appearance in silty rocks of the Anakeesta formation, and are associated with biotite from there to the south edge of the report area, wherever rocks of favorable composition occur (pl. 13). In the garnet zone, even the sandstones and other coarse rocks are strongly foliated in places, partly by flattening and crushing of the detrital grains, as in the foliated sandstones farther north, but partly by growth of oriented micaceous minerals.

Higher grade metamorphic zones occur in the Great Smoky Mountains, southeast of the report area where the index minerals staurolite and kyanite make their appearance (Hadley and Goldsmith, 1963).

FIRST-GENERATION FOLIATION

The term "first-generation foliation" is used here for the first foliate structure imposed on the rocks during their deformation and metamorphism, to distinguish it from later generations of foliation and other small-scale structures described below. First-generation foliation is either fracture cleavage, slaty cleavage, or schistosity (Billings, 1954, p. 339), depending on the strength of the structures, the rock composition, and the degree of recrystallization.

The Ordovician rocks of the Appalachian Valley north of the Great Smoky fault, although strongly deformed, are not metamorphosed, but in places are cut by a fracture cleavage. This is most conspicuous in the shales of the Blockhouse and Tellico formations, but occurs also in their sandy and silty rocks near the axes of folds (pl. 10*A*). The cobbly Lenoir limestone on the south flank of the Rock Quarry dome is also cut by a coarse fracture cleavage. The fracture cleavage in the Ordovician rocks is geometrically related to the axial planes of the folds; where recorded, it dips steeply southeastward and strikes northeast (pl. 13).

The fracture cleavage in the Ordovician rocks, being related to their folding, was formed during the same general epoch as emplacement of the Great Smoky thrust sheet. As the first-generation foliation farther south developed during regional metamorphism that preceded the Great Smoky thrusting, the cleavage in the Ordovician rocks must be younger, although no confirmation of this deduction has been found in the report area.

The rest of the first-generation foliation in the report area is in the Ocoee series of the Great Smoky thrust sheet, and occurs where the rocks become truly metamorphic, near the southeast edge of the Chilhowee Mountain block. The argillaceous and silty rocks of the Chilhowee Mountain block itself are not foliated, and even those of the Bates Mountain syncline southeast of it are broken only by a steeply dipping fracture cleavage, similar to that in the Ordovician rocks of the Appalachian Valley. From there southeastward, most of the first-generation foliation in the report area is slaty cleavage, produced by fine-grained recrystallization of various micaceous minerals, which has altered the argillaceous and silty rocks to slate and phyllite. Only in the extreme southeastern part of the area, mainly beyond the biotite-garnet isogard, have the minerals recrystallized coarsely enough to produce a true schistosity.

The argillaceous and silty rocks of the Walden Creek group in the northern foothill block are for the most part complexly folded on a small scale, and their slaty cleavage is geometrically related to the axial planes of the local folds (pl. 10*B*). In two areas, the regional pattern of the foliation shows significant anomalies:

1. Between Wear Cove and Pigeon Forge (southwestern part of Pigeon Forge quadrangle) the strike of the cleavage is consistent in local areas, but differs from that in adjacent areas, in places being nearly east-west, in others nearly north-south (pl. 13). On the geologic map, the area is divided into fault blocks, mainly on straitigraphic evidence, and the divergently striking cleavage seem to conform to these blocks, as though they had been faulted and rotated after the formation of the cleavage.
2. Both strike and dip of cleavage also depart from their usual pattern northwest of Tuckaleechee and Wear Coves. In a small area north of Wear Cove cleavage strikes northwest and dips northeast (pl. 13). In a larger area northwest of Tuckaleechee Cove, cleavage strikes variously north or northwest and dips northeast, or strikes northeast and dips northwest. Toward the west, these aberrant structures extend to Carr Creek, nearly 2 miles north of Tuckaleechee Cove.

The aberrant strikes and dips of cleavage northwest of Tuckaleechee and Wear Coves are probably related to the configuration of the underlying Great Smoky fault along the northwestern border of the windows. The aberrant relations probably resulted from rotation of the cleavage after its formation, when the Great Smoky thrust was warped over the window areas during or after its emplacement.

The Pigeon siltstone of the southern foothill block is generally more broadly deformed than the Walden Creek group; but it is pervasively foliated throughout, although the cleavage is faint on fresh outcrops and does not obscure the sedimentary structures. To the north, cleavage in the siltstone is geometrically related to the minor folds (pl. 10*C*). Farther south, where the strata are homoclinal, it dips consistently southward across the nearly vertical beds, but its strike diverges curiously northeastward from that of the bedding (pl. 13). The folds in the siltstone in this area may have been formed in rocks overridden by the Greenbrier thrust sheet at about the time of its emplacement; the cleavage was superposed on the rocks after they had been folded by differently alined forces.

Cleavage in the Metcalf phyllite farther southwest in the southern foothill block is accompanied by greater recrystallization than in the Pigeon and by more extensive obliteration of the original sedimentary structures. Over wide areas the cleavage dips southeast, nearly parallel to the bedding laminae, but it is probably geometrically related to major and minor folds. The dominant strike of the cleavage is east-northeast to northeast, but north-northeast strikes occur in places (pl. 13). Cleavage in the two directions has nowhere been observed in the same outcrops, so that it cannot be determined whether the two sets are distinct.

Throughout much of the mountain block within the report area the sandstones of the Great Smoky group are not foliated, and the biotite and other metamorphic minerals which they contain show little preferred orientation. In the northern part of the Cove Mountain area, moreover, even the interbedded argillaceous and silty rocks show only a faint coarse fracture cleavage related to axial plans of the local folds; this is reflected by an absence of recorded cleavage in this area on the map (pl. 13). Farther south, the argillaceous and silty rocks have been converted to slate or phyllite, whose cleavage dips southeastward at a steeper angle than that of the enclosing sandstone beds. This cleavage is geometrically related to a large synclinorium whose axis lies southeast of the report area, of which the mountain spurs form the northwestern flank.

In the southeastern part of the report area, the rocks of the Great Smoky group are more thoroughly recrystallized, and the foliation become a true schistosity, especially in the argillaceous, silty and finely sandy layers. An impresive feature of the area is the development of foliation in the sandstones as well, resulting not only from the growth of micaceous minerals but from flattering, elongation, and shearing of the clastic grains. In many outcrops, foliation is parallel to the southeastward-dipping bedding (as shown by a special symbol on pl. 13), but this may be mainly on the southeastern flanks of folds, the northwestern steeply dipping flanks of which are less apparent.

LINEATION

Many kinds of lineation have been observed and measured by geologists (Cloos, 1946(p. 9–21). The lineations shown on the geologic maps of the report area (pls. 2–7, 13) were produced by (a) streaking of mineral constituents in the fine-grained argillaceous and silty rocks, (b) elongation of clastic grains, especially quartz, in the sandstone and conglomerates (fig. 10), and (c) elongation of concretions, whose original form was probably nearly spherical (fig. 9*B*). These linear structure are developed in the planes of the first-generation foliation and are presumably genetically related to the foliation.

Other varieties of linear structures, not shown on the maps, are faintly to prominently displayed in the rocks of the report area, such as the line of intersection between cleavage and bedding and the plunges of minor folds and crinkles. Their geometric relations to the first-generation foliation differ from those of the lineations shown on the maps, and some of them are of different ages.

In the central and northern parts of the report area, linear structures of the types which were mapped are developed only locally, in areas of strong differential movement, as in conglomerate of the Shields formation between Tuckaleechee and Wear Coves, and in the Thunderhead sandstone near the Little River west of The Sinks. Farther south, lineation is developed at many places in rocks of varied composition and is doubtless much more extensive than has been mapped. Streaking of mineral segregations is widespread in the Metcalf phyllite, and elongation of clastic grains and concretions is equally so in the sandstones of the Great Smoky group.

All the linear structures which have been mapped in the report area extend down the dip of the foliation, those in the eastern part of the area plunging south and those in the western part more toward the southeast (pl. 13). The relation of the lineation to the foliation and to the trends of the folds indicates that it parallels the *a* structural axis, or direction of transport. The slight difference in trend of lineation between the eastern and western part of the report area suggests variations in the orientation of the deforming forces as they existed during the time of formation of the first-generation foliation.

SECOND-GENERATION FOLIATION

SLIP CLEAVAGE

In many parts of the report area, especially toward the south, the first-generation foliation has been deformed later, so that the rocks possess a polymetamorphic fabric. Here, as in many other metamorphic areas, the most extensive of these structures is slip cleavage (White, 1949, p. 591–593; Billings, 1954, p. 339), which has displaced, crimped, or bent the first-generation foliation, generally along planes oriented in different directions.

Within the report area, slip cleavage was observed at many localities, mainly in the rocks of the southern foothill block and the mountain block (pl. 13), although at many places it is more evident in float blocks than on the outcrop. Its most prominent expression is in the Metcalf phyllite (fig. 16), where it has thrown the earlier slaty cleavage into small chevron folds; but it was also observed in the Pigeon siltstone, Roaring Fork sandstone, and argillaceous layers in the Great Smoky group. Throughout the area it dips at high angles and strikes in diverse directions (pl. 13). In some outcrops, several sets are present, dipping and striking in different directions, the later crossing and deforming the earlier. Even where best developed, the slip cleavage is not all-pervasive, but is concentrated in parts of the rock, with intervening areas little disturbed.

Southeast of the report area the slip cleavage increases in intensity and produces a second-generation schistosity, superposed on the first-generation schistosity. Here, it appears to be related to a system of large-scale structural features younger than those which accompanied the first-generation foliation (Hadley and Goldsmith, 1963).

Some geologists have believed that slip cleavage in the metamorphic rocks of the Southern Appalachians formed at a time much later than the first-generation foliation (for example, Crickmay, 1936, p. 1386–1392). On the contrary, observations in the Great Smoky Mountains indicate that it develops gradually southeastward, without the discontinuities in space or time that have been claimed. Probably it formed as a late phase of the same orogenic cycle as that which produced the first-generation foliation.

SHEAR CLEAVAGE

In places, another kind of cleavage is superposed on the first-generation foliation, and forms planes a few inches apart, along which each higher slice has been moved relatively northwestward over the slice beneath (fig. 17). Movement on any single plane amounts to only a few inches, but the cumulative movement, distributed through the whole mass of rocks affected by the cleavage, is undoubtedly great. This is a shear phenomenon, and the cleavage is a form of shear cleavage.

Shear cleavage is less extensive than the slip cleavage and occurs mainly in the Metcalf phyllite of the western part of the report area, especially in the belt between the Greenbrier and Great Smoky faults, and thence northeastward near the Line Springs and Great Smoky faults. Unlike the slip cleavage, it lies nearly flat, or dips at low angles in various directions. Strikes of the low-dipping shear cleavage (pl. 13) have little meaning; more significant is the systematic northwestward transport along the cleavage of each higher rock slice over the lower.

Incomplete observations suggest that the shear cleavage cut through not only the slaty cleavage but the slip cleavage, and is therefore younger than both. It seems to be more closely related to the irregular shears and gashes, described below.

IRREGULAR SHEARS AND GASHES

In parts of the central Great Smoky Mountains the rocks are further disrupted by less systematic small-scale gashes, fractures, and minor thrusts, most of which dip at low angles southeastward (pl. 10*C*; fig. 18). In places, they have sliced the rocks to such an extent that the first-generation foliation is reduced to lenses, scales, and knots, separated by gouge zones several inches thick. The rocks are gashed and fractured over small to large areas, between which they remain unaltered. In places, the gashes are followed by quartz veins of a generation later than most of the veining in the region.

These irregular shears and gashes are common through much of the southern foothill area, in the northern part of the outcrop of the Pigeon siltstone and Metcalf phyllite, as well as in some of the argillaceous rocks of the Walden Creek group along the northwestern sides of Tuckaleechee and Wear Coves. The shears and gashes are especially abundant in the more argillaceous overriding rocks close to the Great Smoky fault near the coves, but some occur far from the coves and have no obvious relation to this fault or to other large-scale structural features.

Relation of the irregular shears and gashes to other second-generation small-scale structures so far described is varied. These shears and gashes are most prominent where slip cleavage and shear cleavage are weak, and if they are younger, they have largely overwhelmed them. The open character of the fractures, the gouging and slicing which accompanies them, and the breaking rather than wrinkling or bending of the first-generation foliation, suggest that they formed under less confining pressures than any of the other small-scale structures, and probably during a later period. It is tempting to suggest that they were formed during the time of emplacement of the Great Smoky thrust sheet.

JOINTS

The rocks of the report area are cut by a multitude of joints, which probably include the youngest small-scale structures in the rocks. During early phases of the investigation extensive observations were made on joints in the Gatlinburg quadrangle, but this study was not extended into adjacent quadrangles.

Some of the joints in the Roaring Fork sandstone and Great Smoky group formed in competent sandstone layers between less competent argillaceous layers, and are a fracture cleavage, related to the slaty cleavage in the incompetent layers. Most of the other joints cut cleanly through rocks of varied composition and structure, and formed much later. In homogeneous rocks of complex structure, such as the Pigeon siltstone, they dip in diverse angles and directions and defy any easy analysis. Nevertheless, many joints in all the rocks stand vertically or dip steeply, one conspicuous set trending parallel to the prevailing structural grain of the region, and another at nearly right angles.

The joints parallel to the prevailing grain of the region are characteristically followed by veins of quartz, and in places by veins of other minerals. Those joints which trend at nearly right angles are as clean cut, yet are not veined. Possibly both formed during the same epoch, the veined and unveined joints expressing a different resolution of the forces which existed at the time of their formation.

CHRONOLOGY OF DEFORMATION

The many structural features of the central Great Smoky Mountains, large and small, are not only complex spatially, but their mutual relations indicate that their creation required a long span of geologic time. The structures are sufficiently differentiated as to suggest that their development was episodic, rather than a continuing process, some of the events possibly being separated by considerable times of quiesence. Nevertheless, ages of the different structures can be determined only by their mutual relations, and direct evidence which would relate them to a definite time scale are lacking.

SEQUENCE OF STRUCTURES

One of the earliest structural features of the Great Mountains is the Greenbrier fault, along which rocks of a southeastern part of the Ocoee series were carried over the northwestern part. During emplacement of the Greenbrier thrust sheet, rocks along the contact were somewhat broken, and their fragments were moved beneath the main fault as intermediate slices. The competent rocks of the thrust sheet seem to have been little deformed during emplacement, but the less competent rocks beneath were variably folded, by amounts which increased northwestward. The overridden rocks are deeply truncated by the Greenbrier fault along its present trace on the north face of the Great Smoky Mountains, probably as a result of folding which occurred there, just before or during the Greenbrier thrusting. The Pigeon siltstone north of the present trace of the fault may have been folded during this time, as its folds are crossed divergently by the regional cleavage, which developed later than the thrusting.

Various structural and metamorphic features have been superposed on the Greenbrier fault and its thrust sheet, some of which, at least, probably formed during a later phase of the same orogenic epoch. Rocks near the fault, and some distance to the north and south, are regionally metamorphosed; the metamorphic zones are not displaced by the fault, hence are younger. The metamorphism occurred during a climax of heat and dynamic pressure, exerted while the rocks were buried at considerable depth. First-generation foliation which accompanied the regional metamorphism is geometrically related to axial planes of the folds in the rocks affected, and the folds probably formed during the metamorphism. This metamorphism and folding diminish northward, into the present area of the Walden Creek group; but they die out south of the present Chilhowee Mountain block, where the Sandsuck formation and Chilhowee group are little altered.

The discontinuity between the Snowbird and Walden Creek groups, now represented in the report area by the Dunn Creek and Line Springs faults, may have formed during the same general epoch. They seem to have been displaced before the Great Smoky thrusting (this report), and the Dunn Creek fault may have developed before the regional metamorphism (Hamilton, 1961).

A later deformation is expressed by the Great Smoky fault and structures related to it. The Great Smoky fault and related structures are younger than the regional metamorphism, and produced few metamorphic effects or small-scale structures; irregular shears and gashes in the overriding rocks and fracture cleavage in the less competent overridden rocks might date from this epoch. The Great Smoky fault developed northwest of the Greenbrier fault; it carried rocks of the Ocoee series that had been deformed and metamorphosed during the previous orogeny over Paleozoic rocks farther northwest that had not been metamorphosed. Movement on the Great Smoky thrust sheet also carried the rocks of the Greenbrier thrust sheet passively northwestward, perhaps doubling their transport away from their original geographic location.

As during the Greenbrier thrusting, some of the rocks intermediate between the overriding and overridden rocks along the Great Smoky fault were broken, and their fragments were carried beneath the main thrust sheet as intermediate slices. The faults which bound these slices, of which the Miller Cove fault family are the largest, are therefore contemporaneous with the Great Smoky fault. Precise relations of some of the other structures of this general age to the Great Smoky fault are less certain. A reconstruction of the rocks overridden by the fault suggests that they had previously been little folded (fig. 23). On the other hand, a regional map (Rodgers, 1953, fig. 5, p. 126) indicates that the Great Smoky fault zone crosses diagonally the ends of a folded and faulted belt which is as much as 25 miles broad in northeastern Tennessee, where it includes the major Pulaski and Holston Mountain faults. The Great Smoky fault thus seems to be younger than the structures in this belt and overrides them extensively (King and Ferguson, 1960, p. 85). The age relations of the folds and faults in the Valley and Ridge province northwest of the Great Smoky fault are undetermined, but they are probably contemporaneous or later.

More problematical is the relation of the Gatlinburg fault family of the Great Smoky Mountains area to the Great Smoky fault. No contact or intersection between faults of the family and the Great Smoky fault has been observed, and their peculiar combination of dip-slip and strike-slip displacement indicates a resolution of forces so different from that which produced any of the other later structures that correlation is difficult. Their straight courses, well-marked topographic expression, and probable accompanying gouging and slicing indicate that this family is a late feature in the deformation of the rocks of the region, and it may be younger than the Great Smoky fault.

AGES OF OROGENIC EPOCHS

Although the structural features of the Great Smoky Mountains cannot be assigned directly to a geologic time scale, their ages are suggested indirectly in surrounding areas by the record of the sedimentary rocks.

Basement rocks southeast of the Great Smoky Mountains were deformed, metamorphosed, and plutonized during Precambrian time. Rocks of the Ocoee series lie unconformably on the basement, and their deformation and metamorphism occurred later (Hadley and Goldsmith, 1963). Lack of any metamorphic or structural discontinuity between the Ocoee series, the Chilhowee group, and succeeding Paleozoic rocks indicates that this deformation and metamorphism occurred during Paleozoic rather than Precambrian time.

In the southern Appalachians the early part of Paleozoic time was probably not an orogenic epoch. The great carbonate sequence of the Valley and Ridge province, which extends from the Lower Cambrian through the Lower Ordovician, was laid down far from any lands undergoing active uplift or erosion. The few interbedded clastic layers in the sequence were probably derived from distant parts of the continental interior, and no evidence of lands to the southeast is available.

In the Tennessee segment of the southern Appalachians, important rearrangements of the geography occurred during Middle Ordovician time. In the belt next northwest of the Great Smoky Mountains a sequence of marine Middle Ordovician clastic rocks, about 7,000 feet thick, was deposited. This sequence passes northwestward into a thinner more limy sequence that was evidently derived from newly uplifted land to the southeast (Neuman, 1955, p. 167–171). Elsewhere in the Tennessee segment, lenses of coarse conglomerate occur in beds of the same age; the conglomerate fragments were derived from earlier Ordovician and Cambrian rocks that were being eroded in the area to the southeast (Kellberg and Grant, 1956, p. 715–716).

It is tempting to correlate the orogenic epoch suggested by the Ordovician clastic rocks with the Greenbrier thrusting and the earlier deformation and metamorphism of the rocks of the Ocoee series in the Great Smoky Mountains. The Middle Ordovician clastic rocks that were laid down northwest of the Great Smoky Mountains, although of considerable thickness, are relatively fine grained, and must have been derived from an area more distant than the present outcrops of the deformed and metamorphosed Ocoee series. Nevertheless, these rocks lay much farther from the Ordovician rocks when they were being deposited, and were subsequently brought nearer by transport on the Greenbrier and Great Smoky thrust sheets.

The later orogenic epoch, during which the Great Smoky fault and related structures were formed, occurred much later in Paleozoic time, for Mississippian rocks are involved in the frontal structures of this fault. Although these Mississippian rocks are more clastic and less limy than equivalent Mississippian rocks farther northwest, the difference is slight, and they could not have been derived from nearby lands undergoing uplift. Pennsylvanian and early Permian rocks northwest of the Valley and Ridge province are conformable with the earlier Paleozoic rocks, but their clastic and continental nature indicates that deformation to the southeast was in progress during their deposition (King, 1950b, p. 662–663). The writer once thought it possible that the southeastern part of the Valley and Ridge province was involved in this deformation of Pennsylvanian and early Permian time. Discovery of Pennsylvanian rocks in windows along the northwest edge of the Valley and Ridge province, opposite the Great Smoky Mountains, and the likelihood that they extend some distance southeastward under the thrust sheets of that province, make this suggestion less attractive (Swingle and others, 1956). Deformation of even the southeastern part of the Valley and Ridge province probably occurred later than the Pennsylvanian, although it was perhaps completed by the end of the Paleozoic era.

CENOZOIC DEPOSITS AND LANDFORMS[18]

Overlying the Precambrian and Paleozoic rocks of the central Great Smoky Mountains, whose stratigraphy and structure have been described, are various residual materials and unconsolidated deposits which formed during the Cenozoic era. The Cenozoic was, however, primarily a time of terrestrial erosion; the Cenozoic residuum and deposits formed during relatively brief episodes and are thin and sparsely distributed. Study of the Cenozoic deposits and landforms serves to link the earlier geologic history of the Great Smoky Mountains, shown by the bedrock, with the modern topography, geologic processes, and plant and animal life.

MAP RELATIONS

Cenozoic deposits are shown on the geologic maps (pls. 1–7), where they are thick enough to conceal the bedrock over significant areas. The principal Cenozoic deposits shown on the maps are (a) alluvium of the floors of the present stream valleys, (b) alluvium of terraces that now stand at various heights above the floors, and (c) surficial accumulations on the steeper slopes.

All these deposits are seemingly of later Cenozoic age, and formed at various times and by various processes during the Recent and Pleistocene epochs.

[18] Based on incidental observations by King, supplemented by observations made during shorter inspections by C. S. Denny, G. M. Richmond, and H. E. Malde, which are available in notes and manuscript reports, and observations of J. B. Hadley and R. B. Neuman in adjoining areas to the east and west. Additional information has been obtained from soil maps of Sevier and Blount Counties (Hubbard and others, 1956) and from other published sources.

Nevertheless, on the maps they are distinguished neither as to age nor kind. The only differentiation made on the maps is to outline the terrace scarps which occur here and there in the deposits.

Besides these Cenozoic deposits, large areas mapped as bedrock are thinly covered by other Cenozoic materials: (a) residual materials (residuum and saprolite), which were formed by leaching and decay of the bedrock in place, and (b) colluvium or creep mantle, made up of residual materials and other products weathered from the bedrock, which have moved greater or lesser distances down the slopes. These unmapped Cenozoic materials also have an important role in the Cenozoic history.

The areas underlain by limestone and dolomite in the Appalachian Valley are covered by residuum, colluvium, and older alluvium, complexly intermingled by surficial mass movements. On the soil maps these areas are shown as residual soils whose parent materials are limestone and dolomite (Decatur, Dewey, and Fullerton soil series), or as colluvial and terrace soils derived therefrom (Emory, Nolichucky, Waynesboro, and other soil series) (Hubbard and others, 1956, p. 14–15). All this hilly ground is indicated as bedrock on the geologic maps, on the assumption that bedrock underlies much of it at shallow depth.

TERTIARY

THE GREAT DEGRADATION

After deformation of the rocks of the Great Smoky Mountains had been completed, presumably in late Paleozoic time, the region was subjected to subaerial erosion and was degraded, from levels high above any rocks or topographic forms now preserved, to its present configuration. Most of the degradation whose results are now visible—the carving of the mountains, the cutting of the intervening gorges, and the excavation of rocks in the surrounding areas to produce lowlands—probably was accomplished during the Mesozoic and Tertiary periods. Subsequent erosion during the Quaternary period was relatively minor.

The fact of the degradation is evident; details as to how it was accomplished are not. It is widely believed that degradation of the southern Appalachian region was interrupted by several times of crustal stillstand, during each of which the region was reduced to a peneplain or partial peneplain, and between which degradation was renewed as a consequence of broad crustal arching. Two principal peneplains are commonly thought to have been formed—an Upland or Subsummit peneplain, sometimes called the Schooley, and a Valley Floor peneplain, sometimes called the Harrisburg (Fenneman, 1938, p. 186–194). Some geologists have suggested the former existence of four or more peneplains in the same region (Keith, 1895B, p. 522–524), whereas others have doubted the existence of any (Rich, 1933, p. 1231–1233; Cooper, 1944, p. 213–216). These doubts apply most cogently to the higher peneplain and to its supposed remnants on narrow homoclinal ridges of the Valley and Ridge province, which might, instead, have been produced by normal slope retreat during a single cycle of erosion. The doubts would apply less forcefully to a region of homogeneous resistant rocks, such as the Great Smoky Mountains. Nevertheless, the Great Smoky Mountains probably formed a drainage divide through much of the period of degradation and remained as a highland even during prolonged stillstands; and former peneplains would thus have been less perfectly developed here than elsewhere.

UPLAND SURFACE

When one stands on some vantage point on the summits of the Great Smoky Mountains, as at Cliff Top on Mount Le Conte (fig. 4), one sees at first only a tangled confusion of peaks and ridges. Later, one observes that each ridge is separated from the next by a vast gulf, or valley, whose bottom is a thousand feet or more below. The ridge summits of the Great Smoky Moutains vary in height from place to place by hundreds of feet, yet the crests in each neighborhood rise approximately to more or less the same height. If, in one's mind's eye, the former rocks in each deep intervening valley in the view shown in figure 4 were restored, a hilly or rolling topography would be produced, with here and there a higher summit projecting above the rest. This surface would not be underlain by a single resistant formation, but would extend across the edges of a variety of steeply tilted rocks of the Great Smoky group. If a surface of this kind ever existed, it represents the earliest recorded pause in the degradation of the region, probably correlative with the Upland or Subsummit peneplain of other areas.

More definite suggestions of a former erosion surface exist in places. The northern spurs of Mount Buckley and Clingmans Dome, in the southeast corner of the report area, flatten at an altitude of about 5,100 feet into a group of short benches, not indicated on the generalized contour maps of the area. Other accordant ridge crests of greater length at about the same altitude occur on the North Carolina side of the State-line divide southeast of the report area, such as Thomas Divide, Richland Mountain, and Hughes Ridge. On some of these are occasional small patches of gently rolling summit. The accordant benches and ridge crests suggest, but do not prove, the possible former existence of an erosion surface of low relief on the uplands of the Great Smoky Mountains, above which residual peaks projected a thousand feet or so higher.

VALLEY FLOOR SURFACE

Another former erosion surface of subdued relief is more certainly indicated at a much lower level in the Great Smoky Mountains. From Fighting Creek Gap (fig. 5), one sees to the east the massive face of Mount Le Conte, which descends steeply across rocks of the Great Smoky group, from 6,500 feet at the summit to 2,500 feet at the base, beyond which foothill ridges slope northward across rocks of the Snowbird group. These foothill ridges seem to define a former Valley Floor surface, below which modern drainage is incised to depths as great as 500 feet (cf. Glenn, 1911, p. 63). The seeming regularity of this surface as suggested by distant views is not confirmed when the ridges are studied in detail. Their tops rise on the sandstone units of the sequence and fall on the interbedded less resistant units of argillaceous and silty rocks; moreover, ridge crests in certain areas maintain consistent heights which differ by several hundred feet from the heights of ridge crests in other areas. Some of these variations may have resulted from differential lowering of remnants of the surface during subsequent degradation of the region.

Indications of a similar surface, with about the same imperfection of preservation, occur widely in the northern foothills of the Great Smoky Mountains, in the report area and elsewhere. The surface is especially prominent in areas formed by homogeneous bodies of silty and argillaceous rocks, such as the Pigeon siltstone, Metcalf phyllite, and lower units of the Wilhite formation. Through much of the extent of these formations, ridge crests rise to altitudes of 1,500 or 2,500 feet, depending on their distance from the mountains, and are incised to depths as great as 500 feet by a network of steep-sided valleys. Projecting above the general level are knobs and ridges formed by more resistant sandstone and conglomerate. The largest and most massive of these eminences is Cove Mountain (summit above 4,000 feet), which extends from the mountain area well into the foothills.

A probably correlative surface of much the same character forms the summits of the Slate Knobs in the Appalachian Valley west of Sevierville. The knobs are carved from the Tellico formation, again a homogeneous body of silty and argillaceous rocks. Their summits rise to fairly accordant altitudes of 1,000 to 1,350 feet and contrast with the more irregular surface formed on the adjacent limestones and dolomites.

All these features seem to define a former extensive surface of subdued relief which sloped northward, away from the Great Smoky Mountains across the present foothills, into the Appalachian Valley. It is probably equivalent to the Valley Floor peneplain of other areas.

HIGH-LEVEL GRAVELS

Few remnants on the ridge summits which can be ascribed to former subaerial deposits were observed in the report area. Several dozen well-rounded waterworn cobbles as much as 4 inches in diameter were seen on the summit of Middle Ridge, a northeastern spur of Cove Mountain 2 miles west of Gatlinburg (Gatlinburg quadrangle), at an altitude of about 3,000 feet. They lie on the ground surface, and no matrix is preserved. The cobbles are principally sandstone of the Great Smoky group, which also forms the bedrock of Middle Ridge; but the fragments derived from this bedrock are angular and not stream worn. The ridge summit on which the cobbles occur is intermediate in altitude between the supposed Upland and Valley Floor surfaces, and seems to be unrelated to either. A few well-rounded cobbles of sandstone of the Great Smoky group were picked up on the slopes of Big Ridge about 2 miles northeast of Gatlinburg (Cartertown quadrangle), and might have been derived from a former deposit on the summit. They are clearly of foreign origin, as Big Ridge is formed of rocks of the Snowbird group. A curious feature of the cobbles at both localities is that they are little weathered, but they are perhaps the most resistant fragments of former more extensive deposits, the rest of which have been destroyed by weathering. The ridge summits elsewhere in the foothills of the report area were traversed extensively during the fieldwork, without discovering other traces of former gravel deposits.

RESIDUAL MATERIALS

As elsewhere in the southern Appalachians (Pardee and Park, 1948, p. 24–27; Rodgers, 1953, p. 114–121), parts of the bedrock in the central Great Smoky Mountains have decayed greatly at their original sites, leaving residual materials that have not been removed by erosion. These include insoluble quartz sand, vein quartz, chert, and a clay derived from argillaceous constituents in the parent rocks, as well as weathered products of such less stable minerals as feldspar and mica.

The principal varieties of residual material can be distinguished: (a) residuum, derived from solution of limestone and dolomite, consisting of such minor original insoluble constituents as clay, chert, and quartz sand, which no longer preserve the former rock structure; (b) saprolite (Becker, 1895, p. 289–290), derived from such less soluble parts of the bedrock as clastic sedimentary rocks, and metamorphic and plutonic rocks, consisting of a porous claylike aggregate with nearly the same volume as the parent rock, whose original structures are well preserved. Differences between the two varieties are not fundamental, as intermediate varieties occur, and as all were formed by the same processes, in the same environment. In the central Great Smoky Mountains, exposures of clastic sedimentary rocks are more extensive than limestone or dolomite, and saprolite is correspondingly more extensive than residuum.

SAPROLITE

Saprolite is extensive on the sandstones, siltstones, and argillaceous rocks of the Ocoee series in the foothills of the Great Smoky Mountains and on similar rocks of the Tellico formation in the Appalachian Valley, mostly near the hilltops, well above modern drainage.

Exposures which indicate the depth of rock decay occur in the area of outcrop of Pigeon siltstone east of the West Prong of the Little Pigeon River. Near the river and its larger branches, fresh, unweathered siltstone is widely exposed. On intermediate slopes outcrops are poor, and the surface is covered with a buff loamy soil full of siltstone fragments which have weathered along cleavage planes. Within a hundred feet of the ridge crests all the siltstone has decayed to a yellow or brown saprolite, which still preserves bedding laminae and other original structures. Toward the top of the ridges original structures are less apparent, and the saprolite is deeply stained red brown or red. In places, the saprolite is overlain by structureless red soil.

Parts of the same profile of weathering are also exposed in artificial excavations, especially in cuts along the newer highways. Typical cuts occur along Tennessee Highway 73 west of Gatlinburg on the grade below Fighting Creek Gap (Gatlinburg quadrangle), and east of Gatlinburg near Dudley Creek (Cartertown quadrangle). Some of the highway cuts expose 50 to 100 feet of saprolite, yet not all of them extend into the unweathered bedrock beneath. Where the contact between saprolite and bedrock can be observed, it is fairly abrupt, with no more than a few feet of slightly weathered rock between. The highway cuts also show that the saprolite is overlain unconformably by colluvium, terrace gravel, and other Pleistocene deposits, in many places with the upper red part of the saprolite removed by erosion.

Saprolite is poorly preserved at higher altitudes in the Great Smoky Mountains, where most of the surface is formed of fresh rock, or colluvium and slope deposits derived from it. It was probably much more extensive at a former time, and may then have mantled the whole mountain area. Thus, along the mountain crest on the road between Newfound Gap and Clingmans Dome, southeast of the report area, most of the roadcuts expose fresh bedrock, overlain directly by angular colluvium. Nevertheless, traces of saprolite occur along joints and zones of weakness that penetrate the bedrock. This saprolite almost surely is the last remnant of a deeply decayed body of rock, now nearly removed by erosion.

RESIDUUM

Residuum has formed over areas of limestone and dolomite of the Knox group, in the Appalachian Valley and in Tuckaleechee and Wear Coves, where it occurs at altitudes several hundred feet lower than the saprolite. In these areas it is visible in natural outcrops in many fields and gullies, but artificial openings that would better reveal it are uncommon; some artificial openings occur along the newer highways, mainly east and west of the report area.

Artificial openings in and near the report area indicate that the residuum much resembles that on soluble carbonate rocks elsewhere in the southern Appalachian region (King and Ferguson, 1960, p. 90–91)—a mass of clay, yellow or brown below, changing to red above. formed of the insoluble constituents of the parent rock, mainly argillaceous material, but including quartz sand and chert. Large volumes of material were removed during weathering of the limestone and dolomite, with resulting collapse and contortion of the residuum. Later the residuum was involved in mass movements down topographic slopes, during which some younger alluvial and colluvial material was incorporated. During and after accumulation of the residuum it was locally impregnated by iron and manganese oxides that were once prospected or mined in Tuckaleechee Cove, Wear Cove, and elsewhere (Willis, 1886, p. 335–336; Stose and Schrader, 1923, p. 106).

AGE

Most of the residual materials accumulated at a time well before the present. Although the rocks of the region are now being weathered, the products are being removed by erosion nearly as rapidly as they form. The surface of the residual materials is one of erosion, and they are overlain unconformably by colluvium and alluvium of late Pleistocene age. Apparently they were once more extensive, and have been eroded from wide areas. Much of the saprolite is preserved along ridge crests, well above modern drainage and near the level of the former Valley Floor surface; the residuum is at a somewhat lower altitude, but it may have been differentially lowered after accumulation.

Most of the residual materials may have accumulated when the Valley Floor surface was undissected and had a low relief, so that products of weathering could not be easily carried away; they probably also accumulated in a warm, humid, subtropical climate (Hewett, 1916, p. 45–57; Rodgers, 1948, p. 40; King, 1950a, p. 55–57; Bridge, 1950, p. 196–198). The Valley Floor surface has been variously ascribed an early Tertiary or late Tertiary age (Stose, 1919, p. 34–40; Johnson, 1931, p. 14–21), but the suggested climate has probably not existed in the southern Appalachian region since middle Tertiary time.

The residual materials may have accumulated early in the Tertiary. Small pockets of kaolinitic clay, bauxite, and lignite are widely dispersed amidst the more ubiquitious residual materials on the Valley Floor surface in Tennessee and adjacent States; the lignite in Alabama and Georgia contains identifiable fossil plants of Paleocene or early Eocene age (Bridge, 1950, p. 197). On the other hand, strata as young as the Miocene in the Coastal Plain of southern Georgia are widely covered by a residuum resulting from leaching of their carbonate constituents (MacNeil, 1947), whose accumulation may have occurred during the same time as that of the residual materials in the Appalachian region.

QUATERNARY

EARLY PLEISTOCENE

In the Great Smoky Mountains a large hiatus exists between the residual materials, probably of Tertiary age, and the materials which lie upon them, probably of late Pleistocene age. Very likely the fluctuating climates of early Pleistocene time produced many changes in the erosional and depositional regime of the region; nevertheless, if any deposits of this time are still preserved, they have not been identified. Such deposits would have been more deeply eroded and weathered than any which have been observed, and would have a thicker soil profile.

The record of later Tertiary and early Pleistocene time in the Great Smoky Mountains is thus primarily one of erosion. After the prolonged stillstand which produced the Valley Floor surface, degradation of the region was resumed and the surface was again incised by streams. Much of this degradation was accomplished before late Pleistocene time.

In places, incision of the Valley Floor surface seems to have proceeded at an accelerated pace. In the upper course of Carr Creek and elsewhere in the foothills northwest of Tuckaleechee and Wear Coves, valley-in-valley forms are prominent. Spurs slope off the adjacent ridges with concave upward profiles that flatten toward the axes of the valleys, and seemingly define a series of former open valleys. These open valleys have now been sharply incised to depths as great as 200 feet, so that the modern streams flow in gorges at a lower level, bordered by steep and, in places, precipitous slopes.

LATE PLEISTOCENE

GENERAL CONDITIONS

During late Pleistocene time various alluvial and colluvial deposits accumulated in parts of the Great Smoky Mountains. In places, several sets of deposits can be differentiated, the earlier of which were eroded before accumulation of the later, with accompanying development of thick mature soils. The later deposits have likewise been eroded since their accumulation, but their soils are thinner and weaker. The degree of weathering of the deposits is about like that of the deposits of the Wisconsin stage in other regions, and they are probably no older. Each set of deposits probably formed during a glacial substage within Wisconsin time, and each intervening time of erosion and soil formation during an interglacial substage.

Some evidence is available as to the climate of the region during the glacial substages, although more information would be desirable. Striations on cobbles which occur in terrace gravels of the Pigeon, Little Tennessee, and other rivers which drain the Great Smoky Mountains and adjacent parts of the Unaka province are believed to have been formed by movement of river ice during winters more severe than those today (Wentworth, 1928, p. 952–953). Analyses of pollen from ancient peat bogs in the Piedmont of South Carolina indicate an abundant growth of fir and spruce in the vicinity (Eargle, 1940, p. 337; Cain, 1944), again suggesting a much cooler climate than at present. On the other hand, according to Taber (1950, p. 37), quartz crystals with fluid inclusions occur in the surface soil of the eastern Piedmont of North Carolina, yet would have been destroyed had the ground in this lowland area been deeply frozen during the glacial substages. Perhaps the climate of the southern Appalachian region during the glacial substages was similar to that in northern New England today—one which would have brought the timberline on the mountain slopes down to altitudes of about 4,500 feet, as on Mount Washington in New Hampshire. This climate would have displaced the spruce-fir forests and the deciduous forests about 2,000 feet below their present occurrences, onto the lower mountain slopes and foothills (Braun, 1951, p. 145).

Marked lowering of temperature during the glacial substages must have brought about conditions of erosion, transportation, and deposition which no longer exist in the region. Thus, as suggested long ago by Kerr (1881, p. 352), surficial materials were probably moved with the aid of frost action more intense than today. The effect of these processes on the late Pleistocene deposits and landforms will be treated more fully below.

Climate of the interglacial substages, on the other hand, must have been much warmer and drier than during the glacial substages. The thickness and maturity of the soil profiles which developed during the interglacial substages even suggests that these were warmer, drier, and longer than the Recent epoch which followed the Wisconsin.

MOUNTAIN CRESTS

The higher parts of the Great Smoky Mountains are maturely dissected and are dominated by steep slopes which descend thousands of feet from narrow ridge crests to equally narrow valley bottoms. Occurrence of saprolite in remnants here and there suggests that this was once more extensive, perhaps covering the whole mountain area beneath a gently modeled landscape. The landscape was subsequently steepened and sharpened by erosion during and since Pleistocene time, which has removed most of the saprolite, and in places has penetrated deeply into the bedrock as well.

Most of this harsh mountain landscape is now mantled by forest, except for the grass and heath balds on some of the divides. The forest and its soils exert a stabilizing influence on the slopes, and erosion is active only during occasional torrential rainstorms, when the forest cover and some of the bedrock is rapidly removed in local areas by gullying and landsliding (Moneymaker, 1939, p. 190–194). Are the erosional processes now at work in the mountains adequate to produce the existing landscape, or have more vigorous processes shaped it in the past? If timberline were lowered several thousand feet during parts of the Pleistocene as a result of cooler climate, erosion of the higher mountains would have been less inhibited by vegetation and would have been enhanced by the work of ice, snow, and frost. Nevertheless, no cirques or other landforms that could be ascribed to glaciation occur in the Great Smoky Mountains; shaping of landforms during the times of cooler climate assumed more subtle guises.

Lower courses of minor valleys on the mountain slopes are commonly narrow rock gorges, through which streams descend steeply across ledges and cascades. In their upper courses, however, the channels are choked by angular rock debris, and if any water flows, it is beneath the surface. Several hundred feet below the ridge crests the valleys widen into rock-strewn swales, with steep headwalls in which bedrock is again exposed. The rock-strewn swales appear to be comparatively stable now, as they are overgrown by forest; they may have been shaped earlier by frost riving of bedrock in the headwall and by movement of the resulting debris downslope by solifluction.

The same processes probably also shaped the larger valleys, many of which open headward into amphitheatral basins several thousand feet across, which have steep rock-cut sides and heads and more gently sloping floors covered by mass-wasted debris. The basins are especially prominent on north-facing cooler moister slopes, as on the northwest side of Cove Mountain above Wear Cove, the northeast side of Sugarland Mountain, and at the head of Jakes Creek southeast of Blanket Mountain (all in Gatlinburg quadrangle). Slope retreat of the amphitheatral headwalls has caused many of the ridge crests to be sharp, or even knife edged. Sharp-crested ridges are especially common in the slate and schist of the Anakeesta formation, but they have formed also in the Thunderhead sandstone. In the report area they occur, for example, along the crests of Sugarland Mountain (Gatlinburg quadrangle) and Miry Ridge (Silers Bald quadrangle).

On the mountain crests, where bedrock is not exposed, much of the surface is covered by mantle of fresh angular rock slabs and slivers, lying without sorting or bedding in a sparse clay or silt matrix. Artificial cuts, such as those on the Newfound Gap-Clingmans Dome road, indicate that the mantle lies in most places directly on unweathered bedrock and attains thicknesses of 10 to 15 feet. It was derived from very local sources, and seems to be a frost-riven creep mantle, probably produced during climates cooler than those today.

Nevertheless, on the crests of the Great Smoky Mountains most of the minor features distinctive of areas above timberline (Smith, 1949, p. 1501–1502) can be recognized with difficulty, if at all. Some of the swales high up on the mountain slopes contain long, narrow strips of closely packed angular rock fragments which resemble stone stripes; they occur, for example, on the side slopes of Kuwahi Branch north of Mount Buckley at an altitude of 5,000 feet (Silers Bald quadrangle) and along the Bote Mountain trail just below the mountain crest at an altitude of 4,800 feet (Thunderhead quadrangle).

BLOCK FIELDS

GREAT SMOKY MOUNTAINS

Many of the steep slopes of the Great Smoky Mountains, especially in areas of outcrop of Thunderhead sandstone, are covered by block fields, the larger of which are mapped. The block fields generally occur in swales on the slopes, whose sides are in sharp contact with the intervening spurs, on which there are few large blocks at the surface. Most of the block fields that are mapped have heart-shaped outlines, narrowing downslope into valleys, but some of them, notably those at Road Turn and Steep Branches on the northeast slope of Sugarland Mountain (Gatlinburg quadrangle), spread out at their bases into fields of lower declivity, which descend to the adjacent river. The latter are well displayed along U.S. Highway 441. Some of the block fields are surmounted by ledges and cliffs of Thunderhead sandstone, but others have no ledges above, nor even conspicuous rock outcrops.

The block fields are formed of coarse angular rock debris, with numerous blocks 3 to 10 feet in diameter and a few as large as 50 feet. These are closely packed, in great disorder, without any matrix, forming rough ground that is difficult to walk or climb over. Streams do not flow across the surfaces of the block fields, but running water can be heard in places, some distance down amidst the blocks.

All the block fields are stable now, and are covered by forest, whose trees have not been tilted or disturbed during growth. The blocks themselves are lichen covered, and some of them have been spalled or broken in position where they now lie. As the block fields form a surface that is resistant to erosion, they probably have been preserved for a long period without conspicuous modification, but in a few places they are trenched by ravines. Exposures in some of these ravines indicate that the blocks form a layer 10 feet or less thick, which rests on a more heterogeneous colluvium composed of small to large rock fragments, in a yellow or brown clay matrix. On this colluvium, a mature soil has developed, indicating that the deposit is probably of early Wisconsin age.

The block fields seem to be of somewhat diverse origin. The heterogeneous colluvium on which they lie must have developed early in Wisconsin time by mass movement downslope of a previous saprolite mantle and by weathering of bedrock which was laid bare thereby; these processes were probably aided by frost riving and solifluction. In places, sizable cliffs and ledges of bedrock were laid bare, and large weathered blocks were discharged from them onto the colluvium below, which carried the blocks downslope with it, mainly on or near the surface. On the other hand, the block fields without conspicuous ledges above may be a lag concentrate derived from the heterogeneous colluvium itself, by washing away at the surface of the clay matrix and finer rock debris, or by forcing the larger blocks to the surface by frost heaving. If the heterogeneous colluvium and the block fields originated during an early Wisconsin glacial substage, the block fields were probably accentuated and concentrated during the later glacial substages.

CHILHOWEE MOUNTAIN

The northwest slope of Chilhowee Mountain is partly covered by block fields and coarse colluvium that differ somewhat from those of the Great Smoky Mountains. They are composed of angular quartzite blocks, some more than 10 feet in diameter, derived from cliffs and ledges of the Cochran and Nebo formations which rim the mountain, with intermingled quartz pebbles released from conglomerate beds of the Sandsuck formation, and a matrix of red or yellow sandy clay, the whole forming a deposit whose thickness locally exceeds 25 feet. The block fields lie on concave-upward slopes carved from the shaly and silty rocks of the Sandsuck and Tellico formations. At their upper ends they extend into swales near the bases of the quartzite cliffs, at altitudes somewhat above 2,000 feet, but they form a more continuous mantle lower down, interrupted by only a few projecting rock ridges; at their lower ends they flatten and merge with stream terraces.

Deposits of several ages occur. The older and originally most extensive deposit is now trenched by ravines to depths of 50 feet or more, some of which penetrate bedrock; where most eroded, the deposit is preserved as strips on the spur tops. The deposit is moderately to deeply weathered, and has a mature soil that suggests an early Wisconsin age. The younger deposits are less weathered, and occur as narrower strips between the older, generally recessed farther into the mountain slope.

Although some quartzite blocks are now accumulating as talus below the cliffs on Chilhowee Mountain, and are being moved downslope by creep and rill wash, the most active times of block accumulation were clearly earlier.

FINE-TEXTURED COLLUVIUM

The rest of the bedrock slopes in the region, except for actual outcrops, is covered by a colluvium which is finer textured than that in the block fields. It is of

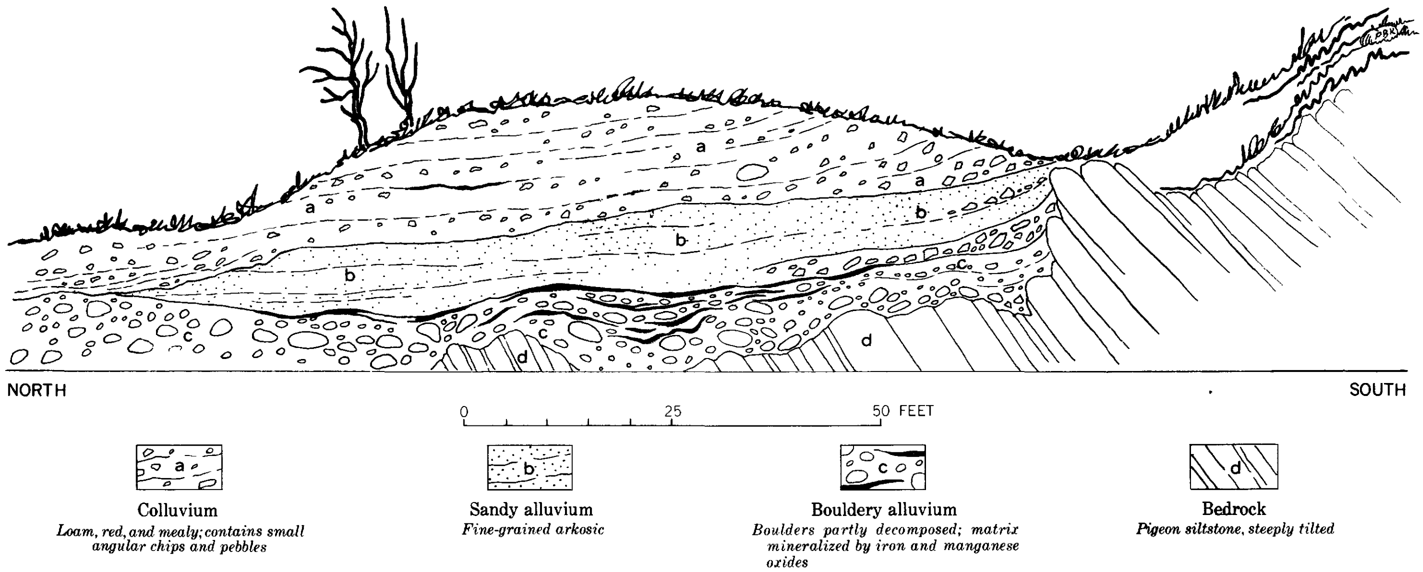

FIGURE 24.—Section showing old gravels deposited by West Prong of Little Pigeon River and subsequently covered by colluvium or creep mantle derived from the adjacent valley slope. Exposed in an excavation on east side of river in northern part of town of Gatlinburg, on U.S. Highway 441, 1,250 feet north of Roaring Fork. By P. B. King, 1947.

local derivation, and was formed by mass movement down the slopes immediately adjacent.

Most artificial openings show that the bedrock, saprolite, or residuum is covered by a few feet of colluvium which follows the slopes of the present topography and is of relatively recent age, produced by modern processes of downhill creep. In many places, however, this is underlain by a much thicker, earlier colluvium, whose soils and degree of weathering indicate that it is of late Pleistocene age. In some of the excavations one can observe that this colluvium is unrelated to details of modern topography; for example, it fills swales which now lie on ridge tops. The excavations show, as well, the existence of colluvium of several ages, the younger lying unconformably on the earlier. Colluvium of late Pleistocene age occurs in deep cuts on Tennessee Highway 73 on the grade east of Fighting Creek Gap (Gatlinburg quadrangle), and on the Cades Cove road from the southwestern part of the report area to Crib Gap (Cades Cove quadrangle).

Most of this colluvium of late Pleistocene age contains much clay and silt, mostly derived from earlier saprolite and residuum. Commonly, this is red in the older deposits and yellow in the younger, perhaps because the older colluvium was derived from the redder higher parts of the residual materials, and the younger from the yellower deeper parts, which were penetrated by erosion later. In the older colluvium, moreover, rock fragments are relatively sparse, whereas they are abundant in the younger, indicating that by then the fresh bedrock beneath the residual materials was widely exposed.

Because of their local sources, the nature, shape, and size of the rock fragments vary. Those derived from the Great Smoky group consist of angular sandstone blocks of all sizes, from a few inches in diameter to dimensions as great as those in the block fields; whereas rock fragments derived from the Snowbird and Walden Creek groups are smaller, and consist mainly of chips and slabs of slaty rocks. Rock fragments of all sizes lie together in great disorder in the clay and silt matrix, without sorting and layering, suggesting a nearly simultaneous downhill movement of the whole mass, probably by solifluction. A typical thick, unbedded colluvial deposit is well displayed in a cut on Tennessee Highway 73, just west of its junction with the Elkmont road (Gatlinburg quadrangle).

Colluvium of late Pleistocene age probably originally mantled most of the hillsides and mountainsides to a thickness of at least several feet, thickening at the bases of the slopes and edges of the valley bottoms. In places, it also spread into the valley flats, burying earlier stream alluvium (fig. 24). Much of the downhill movement was concentrated in swales on the slopes to form channellike bodies of colluvium about 25 feet thick and 100 feet across, which are prominently exposed in many of the highway cuts. Some of them now lie on interfluves between modern ravines, probably because they were more resistant to subsequent erosion than the more lightly mantled intervening slopes—a form of "gully gravure" as described by Bryan (1940, p. 91–92).

The oldest colluvial deposits are topped by a thick mature soil, in which the red color of the saprolitic material of the matrix was altered to brown or yellow. Soils of the later colluvial deposits are thinner and weaker. All the colluvium, except the thin layer that covers modern slopes, probably formed during glacial substages of Wisconsin time, when mass movement by solifluction was at a maximum.

BOULDERY ALLUVIUM OF PIEDMONT COVES

At the northern foot of the high Great Smoky Mountains, many valleys widen into gently sloping piedmont coves, a square mile or less in extent, which are floored by coarse bouldery alluvium. Within the report area, piedmont coves occur on Le Conte Creek at Twin Creek Government Headquarters, on the West Prong of the Little Pigeon River at The Sugarlands, on Sugarland Branch at Little Sugarlands, on the Little River 2 miles above Elkmont, between Jakes Creek and Mannis Branch north of Blanket Mountain (Gatlinburg quadrangle), and on Laurel Creek at Big Spring Cove (Thunderhead quadrangle). Northwest of Cove Mountain, out of alinement with the rest but of the same nature, is Five Sisters Cove on Little Greenbrier Branch (Wear Cove quadrangle). Piedmont coves also extend far eastward along the north side of the Great Smoky Mountains, where some of them are more extensive than any in the report area (Hadley and Goldsmith, 1963). Nearly all the piedmont coves were at one time cleared and farmed, but those in the report area lie in the national park, and have now reverted to brush and forest.

The piedmont coves are related to no particular bedrock formation: those to the east lie in the Snowbird group, those farther west in the Elkmont sandstone, and the westernmost (Big Spring Cove) over limestone in a window of the Great Smoky thrust sheet. Instead, the feature shared by all is that they occur in valleys immediately adjacent to high mountains that are formed of thick-bedded sandstone of the Great Smoky group.

The floors of the piedmont coves are alluvial slopes, with gradients of 200 to more than 400 feet to the mile, gentle only by comparison with those of the adjacent ridges and mountains. Their surfaces are dotted with protruding boulders, a few feet to more than 50 feet in diameter, between which is stony fine sandy loam of the Jefferson and Barbourville soil series (Hubbard and others, 1956, p. 157). In areas that were formerly cultivated the smaller cobbles and boulders have been gathered from the soil and built into fences along the edges of the fields. The boulders, even the largest, are somewhat more rounded than those in the block fields described above. They are somewhat weathered, and have rinds less than half an inch thick.

Thickness of the deposits is largely conjectural. Drilling by the Bureau of Mines in the center of Big Spring Cove penetrated 45 feet of overburden before reaching bedrock. Many boulders were found in the upper 15 feet, mainly sand and clay in the lower 30 feet. In other coves, ravines trench the deposits to depths of 50 feet without encountering bedrock. Presumably the gradient on the surface of the deposits is less concave than the original gradient on bedrock, so that the deposits are thickest near their upper ends and thinner farther down. Deposits of the smaller coves disappear entirely downstream, beyond which the valleys are cut in bedrock to their bottom. Near the upper ends of the coves the deposits may have been laid on a hilly surface. Bedrock knobs occur in places well out from the edges of some of the coves, probably on the tops of hills which were not quite engulfed by deposits.

The upper surface of the bouldery deposits is preserved in many places because they are resistant to erosion, but the deposits are partly dissected by ravines, some of considerable depth. In places, the main streams are deflected sideward, and are now cutting below the bouldery deposit along its contact with the adjacent bedrock hills. In The Sugarlands the deposits form several terrace levels, but these cannot be shown adequately on the map because of its generalized contours. On Le Conte Creek the main deposit slopes downstream into an extensive alluvial flat in the southern part of the town of Gatlinburg. Here, an earlier deposit forms terrace remnants nearly 100 feet higher on either side, and the course of Le Conte Creek itself has been deflected farther west, where it is cutting in bedrock below any of the deposits.

The boulders in the alluvium obviously were derived from the block fields and coarse colluvium of the mountain slopes. Some of the coves are even bordered headward by block fields whose fragments were discharged directly into the coves, but at least some of the boulders were carried more than a mile from their sources. Processes by which the boulders were brought to their present sites are not fully understood. Transportation into the coves was on slopes of much lower declivity than those of the block fields, and probably involved the work of running water. The writer observed that boulders as much as 5 feet in diameter were transported by the West Prong of the Little Pigeon River during the flood of September 1, 1951, but he doubts that boulders much larger can be transported by streams today, except during catastrophic floods, centuries apart. The bouldery alluvium may well have been transported by processes more effective than now during glacial substages of late Pleistocene time. During these substages, transportation of boulders by running water may have been aided substantially by solifluction, even on slopes of relatively low declivity.

By contrast to the valleys which drain from the higher mountains into the piedmont coves, the valleys which head in the foothills are more sharply incised and are cut largely in bedrock; the largest of these in the report area is that of Twomile Branch between Le Conte Creek and the West Prong of the Little Pigeon River (Gatlinburg quadrangle). In these valleys only poorly resistant rocks like those of the Snowbird group are exposed, which yield fine-textured debris on weathering. The valleys may not have been filled with deposits during the period of alluviation; but if they were filled, the fine-textured debris was easily removed later.

TERRACE DEPOSITS

In parts of the report area are terraces capped by stream deposits which stand a few feet to more than 100 feet above modern drainage. They occur mainly in the foothills and Appalachian Valley, along the West Prong of the Little Pigeon River, the Little River, and their principal tributaries, but they are also extensive in Tuckaleechee and Wear Coves. In parts of the foothills, however, even the largest streams flow for considerable distances in narrow gorges, without terraces.

Unlike the deposits described previously, those of the terraces differ little from deposits now forming in the region, and are products of stream work similar to that at present; no special processes need be invoked to create them. Nevertheless, some of the terrace deposits are of considerable antiquity, as they now lie many feet above modern drainage, and were dissected after they were formed. The deposits, moreover, support soils like those on deposits in the mountains for which a Wisconsin age is ascribed, and they were probably contemporaneous with these deposits. The terrace deposits were no doubt derived from reworking and transportation by streams of materials that were forming in the mountains during late Pleistocene time. In fact, along some streams the bouldery alluvium of the piedmont coves can be traced downstream into terrace deposits.

The terrace deposits probably were formed during the glacial substages of late Pleistocene time, when large volumes of material were available in the mountains as a result of mass wasting under rigorous climatic conditions, and when stream runoff was at a maximum. Formation of soils on the deposits, and downcutting to a lower base level, occurred during the warmer drier interglacial substages.

The terrace deposits consist mainly of stream-rounded pebbles, cobbles, and boulders. On terraces farthest upstream these fragments are largely sandstone and other resistant rocks from the Great Smoky group of the mountain area, but in the foothills farther downstream fragments from the Snowbird, Walden Creek, and Chilhowee groups are contributed, and in the Appalachian Valley, chert and carbonate rocks. The size of fragments derived from the Great Smoky group diminishes downstream. Sandstone boulders more than 3 feet in diameter are common in terrace deposits near Gatlinburg, 4 miles or more from their source, but at Pigeon Forge, 6 miles farther down the West Prong of the Little Pigeon River, most of the boulders are less than half a foot in diameter. Toward the sides of the valleys the stream deposits merge with colluvium derived from adjacent hills, and in places the colluvium has spread over earlier stream deposits (fig. 24). The amount of colluvium in the terrace deposits increases where streams were least active, in smaller valleys and headwater areas. Much of the terrace material along the edges of Wear Cove and Whiteoak Sink is thus colluvial rather than alluvial.

GATLINBURG AREA

The town of Gatlinburg lies in a ramifying alluvial area, once known as White Oak Flats, formed near the junction of the West Prong of the Little Pigeon River and Le Conte Creek. The flat is constricted abruptly downstream where the river enters more resistant formations, especially a band of Rich Butt sandstone, crossed by the river at Dudley Bluff.

Many terrace remnants occur along the south and southeast edges of the flat, which indicate that an even more extensive alluvial area formerly existed at a higher level. Remnants of terrace deposits are preserved, for example, on two elongate spurs south of the river and east of Le Conte Creek, as well as southeast of the river at its junction with Roaring Fork, and east of the river at the north end of Briar Knob; not all these remnants are large enough to be shown on the geologic map. For the most part, the terrace deposits stand about 100 feet above modern drainage, and they seem to express a single epoch of planation and alluviation. Development of an alluvial flat at Gatlinburg during this epoch was probably aided by the hard-rock sill of Rich Butt sandstone downstream, which created a perched base level.

These terrace deposits may be of early Wisconsin age, for deposits older than the present alluvium occur at lower levels. At the locality sketched in figure 24, in the northern part of the town of Gatlinburg, old river deposits, now deeply weathered and mineralized, are overspread by later colluvium, yet these stand less than 40 feet above the present river and well below the terrace remnants. Also, the lower end of the bouldery alluvium along Le Conte Creek extends into the southern part of the town of Gatlinburg in an extensive tract which is much lower than the terrace remnants on the two elongate spurs referred to above, and only slightly above modern drainage.

PIGEON FORGE AREA

For about 5 miles below Gatlinburg the West Prong of the Little Pigeon River flows in a rock gorge, where no terrace deposits are preserved, but its valley widens again to a mile or more near Pigeon Forge, in the area of outcrop of the Walden Creek group. West of Pigeon Forge, between the river and Mill Creek, a ridge 3 miles long and a quarter of a mile wide lies in the valley, and is formed by a flight of terraces. The highest terrace, which at the south end of the ridge stands 100 feet above the river, consists largely of slaty bedrock and has only sparse remnants of gravel on top. It is succeeded northward by another terrace, 50 feet above the river, with a broad gravel cap. At the north end of the ridge is still another terrace, 25 feet above the river, again with a broad gravel cap, but with no bedrock exposed. Farther downstream, toward Sevierville, other terrace remnants line the sides of the river valley.

Walden Creek, which enters the West Prong of the Little Pigeon River from the west 2 miles below Pigeon Forge, flows in a broad alluvial flat in the lower 6 miles of its course. Bedrock projects in steep hills on its southeast side, but forms a wide bench on the northwest side whose top is 100 to 150 feet above the creek. Here and there on top of the bench are small remnants of terrace gravel.

WEAR COVE

Wear Cove lies near the head of Cove Creek, a tributary of Walden Creek, but has been carved into a lowland because of the limestone and shale bedrock. In the center is a wide alluvial flat along the creek, but terraces rise in flights on either side, especially on the southeast where there are as many as three levels. The scarps of these terraces are shown on the geologic map, but terraces at distinct levels at one locality seemingly merge into single terraces elsewhere.

The terrace deposits in an exposure northwest of the main road junction in the cove lie unconformably on limestone residuum and are 8 to 10 feet thick. They are an unsorted aggregate of angular to rounded sandstone and slate fragments, in a matrix of reddish-yellow clay, derived from residuum, and are topped by a mature soil, probably indicating an early Wisconsin age for the deposit. The nature of the deposit suggests that it reached its present position by colluvial rather than alluvial processes, possibly during glacial substages of Wisconsin time.

ELKMONT AREA

For several miles below Elkmont, in the upper course of the main east prong of the Little River, are numerous remnants of an old valley level about 100 feet above the river, preserved mainly in the necks of meanders. Most of the remnants expose only bedrock or saprolite, but stream deposits are preserved on a few. Deposits occur, for example, in the angle between the Little River and Laurel Branch, where they are well exposed in a former orchard. Here, well-rounded stream-transported cobbles and boulders occur on the outer part of the terrace, but give place to angular colluvium next to the adjacent hills.

At the time when these deposits and their underlying surface were formed by the Little River, its valley near Elkmont had a flat bottom half of a mile wide. As a result of downcutting, the valley is now more narrow and tortuous. The river meanders probably formed on the wide valley of the earlier period, and were later entrenched in bedrock.

Farther downstream, the river enters the Little River Gorge, with steep rock walls cut in the Metcalf phyllite and Great Smoky group, in which it continues to Tuckaleechee Cove. In this segment there is no trace of former valley levels or terrace deposits.

TUCKALEECHEE COVE

Tuckaleechee Cove, like Wear Cove, is a lowland of limestone and shale within the foothills, but its erosional history differs because it is on the midcourse of the Little River instead of lying near the head of a drainage area. In more remote parts of the cove, residuum and colluvium are extensive, but rock outcrops are abundant near the river, as well as river deposits both modern and ancient. Terrace scarps are shown on the geologic map in the broad alluvial area in the southern part of the cove, but small patches of stream deposits at levels well above modern drainage also occur in many other places.

The terraces in the alluvial area in the southern part of the cove slope from the bordering hills toward the river and stand about 75 feet above it at their lower ends; only one terrace level seems to exist. Roadcuts and other excavations near Bethel Church, Myers Cemetery, and elsewhere expose well-rounded sandstone pebbles and cobbles, interbedded with layers of sand and silt, the whole probably deposited by the river. All the pebbles and cobbles are moderately decomposed, and some are coated with iron oxide.

The fine-grained matrix is mottled red and yellow, and has weathered to a mature soil that probably formed in middle Wisconsin time.

At the west edge of the report area near Townsend, a patch of similar gravels occurs north of the river and about 100 feet above it. It lies unconformably on limestone residuum, and is topped by a mature soil. On a hilltop to the north at an altitude of 1,220 feet, and 200 feet higher, is a patch of rounded pebbles of quartz and deeply weathered sandstone in a red clay matrix, which rests on limestone residuum. It is probably one of the oldest accumulations of surficial material preserved in the cove.

WHITEOAK SINK

Whiteoak Sink, a topographically detached part of the Tuckaleechee Cove window, has drained through underground channels during much of its later history, posing perplexing problems as to how material could be removed during its erosion. At an earlier period the sink drained eastward down Meadow Branch through Dosey Gap, but its floor now lies 140 feet below the level of the gap.

The western half of the sink is a broad terrace—once cleared and farmed (mainly in Kinzel Springs quadrangle)—which stands 70 to 90 feet above the deepest part. It is covered by colluvium, formed of strongly decayed fragments of sandstone and phyllite, in a yellowish-red clay matrix, that is probably of early Wisconsin age. The terrace is lower than any point on the rim of the sink, so that exterior drainage was by underground channels, even at this early period. On the southwest side of the sink, however, traces of an earlier terrace occur about 100 feet higher on the spurs; this terrace might have formed while the sink still drained eastward at the surface.

At the eastern end of the sink, below the main terrace, is a smaller alluvial flat covered by fine-grained deposits, which is controlled by the modern base level. Drainage from the flat descends into several openings on its north and northeast sides, and probably emerges farther north, in the western part of Tuckaleechee Cove.

RECENT

Post-Wisconsin time, which probably occupied little more than the last 10,000 years of the history of the Great Smoky Mountains, was one of adjustment to milder climates, following the rigors of the last glacial substage. It was marked, especially, by erosion of streams to their modern levels, and by development of modern patterns of vegetation. Geologic materials which accumulated during the Recent epoch include the thin colluvium which spreads over modern topography and the alluvium of the present valley bottoms. During the epoch, a moderate soil about a foot thick developed on the surface, with only slight oxide enrichment or clay enrichment of the B horizon.

ALLUVIUM

Alluvium of the modern stream valleys constitutes more than half the area of Quaternary deposits shown on the geologic maps (pls. 2–7), but this is out of proportion to its geologic importance, as most of it is so thin that streams well out in the valley flats cut through it into bedrock. Within the mountains and foothills the alluvium mostly forms narrow strips along the streams, but in the lowlands to the north it covers level valley bottoms half a mile or more wide. Within the mountains the alluvium is coarse and bouldery, but finer grained material dominates farther downstream.

GRASS BALDS [19]

At intervals along the State-line divide throughout its length in the report area, the forest is interrupted by grass balds, whose nature has already been described (p. 11). Geologic studies indicate that the mountain crest, whether bald or forested, is formed of a variety of steeply tilted rocks of the Great Smoky group, covered by a frost-riven creep mantle of Pleistocene age on which a thin forest soil has developed. The balds are thus not controlled by any features of the bedrock or soils, but are probably expressions of the later climatic fluctuations on the mountain tops.

Forests of spruce and fir cover the eastern half of the Great Smoky Mountains, from their crests down to an altitude of 4,500 feet, but they end abruptly west of Clingmans Dome and Mount Buckley at the east edge of the report area. Beyond, hardwood forests extend over the crest, except for scattered grass balds, although many of the summits extend as high or higher than those covered by spruce and fir farther east. Whitaker (1956, p. 60–61) suggests that during an earlier cooler period the spruce and fir forests covered the crest of the range throughout its extent, but were sharply restricted during a succeeding warmer period, when they were able to persist only on the high peaks in the eastern part of the mountains. Areas which they vacated were occupied by high-altitude hardwood forests, mainly beech, oak, and chestnut, which thus covered all the summits in the western part of the range. During a cooler period which followed, spruce and fir were able to repopulate the lower slopes in the eastern part of the mountains, but were unable to spread westward because of several slightly lower gaps

[19] Based largely on an unpublished manuscript by H. E. Malde.

west of Mount Buckley. In the western part of the mountains, where the upper limit of the hardwoods was also depressed, the cool summits were populated by grasses rather than by spruce and fir.

Historical records and Indian traditions suggest that grass balds have existed in the western half of the Great Smoky Mountains for at least 200 years, and perhaps longer. Apparently, however, hardwood forests have been encroaching on the balds for nearly 100 years, probably in response to a warming climate; the balds might be more restricted than they are had it not been for artificial clearing and their use as a summer pasturage for stock. Presumably they will revert eventually to hardwood forest.

According to Whitaker, the extinction of the spruce-fir forests in the western half of the Great Smoky Mountains occurred during the climatic optimum which followed the last glaciation, some 5,000 to 10,000 years ago, but Malde suggests a later chronology, based on known world wide climatic variations, as follows (table 20):

TABLE 20.—*Chronology of vegetational and climatic changes in western part of Great Smoky Mountains*

[By H. E. Malde]

Plant community	*Climate*	*Ages*
Spruce and fir forest	Cooler than present.	1000 B.C. to A.D. 1000
Hardwood forest (spruce-fir forests restricted or extinguished).	Warmer than present.	A.D. 1000 to A.D. 1400
Grass balds	Cooler than present.	A.D. 1400 to A.D. 1860
Encroachment of hardwood forests on grass balds.	Warming	A.D. 1860 to present.

ECONOMIC GEOLOGY

The central Great Smoky Mountains are not rich in mineral resources, and few of these resources have been exploited. No metallic deposits are being worked at present, but a few non-metallic deposits are being worked. The southern half of the report area is now included in Great Smoky Mountains National Park, where mining and quarrying is not permitted.

During the early days of settlement in the region the iron oxides in residual materials, mostly overlying the carbonate rocks of the Appalachian Valley and the cove areas, were taken out for the making of iron implements in local furnaces and forges (Killibrew, 1881, p. 32–34, Willis, 1886, p. 335–336), but none of the deposits were large, and the openings from which they were mined have long since disappeared. Later, some of the residual materials were prospected for manganese (Stose and Schrader, 1923, p. 106), but no production has been recorded. According to local tradition, some of the streams in the mountains have yielded small amounts of placer gold.

Some nonmetallic deposits have been worked for local use. Sand has been produced for construction purposes from deeply weathered parts of the quartzite beds of the lower unit of the Wilhite formation at several places on Pine Mountain (Pigeon Forge quadrangle). Many buildings in the area have been constructed from quartzite of the Nebo sandstone, whose use is enhanced by its ability to break into cubical or rectangular blocks, because the bedding planes are closely spaced and *Scolithus* tubes occur at right angles to the bedding. Most of this quartzite has been taken from talus rather than outcrops, especially near the head of Compton Branch on Chilhowee Mountain (Walden Creek quadrangle). A small amount of slate, used for flagstones, has also been produced from the Pigeon siltstone on the east side of the West Prong of the Little Pigeon River opposite the mouth of Caney Creek (Pigeon Forge quadrangle), in places where cleavage and bedding planes coincide.

Extensive use has been made of stone in highway construction and other engineering works in the area, especially in the national park. The National Park Service maintains a small quarry on Sugarland Branch a mile south of National Park Service Headquarters (Gatlinburg quadrangle), where a sandstone bed in the Roaring Fork sandstone is used for crushed stone; but this rock is less favored than limestone hauled in from a greater distance, because its hardness makes it difficult to crush. A few other openings have been made elsewhere in the park area to obtain stone for local construction. In addition, several quarries have been worked in Tuckaleechee Cove in the Jonesboro limestone to obtain stone blocks for retaining walls and similar purposes along highways in the park area.

At present, the largest mineral production in the area is by Lambert Bros., Inc., of Knoxville, Tenn., who have operated a quarry 1½ miles south of Sevierville since about 1940. About 20,000 tons of crushed limestone is produced per month for use in highway construction and manufacture of concrete; in 1955 the quarry produced 234,000 tons, and in 1956, 128,000 tons. (U.S. Bur. Mines, 1958a, p. 1003; 1958b, p. 1005). The quarry is in the upper part of the Newala limestone on the Rock Quarry dome. Most of the production is from a sequence of about 90 feet of beds (geologic section 6). This sequence has now been opened for a distance of 1,000 feet along the strike and over an extent of about 5 acres, but large reserves are still in sight, for the quarry is on a low hillslope on which the limestone is widely exposed.

A smaller quarry in the same strata has been operated by another firm since about 1955, and the product is used mainly as aggregates in concrete blocks. It is half a mile west of the first quarry, on the west bank of the West Prong of the Little Pigeon River.

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