Geology of the Eastern Great Smoky Mountains North Carolina and Tennessee

By JARVIS B. HADLEY *and* RICHARD GOLDSMITH

GEOLOGY OF THE GREAT SMOKY MOUNTAINS, TENNESSEE AND NORTH CAROLINA

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A study of stratigraphy, structure, and metamorphism in the southern Appalachian region

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By JARVIS B. HADLEY and RICHARD GOLDSMITH

ABSTRACT

The Great Smoky Mountains, a rugged mountain mass with summits more than 6,000 feet above sea level, are along the border of North Carolina and Tennessee in the southern part of the Blue Ridge province of the Appalachian Highlands. The present report, one of three dealing with the Great Smoky Mountains and vicinity, describes the stratigraphic, structural, metamorphic, and surficial geology of an area 600 square miles in extent which includes the eastern half of the mountains.

The rocks of the area consist largely of a very thick mass of metamorphosed sedimentary rocks of late Precambrian age, long known as the Ocoee series, that rest on a basement complex of granitic and metasedimentary gneisses. The rocks of the Ocoee series in the area are newly subdivided into eight formations comprising the Great Smoky conglomerate and Snowbird formation of previous writers, and these two units are accorded the status of groups.

The Snowbird group, resting on the basement complex, includes four intertonguing formations; the Wading Branch formation, the Longarm quartzite, Roaring Fork sandstone, and Pigeon siltstone. These units consist of variously metamorphosed sandstone, siltstone, shale, and mudstone derived in large part from the basement rocks. A basal quartz-mica schist, with quartz conglomerate lenses, and dark-colored graywacke and related pelitic rocks make up the Wading Branch formation, which has a maximum thickness of 1,500 feet. The Longarm quartzite, 5,000 feet thick, consists largely of relatively clean, current-bedded, generally coarse feldspathic quartzite and arkose. The Roaring Fork sandstone consists of 2,000–8,000 feet of medium-grained relatively thick-bedded highly feldspathic sandstone and interbedded dark finer sandstone and siltstone. It overlies the Longarm quartzite but also intertongues with the upper part of the Longarm, and replaces much of it toward the northwest. The Pigeon siltstone, which consists of still finer grained and thinner bedded siltstone and shale, has the same stratigraphic relation to the Roaring Fork sandstone that the latter has to the Longarm quartzite and is found mainly in the northern foothills of the mountains. These formations together are at least 13,000 feet thick in the northern part of the report area. Current bedding and distribution of coarse- and fine-grained deposits indicate that the sediments were transported largely by bottom currents west-northwestward from a land area of basement rocks into a steadily subsiding basin. They thin markedly toward the south and east, where they are overlain and finally overlapped by the Great Smoky group.

The Great Smoky group, 10,000–15,000 feet thick in the report area, consists of variably metamorphosed clastic sedimentary rocks considerably coarser and more varied in texture and composition than the Snowbird group. The thickest and most widespread formation in the group is the Thunderhead sandstone, formed of 6,000–12,000 feet of thick-bedded feldspathic sandstone and fine arkosic conglomerate that occupies most of the eastern part of the mountains. The Elkmont sandstone, 800–3,000 feet thick, consists of somewhat finer feldspathic sandstone and interbedded shale that intertongues with the lower part of the Thunderhead along the north front of the range. The Anakeesta formation is a varied unit of dark carbonaceous and sulfide-bearing pelitic and arenitic rocks and sparse thin dolomite beds that intertongue with the Thunderhead along the crest of the range. In contrast to the rocks of the Snowbird group, those of the Great Smoky group are characterized by graded bedding and poor sorting, which suggests more rapid movements into the depositional basin, probably by turbidity currents. Coarser rocks, including granitic cobble and boulder conglomerate, in the northern part of the area suggest that they were derived from a granitic source area of considerable relief north of the basin of deposition and that sediments of the Great Smoky group were carried southward, in contrast to those of the Snowbird group.

The Rich Butt sandstone, 3,000 feet thick, conformably overlying the Snowbird group in the northern part of the area but separated by faults from the Great Smoky group, lithologically resembles the latter and may be roughly equivalent to the Elkmont sandstone.

Intrusive rocks younger than the Ocoee series are few and widely scattered. They include altered ophitic diorite and diabase like those associated with copper deposits in the southwestern part of the mountains, trondhjemite and pegmatite dikes in the more metamorphosed Ocoee and basement rocks in the southern part of the report area, and small bodies of much altered ultramafic rocks limited to the basement complex but probably early Paleozoic.

A great variety of folds, faults, cleavages, and joints in the Ocoee series have resulted from deformation that began probably in Ordovician time and continued intermittently throughout most of the Paleozoic era. The basement rocks participated in this deformation also so that structures of Precambrian age are at best obscurely preserved. Deformation began in rocks of the Ocoee series with broad eastward-trending folds; subsequent low-angle faulting, in which the Great Smoky group and parts of the basement complex were pushed northward over the main part of the Snowbird group, resulted in the low-angle Greenbrier fault, with horizontal displacement estimated to be 20 miles or more. After this activity, renewed deformation in the southeastern part of the area formed northward-trending folds and high-angle reverse faults; the Greenbrier fault was folded and faulted, and both the Ocoee and basement rocks were strongly sheared. Erosion of large folds in the Greenbrier fault has produced a window in the central part of the area, exposing slices of basement rocks lying on the Snowbird group. Rocks with relatively low dipping cleavage and schistosity produced

during the earlier stages of the regional deformation were much folded and sheared during the later stages, which produced second-generation folds and slip cleavage that greatly obscure older structures in the southern part of the area.

Relatively late high-angle faults are characterized by unrecrystallized gouge and slickensided surfaces and by topographic lineaments. Some are strike faults; others trend northwest across the older structural features. Movement on most of these faults has been small, but two show displacements of a mile or more, the southern rocks having moved northwestward relative to the northern rocks.

Rocks of the Ocoee series were regionally metamorphosed concurrently with the deformation and with intensity increasing toward the southeast. Rocks of the greenschist facies in the northern part of the area are succeeded southward by rocks of the albite-epidote-amphibolite and amphibolite facies. Pelitic rocks thus range from green slate and phyllite at the north to kyanite-staurolite schist at the south, where even massive sandstone and conglomerate beds are strongly foliated and recrystallized and impure dolomite has been altered to diopside-tremolite rock. The basement complex, also involved in the regional metamorphism, was downgraded to chloritic and saussuritic gneisses at the north, but the Paleozoic and pre-Ocoee metamorphisms seem to have been about equal to the south. The distribution of metamorphic biotite suggests that its formation was promoted by the presence of potassium feldspar in rocks of the greenschist facies and that muscovite-chlorite schist with little or no excess potassium was stable well into the lower temperature part of the albite-epidote-amphibolite facies.

Regional metamorphism occurred mainly after the thrusting represented by Greenbrier fault, but its thermal peak had passed before the second spisode of folding and faulting. Thus crushed rocks adjacent to the Greenbrier fault are recrystallized, and metamorphic isograds are not offset by the fault. On the other hand, porphyroblasts in the more highly metamorphosed rocks are commonly broken or rolled between slip cleavage surfaces associated with the second-generation folds, and parts of the metamorphosed rocks have been much sheared or mylonitized since their metamorphism. Some of this late deformation may be associated with extensive low-angle faulting of late Paleozoic age in the rocks northwest of the mountains.

Alluvium, colluvium, and saprolite, locally as much as 100 feet thick, cover unweathered bedrock in many parts of the area. Coarse bouldery colluvial and alluvial fans and aprons, found particularly against the northern front of the range, were formed mainly during Pleistocene time after a period of deep valley cutting. Soils that formed on them suggest two periods of alluviation and colluvial activity, probably early and late Wisconsin in age, separated by a period of erosion in which valleys were cut or reexcavated to depths of 60 feet or more. The saprolite is considerably older than either alluvium or colluvium and may be largely Tertiary in age. It is 60–80 feet thick where best preserved but is everywhere much eroded and has been largely removed from the higher mountain slopes.

Except for the post-Ocoee pegmatites near Bryson City at the southwest edge of the report area, no commercially important mineral deposits are known in the eastern Great Smoky Mountains. These pegmatites are estimated to have yielded 130,000–150,000 tons of feldspar for ceramic, glass, and abrasive use and, in earlier days, considerable kaolin. A small lead-zinc mine near the eastern border of the area has produced one carload of ore reported to contain 12.1 percent lead and 6.5 percent zinc. There has been some prospecting for commercial mica along the southern margin of the area, but no important deposits have been mined.

INTRODUCTION

LOCATION, ACKNOWLEDGMENTS, METHODS OF STUDY

About 600 square miles partly in North Carolina and partly in Tennessee between long 83° W. and 83°30′ W. (fig. 1) is described in this report. The area includes the eastern half of the Great Smoky Mountains, a high mountainous part of the Blue Ridge province lying between the Pigeon River on the northeast and the Little Tennessee River on the southwest, and part of a foothill belt to the north. The boundary between North Carolina and Tennessee follows the crest of the mountains from Clingmans Dome at the west to the village of Waterville at the northeast, so that three-fourths of the area described is in North Carolina and one-quarter in Tennessee. About four-fifths of the area is within the Great Smoky Mountains National Park, established in 1940 and one of the largest national parks. Park headquarters is at Gatlinburg in the northwest corner of the report area.

The fieldwork for this report was done as part of a larger study of the Great Smoky Mountains National Park and surrounding areas by the U.S. Geological Survey under the direction of Philip B. King. Results of these investigations are being presented in separate reports including, besides the present one, reports on the central Great Smoky Mountains by P. B. King and on the Richardson Cove and Jones Cove quadrangles by W. B. Hamilton (see fig. 1). Information obtained in these adjacent areas has been most useful in arriving at many of the conclusions presented herein.

The greater part of the fieldwork in the eastern Great Smoky Mountains was done by Hadley and assistants between October 1946 and July 1954. Beginning in March 1952, Goldsmith mapped the Dellwood quadrangle and adjacent areas, and, together with Hadley, completed mapping the southeastern part of the report area. We gratefully acknowledge the assistance of John K. Lydecker from February to July 1947; Charlie A. Tucker, Jr., March to June 1949; Steven S. Oriel, October to December 1949; Willis H. Nelson, July to December 1950; and Robert F. Yerks, August to October 1951. We also received help in interpreting the surficial deposits from Charles S. Denny and Gerald M. Richmond of the Geological Survey, who visited the area briefly. Harold E. Malde spent 3 weeks in the area and provided many of the photographs used in the report, which also benefited greatly by the criticism of P. B. King, W. B. Hamilton, and R. B. Neuman. G. H. Espenshade kindly permitted publication herein of his description of the Redmond lead-zinc mine in Haywood County, N.C.

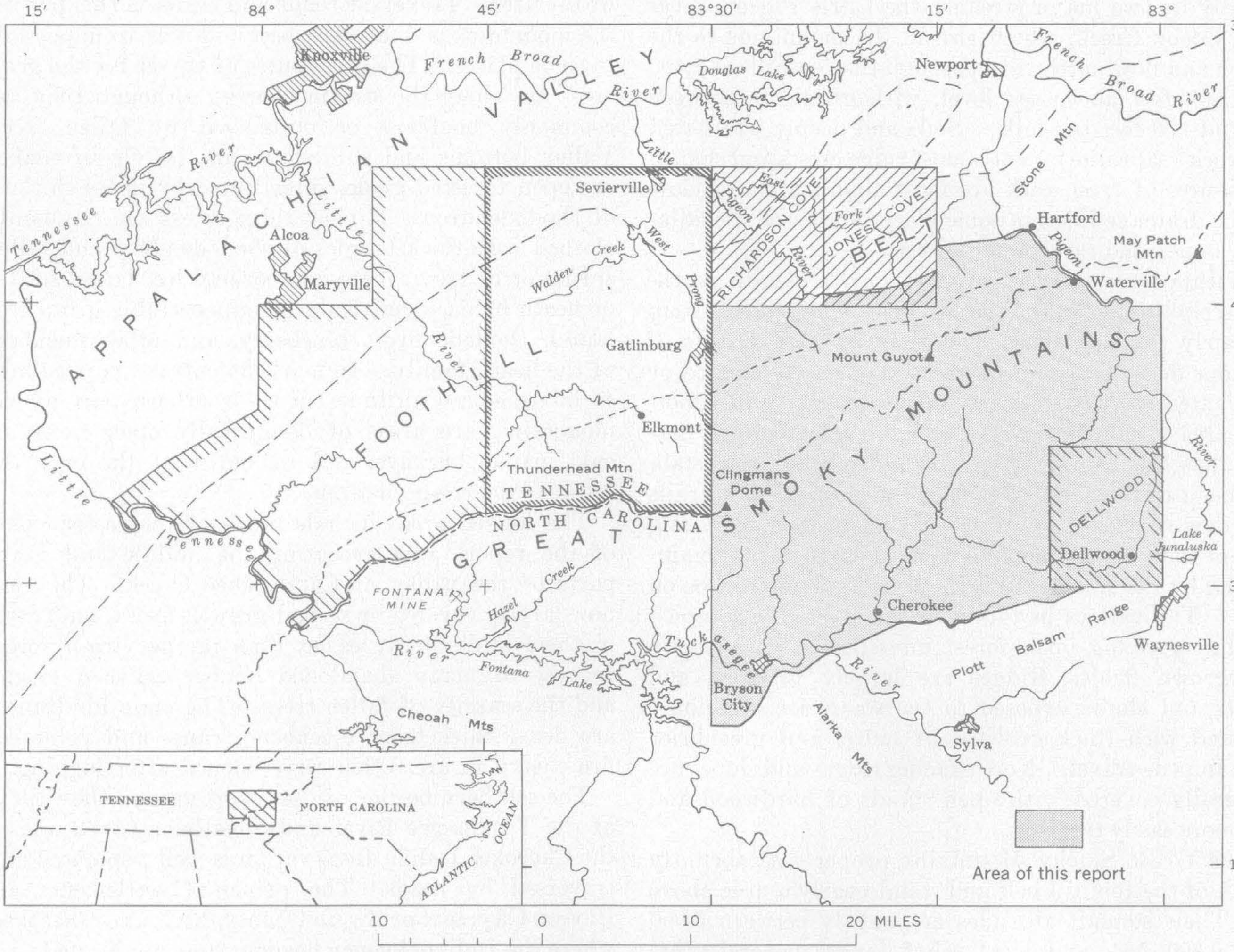


FIGURE 1.—Index map of a part of western North Carolina and eastern Tennessee showing location of the Great Smoky Mountains and the areas covered by this and companion reports.

We wish to acknowledge with special thanks the friendly and unfailing helpfulness of the staff of the National Park Service throughout the work, in providing office facilities and other use of park buildings, transportation and special equipment when needed, and information about the local terrain.

The base maps used were largely 7½-minute quadrangle maps at 1:24,000 scale, including both published maps prepared by the Tennessee Valley Authority and unpublished advance sheets of areas within the park prepared by the Geological Survey. Most of the latter were incomplete and were supplemented by manuscript maps supplied by the Tennessee Valley Authority and by enlargements from the topographic map of the Great Smoky Mountains National Park published by the Geological Survey in 1930 at 1:62,500 scale. The base for the geologic map (pl. 1) is an enlargement, somewhat revised, of part of the map of the Great Smoky Mountains National Park and Vicinity compiled in 1949 and published by the Survey at a scale of 1:125,000.

The stratigraphic and petrographic descriptions of the formations of the Ocoee series and the sections on structure, surficial geology, and mineral deposits were written mainly by Hadley, with contributions from Goldsmith concerning the southern part of the report area. Goldsmith prepared most of the sections on the basement and post-Ocoee intrusive rocks. The section on metamorphism was prepared jointly.

GEOGRAPHY AND ACCESS

The foothill belt in the eastern part of the Great Smoky Mountains area is a maturely dissected lowland, with an average summit level of about 2,000 feet above sea level, surmounted by several ridges rising to a little more than 3,000 feet. Many sharp-crested ridges rise a few hundred feet above narrow valleys drained principally by two major streams, the Little Pigeon River and Cosby Creek, which rise in the mountains to the south and flow northward through the foothills at 1,400 to 1,800 feet above sea level, with gradients between 50 and 100 feet per mile. Soils and deeply weathered bedrock (saprolite) mantle most ridge crests and slopes; exposures of fresh rock are most abundant in or close to the drainage lines, in some places higher on the adjacent slopes, and rarely on the crests.

Within the area of this report, only a narrow northern strip belongs in the foothill belt. Part of this strip is fairly thickly settled, traversed by many roads of various degrees of improvement, and partly cleared or cultivated so that travel is relatively easy. The foothill area within the park, although once similarly settled, has been progressively abandoned since the establishment of the park. Many of the old roads and trails are now overgrown with trees, shrubs, and vines and, except for a few automobile roads and truck trails maintained by the National Park Service, travel must be on foot. The valleys in this area are generally occupied by fairly young open forest interspersed with partly overgrown fields. Ridges are largely forested, and crests and slopes exposed to the south are commonly covered with thick growths of laurel and greenbrier that impede travel. North-facing ridges and slopes are generally covered with open stands of hardwood and are more easily traveled.

The Great Smoky Mountains proper rise abruptly south of the foothill belt and stand nearly a mile above it. Their summit altitudes are mostly between 5,000 and 6,500 feet, and local relief ranges generally between 1,000 and 2,500 feet. The mountain area is as maturely dissected as the foothills and probably 90 percent of it consists of slopes of 20° or more. Valleys are narrow with steep sidewalls that are locally cliffed. The larger streams, with gradients of several hundred feet per mile in their upper courses, plunge in abundant cascades and waterfalls.

Much of this country was too rough for habitation, either by the first European settlers in the region or by the Indians before them. Although timber-cutting operations in the first quarter of the present century penetrated much of the mountains, many areas in the eastern part of the Great Smoky Mountains National Park were never reached and remain covered by some of the largest stands of virgin forest in the eastern United States. Such forest covers the north slope of the mountains from the West Fork of the Little Pigeon River to Mount Guyot, as well as most of the drainage basins of Deep Creek, Cataloochee Creek, and Raven Fork. Excellent trails and two roads provide access through the mountains in the western and eastern parts of the area. Travel off roads and trails in this part of the mountains is difficult at best and next to impossible in some places. The best routes of travel for the geologist are along the stream courses, although they are commonly bouldery or obstructed by fallen trees. Valley bottoms and side slopes in the virgin timber are open forested glades interrupted by dense thickets of rhododendron. Higher ridge crests are commonly clothed with thick tangles of rhododendron and fallen spruce or fir trees; many are covered by "laurel slicks" or heath balds, a particularly impenetrable growth of laurel, rhododendron, blueberry, and other members of the heath family. In marked contrast, particularly at intermediate altitudes in the southern part of the mountains, are areas of delightfully open forest of oak, maple, buckeye, and remnants of the once extensive American chestnut.

The logged areas include much of the eastern part of the report area excepting the middle and lower parts of the valley of Cataloochee Creek. They are now largely covered by second-growth forest, but travel in them is distinctly easier than in the virgin forest because of many abandoned lumber railroad grades and the scarcity of fallen trees. The main hindrances are dense thickets of blackberry canes and volunteer fire cherry in areas that were burned after logging.

The southern border of the report area in the valleys of the Tuckasegee River and Jonathans Creek and in the Cherokee Indian Reservation is well populated and traversed by roads. The principal settlements are Bryson City, seat of Swain County, N.C., and Cherokee, where the Indian Agency headquarters are located.

PREVIOUS WORK IN THE AREA

The rocks of the Great Smoky Mountains region have been studied intermittently for about a century but, owing to their inaccessibility and geologic difficulty, progress in understanding them has been slow. The first attempt to classify the rocks of the region was made by J. M. Safford, State Geologist of Tennessee, who explored several of the major valleys in the northwestern part of the Great Smoky area, and in reports published in 1856 and 1869 gave the name Ocoee to the rocks that make up much of the foothill and mountain areas.

In 1889, Arthur Keith of the U.S. Geological Survey began his extensive studies of the southern Appalachian region. Folio reports by him were published on areas adjoining the present report area, both on the west (Keith, 1895, 1907) and on the east (Keith, 1904), and maps of the intervening areas were prepared (Keith, unpublished manuscript maps of the Mount Guyot and Cowee quadrangles). Although these reports contain many misconceptions of the structure and stratigraphic succession in the area, they provide a partial basis for the present classification of the rocks and reveal shrewd judgments concerning many features.

From Keith's time to that of the present studies, little work was done in the Great Smoky Mountain region. On the geological map of the United States of 1933, the Ocoee series of the Great Smoky Mountains was divided on the basis of reconnaissance into a less metamorphosed part of Early Cambrian age to the northwest and a more metamorphosed part of late Precambrian age to the southeast, the latter being correlated with the Glenarm series of southeastern Pennsylvania (Jonas, 1932, p. 228–243). This work was followed by two papers by G. W. and A. J. Stose (1944; 1949), in which renewed attempts were made to clarify the relations of the Ocoee series. The earlier of these papers presents a good summary of the changing ideas of Keith on the age and relationship of the Ocoee and restates arguments for its Precambrian age.

During the Second World War, copper deposits on Hazel Creek and adjacent areas in the southwestern part of the Great Smoky Mountains and a lead-zinc deposit near the eastern boundary of the report area were examined by the Geological Survey and described in reports placed in files open to the public (Espenshade, 1943; Espenshade and others, 1947). In 1946–47 feldspar deposits near Bryson City in the southwestern part of the report area were studied by E. N. Cameron (1951) as a part of a comprehensive wartime study of pegmatites by the Geological Survey. Although limited to a smaller area, Cameron's conclusions parallel ours in many respects, especially in regard to multiple deformation in the region (Cameron, 1950).

BEDROCK UNITS

Most of the eastern Great Smoky Mountains and the foothills to the north are made up of variably metamorphosed sandstone, conglomerate, and siltstone, many thousands of feet thick and known as the Ocoee series of late Precambrian age (table 1). In the southeastern part of the mountains these rocks are underlain by a complex assemblage of plutonic rocks and layered gneiss which occupy about 100 square miles or one-sixth of the report area and are exposed over large areas to the east and south. The plutonic rocks include massive augen gneiss, granitoid gneiss, and little-foliated granitic rocks similar to rocks mapped by Keith as Max Patch and Cranberry granites in the adjoining Asheville quadrangle. The layered rocks are paragneiss derived from ancient sedimentary and possibly volcanic rocks and known throughout the Blue Ridge and Piedmont provinces as the Carolina gneiss. The Carolina gneiss and associated plutonic rocks form a basement complex much older than the Ocoee series and separated from it by a major unconformity. Available radiometric data suggest that the complex is approximately contemporaneous with the metamorphism of the Grenville series in the western Adirondack Mountains about a billion years ago, although younger rocks may be present.

Intrusive rocks younger than the Ocoee series are few and diverse in character. They include semiconcordant metadiorite in the Ocoee series in the northwestern part of the area; pegmatite dikes cutting both the Ocoee series and basement rocks in the extreme southeast; and several small bodies of ultramafic rocks that occur only in the basement or adjacent to it but are probably younger than the Ocoee series.

TABLE 1.—*Formations in the eastern Great Smoky Mountains, North Carolina and Tennessee*

Below Greenbrier fault	*Above Greenbrier fault*
Chilhowee group:	
Cochran formation	
--------Fault contact------------------	
Ocoee series:	Ocoee series:
Walden Creek group:	Great Smoky group:
Wilhite formation	Anakeesta formation
--------Fault contact------------------	Thunderhead sandstone
Rich Butt sandstone	Elkmont sandstone
Snowbird group:	Snowbird group:
Pigeon siltstone	
Roaring Fork sandstone	Roaring Fork sandstone
Longarm quartzite	Longarm quartzite
Wading Branch formation	Wading Branch formation
--------Unconformity----------------	--------Unconformity-----------------
Basement complex:	Basement complex:
Plutonic rocks	Plutonic rocks
	Carolina gneiss

BASEMENT COMPLEX

Rocks of the basement complex occur in several different localities in the southeastern part of the map area (pl. 1). They are exposed in a large part of the Dellwood quadrangle (pl. 2) and a belt extending southwestward along the valley of Soco Creek to the vicinity of Cherokee. Three areas along the Pigeon River near the east edge of the map area (fig. 2) include an anticlinal body exposed on Harmon Den Mountain, a second and larger anticlinal body that forms most of Hurricane Mountain and the adjacent ridges, and a narrow fault slice extending from Harmon Den Mountain southwestward to the valley of Cataloochee Creek. Another large area of basement rock is in the Straight Fork window (pl. 13) and two more bodies are exposed near Ela and Bryson City in the southwestern part of the report area.

These bodies of basement rock differ considerably from one another not only because of variations in the original complex but also because of differences in subsequent structural and metamorphic history. Some are autochthonous with regard to the adjacent younger rocks; others have been thrust on low-angle faults over their sedimentary cover. All are polymetamorphic, for they were subjected to various degrees of metamorphism in both Precambrian and Paleozoic time.

CAROLINA GNEISS

DEFINITION

Although first mentioned in Keith's description of the rocks of the Washington, D.C. area (Keith and Darton, 1901) the Carolina gneiss was more clearly defined in the subsequent Asheville and Mount Mitchell folios (Keith, 1903, 1905) dealing with areas 50 miles northeast of that of the present report. Here it was described as an immense series, occurring widely in North and South Carolina, made up of interbedded mica schist, mica gneiss and thin granitic layers with minor hornblende schist and gneiss, and lenses and veins of pegmatite. This unit was mapped by Keith (1904, 1905, 1907) along the east side of the Blue Ridge province and southward into northern Georgia, in a belt including the southern margin of this report area. Areas consisting dominantly of hornblende gneiss Keith mapped as "Roan gneiss" but, as no consistent stratigraphic relation has been demonstrated between the Carolina and "Roan" gneisses, the latter is here regarded as a lithologic variant of the former and bodies of hornblende gneiss formerly mapped as "Roan" are included in the Carolina gneiss. The "Roan" gneiss is hereby abandoned in the area of this report.

Keith (1903, p. 2) early interpreted the Carolina gneiss as the oldest formation in the region, "since it is cut by all igneous rocks and overlain by the sediments," and he ascribed to it an unknown thickness and origin although he suspected that parts of it were metamorphosed sedimentary rocks. Keith (1904, p. 3) also recognized the effects of repeated deformation in the Carolina and associated rocks and reported that

> one deformation produced a foliation of the rock, whatever its original nature. A subsequent deformation folded and crushed the earlier planes and structures. In most of the formation metamorphism has been excessive and has destroyed the original attitudes and most of the original appearance of the rocks.

The present work has confirmed many of Keith's conclusions on the Carolina gneiss. It is principally a very old metasedimentary series, much metamorphosed and invaded by granitic material in Precambrian time, and subjected to further deformation and regional metamorphism during Paleozoic time.

GENERAL DESCRIPTION

The Carolina gneiss in the report area is a heterogeneous assemblage of layered micaceous and hornblendic gneiss, mica schist, and amphibolite. These rocks are medium to coarse grained and variably foliated; they range from even-grained quartzose, feldspathic, and amphibolitic rocks to uneven-grained micaceous and porphyroblastic rocks. They are intercalated in layers and lenses, an inch to several tens of feet thick, which are, at least in part, inherited from earlier sedimentary and igneous structural features.

The largest area of these rocks is in the central and southern parts of the Dellwood quadrangle (pl. 2), where all lithologic types of the formation are well represented. Carolina gneiss occupies the northeastern part of the area of basement rocks near Ela, and other areas, too small to be shown on plates 2 and 3, are scattered among the plutonic rocks of the basement complex, especially in the western part of the Dellwood quadrangle and southeast of Shelton Laurel.

The lack of obvious stratigraphic or structural control makes it necessary to subdivide the Carolina gneiss for mapping purposes largely on a lithologic basis. The principal map unit in the formation consists of bodies of micaceous gneiss, including muscovitic, biotitic, and quartzose types, as well as minor amounts of mica schist. Some of these rocks were derived from shale and sandstone, others possibly from felsic volcanic rocks. Most of the micaceous gneiss bodies are strongly biotitic and probably represent hornblendic rocks to which potassium has been added. Hornblendic gneiss varying widely in color and amount of mafic minerals, is less abundant than micaceous gneiss but it comprises an important map unit in the Dellwood quadrangle. The hornblendic gneiss includes light-colored varieties probably derived from dolomitic sandstone and darker ones that were derived from dolomitic shales or volcanic rocks of intermediate composition. Most hornblendic gneiss contains abundant biotite and thus grades toward the biotitic micaceous gneiss. Amphibolite in the Carolina gneiss includes rocks composed largely of hornblende and plagioclase; the larger bodies are probably intrusive; but many smaller ones probably represent mafic segregations in metamorphosed sedimentary or volcanic rocks.

MICACEOUS GNEISS AND MICA SCHIST

The micaceous gneiss represents a broad compositional group within which two-mica gneiss and associated schist, mica-quartz-feldspar gneiss, and biotite gneiss are distinguished. Mineralogic modifiers are placed in the order of increasing abundance of these minerals in the rock, the modifier nearest the rock name being the most abundant constituent.

BIOTITE GNEISS

By far the most abundant of the micaceous gneiss bodies are composed largely of quartz, plagioclase, and biotite, with subordinate amounts of potassium feldspar and muscovite in some rocks. They range from weakly foliated and indistinctly layered gneiss to well-foliated porphyroblastic gneiss. They occur adjacent to and interlayered with hornblendic gneiss near Purchase Knob and on Utah Mountain and Goat Rock Ridge and are similarly associated with plutonic rocks on both sides of Hemphill Creek and on Purchase Knob. One of the larger bodies of biotite gneiss overlies muscovitic and quartzose gneisses and underlies plutonic rocks in the valley of Campbell Creek. Biotite gneiss and subordinate amounts of two-mica gneiss occupy an irregular area southwest of Suttontown.

Because of its large feldspar content, the biotite gneiss is easily weathered and most roadside exposures are saprolite rather than fresh rock. The most accessible hardrock exposures are beside U.S. Highway 19 at Lake Junaluska, 4 miles east of Dellwood. Natural outcrops can be seen in fields on either side of the road east from North Carolina Highway 284, 1.1 miles south of Cove Creek.

The biotite gneiss is light to medium gray and medium to coarse grained, the finer grained rocks being more even grained than the coarser ones. Foliation consists of subparallel mica flakes, streaks or flat lenses of quartz and feldspar, and folia of biotite enclosing feldspar porphyroblasts. Some rocks of uniform texture and grain size consist of alternate lighter and darker layers, a few inches to 10 or 15 feet thick distinguished by varied amounts of biotite; other rocks are medium-grained less-foliated gneiss with intercalated layers, a few inches to 2 feet thick, of mica-quartz-feldspar gneiss or hornblendic gneiss. Some layers are light-colored quartz-feldspar rocks which contain rounded or platy aggregates of biotite or individual biotite porphyroblasts as large as 3 by 10 millimeters.

The biotite gneiss consists essentially of plagioclase, quartz, and biotite in widely varying proportions (table 2, analyses 10–18). Quartz, ranging in amount from 20 to 35 percent, is subordinate to feldspar in all specimens studied microscopically. The feldspar is dominantly plagioclase (35–65 percent), but microcline, perthite, and untwinned feldspar amount to as much as 30 percent of some rocks. Biotite ranges from 2 to nearly 30 percent, and governs both the color and the degree of foliation of the rock. The biotite gneiss is moderately calcic; its plagioclase is generally andesine, and epidote occurs in many specimens. Accessory garnet, muscovite, sphene, apatite, and magnetite-ilmenite are commonly present; allanite (rare-earth bearing calcium-aluminum silicate) and zircon rarely. Some varieties of biotite gneiss transitional to hornblendic gneiss contains traces of hornblende or abundant epidote (table 2, analyses 15, 16).

The texture of the biotite gneiss is crystalloblastic and equigranular to inequigranular. Feldspar forms porphyroblasts in the more micaceous rocks, where some plagioclase grains are 3.5 mm in diameter. Foliation is marked by scattered subparallel flakes of biotite or, in the more biotitic rocks, by streaks of biotite which weave around small knots of quartz and plagioclase. Plagioclase and quartz form monomineralic as well as polymineralic aggregates, which are flattened and provide a weak foliation in the less micaceous rocks. Aggregates of quartz appear to represent once larger grains crushed and recrystallized. In many rocks, fine-grained quartz, green biotite, and, locally, muscovite and alkali feldspar have recrystallized along late shears.

The overall grain size of the rock increases with increasing amounts of potassium feldspar, which is generally irregularly distributed and inequigranular. The larger grains of potassium feldspar have highly irregular boundaries, include grains of quartz and epidote, and project into plagioclase. Myrmekite occurs adjacent to potassium feldspar in some of the biotite-poor rocks, and some potassium feldspar occurs as blocky inclusions in plagioclase (antiperthite). Biotite, sphene, and epidote are commonly clustered together (fig. 6*A*), sometimes with magnetite or small irregular grains of hornblende, an association which probably has resulted from metasomatic alteration of hornblende to biotite.

Colorless to moderate-greenish-yellow epidote not only occurs in the biotite-epidote-sphene clusters but is also scattered through the rock. Although much of the epidote is in small irregular grains, many grains of the disseminated epidote are larger, equant, and a few contain cores of allanite. This disseminated epidote may be a primary metamorphic mineral or derived from previously stable calcic plagioclase.

The biotite in most of the biotite gneiss is olive or olive brown, but some rocks contain moderate-brown and moderate-reddish-brown biotite; biotite gneiss containing traces of hornblende has only olive biotite. It is noteworthy that the color of biotite in the Carolina gneiss varies with the composition of the rock. In two-mica gneiss, mica schist, and mica-feldspar-quartz gneiss, the biotite is dominantly reddish brown or brown; in hornblendic rocks, as well as in much biotite gneiss, the biotite is olive brown or olive.

TWO-MICA GNEISS AND MICA SCHIST

Rocks in which both muscovite and biotite are prominent are much less abundant than biotite gneiss. Most of them are gneiss containing subequal amounts of quartz, calcic oligoclase, and mica (table 2, analyses 7–9), but some are schist containing as much as 45 percent mica. They generally occur as layers less than 50 feet thick intercalated with more quartzose gneiss,

TABLE 2.—*Modal composition of rocks in the Carolina*

[Tr., trace; c, clinozoisite; ol, oligoclase; an, andesine]

	Micaceous gneisses											
	Mica-feldspar-quartz gneiss						Two-mica schist, gneiss			Biotite gneiss		
	1	2	3	4	5	6	7	8	9	10	11	12
Quartz	65	61	58	48	48	50	25	30	32	31	34	28
Plagioclase	10	11	13	28	21	17	21	32	32	38	35	45
Potassium feldspar	25	8	7	Tr.	16	2	----	----	----	----	8	6
Muscovite	Tr.	6	1	1	1	13	18	7	2	----	1	1
Biotite	1	14	20	22	14	16	25	26	34	27	21	19
Hornblende	----	----	----	----	----	----	----	----	----	----	----	----
Epidote	----	----	----	Tr.	Tr.	----	----	----	Tr.	Tr., c	----	----
Sphene	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	1	1	Tr.
Allanite	----	----	----	----	----	----	----	Tr.	Tr.	----	Tr.	Tr.
Magnetite-ilmenite	Tr.	Tr.	Tr.	Tr.	----	Tr.	2	1	Tr.	Tr.	----	Tr.
Apatite	----	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	1	Tr.	Tr.
Garnet	Tr.	Tr.	----	Tr.	----	----	7	3	Tr.	1	----	----
Zircon	----	----	----	----	----	Tr.	----	----	----	----	----	----
Kyanite	----	----	----	----	----	----	1	----	----	----	----	----
Scapolite	----	----	----	----	----	----	----	----	----	----	----	----
Pyroxene	----	----	----	----	----	----	----	----	----	----	----	----
Composition of plagioclase	ol	ol	An_{28}	An_{32}	An_{29}	an	An_{27}	An_{28}	An_{29}	ol	ol	An_{31}

1. Mica-feldspar-quartz gneiss; ridge south of Olivet Church, Maggie, Dellwood quadrangle.
2. Equigranular mica-feldspar-quartz gneiss; interlayered with porphyroblastic gneiss; Jaynes Cove, Dellwood quadrangle.
3. Mica-feldspar-quartz gneiss with quartz-feldspar laminae; Jaynes Cove, Dellwood quadrangle.
4. Inequigranular mica-feldspar-quartz gneiss; Mauney Cove, Dellwood quadrangle.
5. Lineated mica-feldspar-quartz gneiss; ridge southeast of High Top, Dellwood quadrangle.
6. Porphyroblastic mica-feldspar-quartz gneiss, interlayered with nonporphyroblastic gneiss, Jaynes Cove, Dellwood quadrangle.
7. Two-mica schist; near head of Moody Branch, Dellwood quadrangle.
8. Two-mica gneiss; on North Carolina 284, southeast of Trit Knob, Dellwood quadrangle.
9. Two-mica gneiss; Jonathans Creek, southeast of Cove Creek, Dellwood quadrangle.
10. Inequigranular biotite gneiss; ridge west of Trit Knob, Dellwood quadrangle.
11. Biotite gneiss; ridge southeast of Purchase Knob, Dellwood quadrangle.
12. Metasedimentary layer in migmatitic gneiss; quarry near Pigeon River, 2.5 miles east of Cove Creek. See fig. 6*B*.
13. Biotite gneiss; Germany Cove, Dellwood quadrangle.
14. Biotite gneiss; Moody Branch, Dellwood quadrangle.
15. Biotite gneiss; Fincher Chapel, 3 miles northeast of Dellwood.
16. Biotite gneiss from migmatitic gneiss; road cut near Pigeon River, 2.5 miles east of Cove Creek.
17. Granitoid biotite gneiss interlayered with hornblende-biotite gneiss; Toms Top, Dellwood quadrangle.

less commonly with biotite gneiss, and rarely with hornblendic gneiss. However, some units in which two-mica gneiss and schist dominate are several hundred feet thick. They closely resemble highly metamorphosed pelitic rocks of the Great Smoky group and in some places the two can be distinguished only with difficulty.

Two mica gneiss and associated schist occur with mica-feldspar-quartz gneiss of basement rocks on Cambpell Creek and are mixed with biotite and hornblendic gneiss south and southeast of Purchase Knob. They are abundant also near Dellwood, north of the crest of Utah Mountain and southwest of Hard Ridge, and they occur with quartzose gneiss along the lower part of Jonathans Creek between Cove Creek and Trit Knob. Two mica gneiss is well exposed in a cut on North Carolina Highway 284 a mile north of Dellwood.

The two-mica gneiss is a light- to medium-grey medium-grained inequigranular rock with coarse flaser structure. Indistinct but regular layers of finer grained more quartzose gneiss are common, but such variations are generally masked by segregation knots and lenses a few inches long containing quartz and feldspar and, more rarely, kyanite. Saprolite outcrops are marked by prominent white streaks of clay and quartz and contribute much muscovite to the residual soil.

Two-mica gneiss consists principally of subequal amounts of quartz, calcic oligoclase, and biotite, with less abundant muscovite; almandine garnet (n–1.793, A–11.554), iron oxides, apatite, and sphene are characteristic accessories; and traces of kyanite and allanite are present in some specimens. The muscovite content is highly varied and parts of the gneiss that contain little muscovite approach biotite gneiss in composition. Almandine is somewhat more abundant in the schist than the gneiss but is widespread in both. Kyanite is very sparse in both schist, and gneiss and occurs mainly in segregation knots and lenses.

The two-mica gneiss is typically inequigranular. Muscovite and biotite, in subparallel orientation, are concentrated in streaks which weave around and locally project into irregular knots or lenticles of quartz and oligoclase. Some grains of muscovite, larger and less well oriented than the rest of the mica, are younger than the latest deformation of the rock (postkinematic). Oligoclase in the quartz-oligoclase knots and lenticles consists of grains averaging about 2 mm in diameter, but it also forms individual porphyroblasts as large as 4 mm in diameter in some rocks. Both types of oligoclase contain inclusions of biotite and quartz, indicating continued growth throughout the crystallization of the rock. Garnet is scattered throughout the rock in subhedral grains, generally 1 mm, but locally 5 mm in diameter, which enclose biotite, quartz, and plagioclase. The kyanite in one specimen has (100) cleavage approximately parallel to the (001) cleavage of biotite.

gneiss, Great Smoky Mountains, North Carolina

[Tr., trace; c, clinozoisite; ol, oligoclase; an, andesine]

Micaceous gneisses—Continued						Hornblendic rocks													
Biotite gneiss—Continued						Hornblende-biotite gneiss and amphibolite									Calc-silicate granofels				
13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
30	30	40	25	22	20	26	15	15	5	24	5	9	3	1	37	21	1	36	45
55	38	44	65	50	45	21	60	40	35	19	20	40	35	25	14	53	48	45	45
2	20	--	--	25	30	Tr.	--	--	--	--	--	--	--	--	--	Tr.	--	9	--
Tr.	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
10	10	6	8	2	2	35	15	20	25	36	15	10	5	--	8	1	1	1	Tr.
--	--	--	Tr.	--	--	2	5	20	30	6	33	40	55	50	36	15	16	6	5
--	--	9	1	Tr.	1	7	3	--	3	4	2	--	--	1	--	9	32	1	5
Tr.	1	Tr.	Tr.	Tr.	Tr	5	1	Tr.	1	--	Tr.	Tr.	Tr.	2	1	1	1	1	Tr.
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	Tr.	--
Tr.	--	--	Tr.	--	--	--	--	Tr.	Tr.	--	--	1	1	1	Tr.	--	--	1	--
Tr.	--	--	Tr.	Tr.	--	2	Tr.	2	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	--	--	--
--	Tr.	--	1	--	Tr.	4	--	2	--	--	--	--	1	8	4	Tr.	--	--	1
--	Tr.	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	Tr.	--
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--	--	--	10	25	--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--	--	--	--	--	--	--	12	--	--	--	--	--
An_{35}	An_{33}	An_{37}	An_{37}	An_{15}	An_{28}	An_{28}	An_{34}	An_{32}	An_{36}	An_{33}	An_{28}	An_{32}	ol	An_{36}	An_{43}	an	An_{38}	ol	An_{55}

18. Granitoid biotite gneiss with small clots of biotite; Messer Branch, Dellwood quadrangle.
19. Garnet-bearing hornblende-biotite gneiss from layer 7 in. thick; Shady Grove Church, Dellwood quadrangle.
20. Hornblende-biotite gneiss, interlayered with biotite gneiss; east side Campbell Creek, 1.5 miles south of Maggie.
21. Coarser grained layer in hornblende-biotite gneiss, 0.5 mile west of Shady Grove Church, Dellwood quadrangle.
22. Hornblende-biotite gneiss adjacent to layered migmatitic gneiss in quarry, near Pigeon River, 2.5 miles east of Cove Creek.
23-24. Scapolite-bearing hornblende-biotite gneiss; southeast side of Purchase Knob, Dellwood quadrange.
25. Dark layer 10 mm thick in migmatitic hornblendic gneiss; south side of Purchase Knob, Dellwood quadrange.
26. Garnet amphibolite layer in hornblende-biotite gneiss; south side of Purchase Knob, Dellwood quadrange.
27. Garnet-pyroxene amphibolite from the body southeast of Trit Knob; cut on North Carolina Highway 284, Dellwood quadrangle.
28. Dark calc-silicate granofels from layer 6 in. thick in two-mica gneiss; roadcut, 1 mile northeast of Rock Hill School, Dellwood quadrangle.
29. Calc-silicate granofels, from layer 10 ft thick adjacent to two-mica gneiss; roadcut, North Carolina Highway 284, southeast of Trit Knob, Dellwood quadrangle. Chemical composition is given in table 3.
30-31. Calc-silicate granofels from body 50 ft wide on truck trail 0.8 mile southeast of Purchase Knob, Dellwood quadrangle.
32. Calc-silicate granofels from layer in plutonic gneiss; near Cooper Creek, Ela area.

Magnetite, mostly less than 1 mm in longest dimension, has irregular grain boundaries, a habit prevailing in the micaceous gneiss of the Carolina.

MICA-FELDSPAR QUARTZ GNEISS

Less micaceous more quartzose gneiss is as abundant as two-mica gneiss and is extensively interlayered with it. It is largely mica-feldspar-quartz gneiss consisting of 50 percent or more quartz, 20 to 35 percent feldspar, and 20 to 30 percent mica, dominantly biotite (table 2, analyses 1–6). The gneiss ranges from light to dark gray, and most of it is fine to medium grained. Layers a few feet to 40 feet thick, differing considerably in grain size and composition, probably represent original stratification, and such beds differ little in appearance from metasandstone of the Great Smoky group. Rare layers near Hemphill Creek and Campbell Creek are highly quartzitic. The lighter colored layers contain less biotite, and their texture is finer and more uniform; darker and more micaceous layers are coarser and less uniform, with some development of feldspar porphyroblasts. Foliation is marked by subparallel folia of biotite and by discontinuous dark- and light-colored laminae of metamorphic rather than sedimentary origin.

The best exposures of mica-feldspar-quartz gneiss are just west of Trit Knob and along the farm road to the southwest. Thin layers of the gneiss interbedded with two-mica gneiss are also exposed in cuts along Highway 284 just north of Dellwood.

In contrast to the two-mica gneiss, the mica-feldspar-quartz gneiss is characterized by the presense of potassium feldspar, which is, nevertheless, generally subordinate to plagioclase. Plagioclase ranges from sodic oligoclase to sodic andesine, and part of it is antiperthitic, with crisscrossing rods and lenticles of potassium feldspar amounting to nearly 50 percent of some grains. The biotite is always moderate brown or reddish brown in the direction of maximum light absorption and pale yellow in the direction of least absorption. It commonly contains small grains of allanite and possibly monazite, surrounded by pleochroic haloes.

The quartz and feldspar of the mica-quartz-feldspar gneiss are generally granoblastic, but they commonly occur in granular aggregates suggesting recrystallization after mild crushing, and much of the quartz is moderately strained. Some of the larger potassium feldspar grains are surrounded by a fine-grained mosaic of feldspars and quartz, interpreted as indicating late-stage albitization (Anderson, 1934, p. 189–190). The muscovite is generally fine grained and aggregated with biotite, but in some specimens it forms larger flakes, as much as 2 mm in diameter, which are probably postkinematic. The sparse garnet occurs in small isolated anhedral grains. Sphene is generally associated with biotite.

HORNBLENDIC ROCKS

The hornblende-bearing rocks of the Carolina gneiss are largely dark hornblende-biotite and biotite-hornblende gneiss with lesser amounts of quartz-bearing hornblende gneiss and layered amphibolite containing little or no biotite. They also include light-colored granular moderately calcic quartz-plagioclase rocks with sparse hornblende, herein called calc-silicate granofels. The term "granofels" rather than granulite is used for essentially nonfoliated, granoblastic metamorphic rocks with a grain size greater than 0.5 mm. No particular composition is implied, but a granofels is normally composed of equant mineral grains with fairly uniform distribution (see Goldsmith, 1959). These rocks, together with subordinate intercalations of other types, chiefly biotite gneiss, form units of widely varying size in the Carolina gneiss. Some are large enough to be shown on the geologic map (pl. 2); many thinner layers and lenses are included in the micaceous and quartzose gneisses.

Most of the hornblendic rocks contain both hornblende and biotite as major constituents, biotite dominating in some and hornblende in others. For convenience both types are referred to as hornblende-biotite gneiss (table 2, analyses 19–25). Rocks containing 50 percent or more hornblende are termed "amphibolite" (cols. 26, 27).

HORNBLENDE-BIOTITE GNEISS

On the southeast ridge of Purchase Knob and on Goat Rock Ridge, where hornblende-biotite gneiss is best exposed, the more abundant dark layers are ⅛–18 inches thick and range in composition from amphibolite to hornblende-biotite-quartz-andesine gneiss (table 2, analyses 19, 20) they are separated by discontinuous layers, ⅛ to ¼ inch thick, of quartz and feldspar with minor amounts of biotite. Some layers are dominantly light colored with sparsely mafic minerals in small clusters; others contain discontinuous and scattered biotite-rich lenses ⅛ to 1/16 inch thick. All gradations exist between sequences in which light-colored layers are dominant and those in which dark layers dominate.

The hornblende-biotite gneiss includes rocks of considerably varied composition. Plagioclase, largely sodic andesine, greatly exceeds quartz in most rocks, especially those containing the most hornblende. Quartz slightly exceeds plagioclase, however, in some of the more biotitic varieties. Potassium feldspar is generally absent, but it amounts to as much as 10 percent of a few of the more leucocratic rocks. The hornblende is pleochroic with X, light green; Y, green; and Z, blue-green or green. In one specimen green hornblende contains patches of a paler amphibole with different optical orientation. The color of the biotite varies with the amount of hornblende present; it is olive brown or olive gray in the more hornblendic rocks and light or moderate brown in the more biotitic rocks. The total amount of dark minerals ranges generally between 20 and 50 percent and includes much primary epidote. Orange-red and reddish-brown garnet is also abundant in some rocks but it is erratically distributed. Apatite, sphene, and magnetite are common although not abundant accessory minerals. Zircon was not found in any of the specimens examined microscopically.

The texture of the hornblende-biotite gneiss, like that of nearly all rocks of the basement complex, is crystalloblastic and inequigranular. The dominant foliation is marked by subparallel mica and hornblende. Hornblende is generally porphyroblastic and anhedral, occurs in clusters with biotite, epidote, and sphene, and includes grains of sphene and epidote. Biotite commonly borders hornblende grains, penetrates along cleavage planes, and shows other indications of replacing hornblende. Quartz forms lenticular to rounded aggregates and isolated grains. The andesine is anhedral, not zoned, and contains inclusions of quartz, biotite, and hornblende; some grains show diversely oriented sets of albite twins that suggest the coalition of several twinned grains.

In hornblendic gneiss containing appreciable potassium feldspar, the plagioclase is more sodic, more irregular in grain size, commonly mottled, and has myrmekitic borders against potassium feldspar. The latter appears mostly as an intergranular filling, but where it is relatively abundant it also forms large anhedral grains that appear to have replaced plagioclase. The garnet of these rocks is typically anhedral and poikiloblastic with inclusions of quartz, biotite, sphene, and epidote. Sphene occurs in subhedral grains both in the ferromagnesian clusters and in isolated grains throughout the rock.

Scapolitic hornblende-biotite gneiss forms a body 2,000 feet long and 1,200 feet wide on the southeast ridge of Purchase Knob between 3,600 and 4,000 feet altitude. Its outcrops closely resemble those of other types of hornblende biotite gneiss, but it has a mottled appearance caused by many dark clusters, ½ to ¼ inch across, of hornblende and biotite enclosed in a lighter colored rock consisting largely of quartz, andesine, and scapolite. The arrangement of these clusters or dark spots suggests a crude layering in places but is at best inconspicuous.

The rock (table 2, analyses 23, and 24) consists mainly of plagioclase, biotite, and hornblende, with subordinate amounts of quartz and various amounts of scapolite. The combined mafic constituents range from 25 to 50 percent. The hornblende occurs in large poikiloblastic grains enclosing quartz and is commonly bordered by felted aggregates of biotite. Plagioclase generally forms granoblastic aggregates rather than individual grains; much of it is dusty and full of tiny plates of biotite or needlelike inclusions of hornblende, and some is antiperthitic. Epidote occurs in unusually large, strongly pleochroic twinned grains. Scapolite spreads irregularly through the rock and encloses biotite, epidote, and hornblende. Some scapolite forms clusters of grains with subparallel optical orientation and some is concentrated around plagioclase. Scapolite is most abundant in rocks with the least plagioclase and thus appears to take the place of plogioclase. Its birefringence indicates that it contains at least 60 percent meionite and is therefore richer in calcium and calcium carbonate than in sodium and sodium chloride.

CALC-SILICATE GRANOFELS

Light- to dark-colored, little-foliated rocks characterized by relatively large content of lime and alumina occur in both micaceous and hornblendic gneisses. They form layers and large lenses, generally less than a foot but locally as much as 8 feet thick, and are most abundant in two-mica and mica-feldspar-quartz gneiss. They also form small conspicuous bodies in plutonic rocks of the Dellwood-Cherokee belt and locally in the Ela area. Good examples can be seen on North Carolina Highway 284 about 1 mile north of Dellwood and on a truck trail at 4,200 feet altitude eight-tenths of a mile southwest of Purchase Knob.

These rocks are medium grained and equigranular, locally porphyroblastic; most are very pale greenish gray and weather chalky white. Megascopic foliation is generally weak or absent owing mainly to the scarcity of platy minerals.

The large amounts of lime and alumina in these rocks are mainly present in plagioclase and epidote (table 2, analyses 29–32). The plagioclase ranges between 40 and 55 percent, and its anorthite content reaches An_{55}; it is the most calcic plagioclase found in the Carolina gneiss. Iron-poor epidote or clinozoisite amounts to 30 percent or more of some specimens. Hornblende is a minor or subordinate constituent and biotite is sparse. Sphene is always present, and small amounts of orange-red almandine-grossularite garnet (n=1.783, A=11.676, n=1.782, A=11.610) occur in many specimens.

The texture of the calc-silicate granofels is typically granoblastic. Hornblende, garnet, and plagioclase commonly form larger poikiloblastic individuals by coalescence of smaller grains. A similar process in the plagioclase has produced aggregates of grains with somewhat differing optical orientation which pass into larger individuals with complex twin patterns resulting from the merger. Both plagioclase and hornblende contain many included grains of quartz, clinozoisite, and sphene. The plagioclase grains are always anhedral and are weakly zoned, the borders being slightly more sodic than the centers. Both green and blue-green hornblende are present, the latter being somewhat younger than the former. Biotite, ranging from moderate reddish brown to olive brown, is either intimately mixed with hornblende or borders garnet, in a manner suggesting replacement of those minerals.

AMPHIBOLITE

Black and dark-greenish-gray rocks consisting largely of hornblende occur throughout the Carolina gneiss in a variety of forms ranging from thin layers and small pods a few feet wide to mappable units several hundred feet wide. Some of them are intercalated with hornblende and biotite gneisses and probably represent concentrations of mafic constituents during metamorphism. Others form larger, possibly intrusive bodies in the micaceous gneisses, conforming to their structural pattern and deformed with them. One of these bodies at the east boundary of the Dellwood quadrange, 2 miles southeast of Cove Creek, is 900 feet wide and 2,000 feet long and its western termination is forked, suggesting that the body may be folded. A smaller amphibolite body nearer Cove Creek is crescent shaped, and a third, a mile north of Dellwood, is a lenticular body thickened at its west end by folding.

Amphibolite layers and lenses intercalated with hornblende and biotite gneisses and associated with calc-silicate granofels are abundant near Purchase Knob and in the hills northeast of Dellwood. They consist mainly of hornblende and subordinate amounts of plagioclase with biotite and quartz, and minor amounts of epidote, sphene, magnetite-ilmenite, apatite, and almandine (table 2, analysis 26). The plagioclase is generally andesine or calcic oligoclase and is zoned like the plagioclase in calc-silicate granofels. Abundant grains of quartz enclosed in plagioclase, garnet, and hornblende indicate that quartz was present during recrystallization and was probably an original constituent of the rock. Biotite or several generations occurs as enclosed grains, as rims on hornblende, and in microshear zones. The hornblende is generally bluish green, but the central parts of larger grains are brownish green, suggesting marginal modification by addition of soda. The texture of the amphibolite is dominantly granoblastic and somewhat uneven; the coarser grained patches are enclosed in rock of finer texture.

Widely separated pods or lenses a foot or less wide and a few feet long consisting almost entirely of amphibole are associated with hornblendic gneiss. The central parts of these small bodies commonly contain green or brownish-green hornblende mixed with actinolite, whereas their borders are largely hornblende. Biotite is mainly secondary, replacing hornblende and producing a more or less foliate fabric. Very minor amounts of sphene, apatite, and plagioclase are also present.

The larger amphibolite bodies consist of medium- to fine-grained comparatively homogeneous rock composed of green to brownish-green hornblende, subordinate oligoclase or andesine, almandine-grossularite garnet, colorless to pale-green diopsidic pyroxene, and sphene (table 2, analysis 27). Their texture is granoblastic; and hornblende, garnet, or pyroxene are concentrated in thin lenses that streak the rock. The plagioclase grains are poikilitic and unusually irregular in shape. Many show reversed zoning, cores of oligoclase grading outward to rims of andesine, suggesting a response to either increasing metamorphic temperature or introduction of calcium.

ORIGIN OF THE CAROLINA GNEISS

Clues to the origin of the Carolina gneiss can be obtained from its textures, structures, and chemical composition, but this evidence is so obscure that only the broadest kind of choice can be made between stratified and nonstratified rocks and between igneous (including volcanic) and nonigneous origin. Most of the Carolina gneiss is sufficiently layered that it probably originated as a sequence of stratified rocks. Therefore, even the rocks whose composition approaches that of common igneous rocks are probably volcanic rather than intrusive. Possible exceptions are the relatively uniform and isolated bodies of amphibolite.

Parts at least of the muscovitic gneiss and mica schist appear by their layering and composition to have been derived from argillaceous and quartzose sedimentary rocks. This is suggested, for example, by the abundance of muscovite in the mica schist and some of the two-mica gneiss and quartzose gneiss and by the large amount of quartz in some of the mica-feldspar-quartz gneiss. The presence of feldspars and mafic minerals in many of these rocks and the absence of rocks containing more than 65 percent quartz indicate either that the rocks are muddy and feldspathic sandstone or graywacke or that they contained volcanic material. Few of them, however, have the bulk composition of common volcanic rocks. The silica content of some is too high; others approximate in some respects the composition of andesite, dacite, or rhyodacite, but they contain markedly disproportionate amounts of such constituents as iron oxides, magnesia, alkalies, and alumina.

Both the field occurrence and the composition of the calc-silicate granofels (table 3) indicate derivation from calcareous sedimentary rocks to which soda was added during metamorphism. As compared with their closest chemical counterparts among the common volcanic suites, they contain significantly less potassium oxide and more lime in proportion to iron oxides, magnesia, and silica. They are similar to calc-silicate rocks interbedded with less intensely metamorphosed sandstone and schist of the Great Smoky group (p. B102), which are clearly derived from calcareous feldspathic sandstone.

TABLE 3.—*Chemical and calculated mineral composition, in percent, of calc-silicate granofels in Carolina gneiss.*

[L. D. Trumbull, analyst. Laboratory No., 53-2391CD; field No., 143g]

Analysis		*Calculated mineral composition*	
SiO_2	63.79	Quartz	21.8
Al_2O_3	16.55	Orthoclase	4.6
Fe_2O_3	1.13	Andesine (An_{30})	47.4
FeO	3.42	Hornblende [1]	17.6
MgO	1.53	Epidote [2]	5.0
CaO	6.82	Garnet [3]	.9
Na_2O	3.90	Sphene	1.3
K_2O	.77	Apatite	.8
H_2O-	.32		99.4
H_2O+	.57		
TiO_2	.61		
CO_2	.02		
P_2O_5	.35		
MnO	.09		
	99.87		

[1] Hornblende, in percent: SiO_2, 44.2; Al_2O_3, 12.2; Fe_2O_3, 5.9; FeO and MnO, 19.1; MgO, 8.7; CaO, 8.2; H_2O, 1.7.
[2] Epidote, in percent: SiO_2, 40; Al_2O_3, 32; Fe_2O_3, 1; CaO, 25; H_2O, 2.
[3] Garnet, in percent: almandine, 42; grossularite, 47; andradite, 11.

NOTE.—Calc-silicate granofels, complexly folded and interlayered with biotite gneiss, is from cut on North Carolina Highway 284, a mile north of Dellwood. The rock is medium grained light gray, and weathers chalky white. It contains indistinct layers, a quarter of an inch thick, of differing proportions of hornblende, pale-green epidote, and reddish-orange garnet, as well as quartz and feldspar. The texture is granoblastic; hornblende, with minor biotite and epidote, forms clusters ½–¾ inch in diameter. The hornblende is green with bluish-green margins and encloses epidote grains. The potassium feldspar is interstitial to quartz and plagioclase. Kyanite zone.

The plagioclase-rich biotite and hornblende-biotite gneisses are probably closely related in origin. These rocks are abundantly interbedded with muscovitic and quartzose gneisses, but are considerably more calcic and mafic. They might represent therefore either iron-rich dolomitic sediments or andesitic or basaltic tuffs. In either case, the porphyroblastic habit of potassium feldspar and the petrographic evidence of conversion of hornblende to biotite suggest that the proportions of biotite, potassium feldspar, and sodium feldspar were controlled to a considerable extent by alkali metasomatism during the formation of the basement complex. Engel and Engel (1953, p. 1078–1096; 1958, p. 1403) offer similar hypotheses for the origin of Adirondack gneiss similar to the Carolina gneiss and conclude that they probably evolved from sodic tuff or graywacke.

PLUTONIC ROCKS

A large part of the basement rocks of the eastern Great Smoky Mountains consists of massive coarse-textured rocks, less layered and less diverse in composition than the Carolina gneiss. The composition is that of plutonic rocks ranging from granite to granodiorite, with biotite and epidote as the principal mafic constituents (fig. 2). In broad outline these rocks include biotite flaser and augen gneisses, having the composition of quartz monzonite and granodiorite and comprising 75 percent of the plutonic rocks. A much smaller amount of less mafic and less foliated rocks of quartz monzonitic or granitic composition forms smaller bodies within the flaser and augen gneisses. Minor bodies of pegmatite and aplite are also present, as well as various hornblendic, calc-silicate, and quartzose gneisses considered to be included parts of the Carolina gneiss.

The plutonic rocks are gradational with each other and are so intermingled in most places that they cannot be consistently distinguished; therefore, they are shown as a single unit on plate 1. On the larger scale map of the Dellwood quadrangle (pl. 2), areas of augen gneiss are separated from the other plutonic rocks.

PIGEON RIVER AREA

Plutonic rocks of the basement complex are prominent near and east of the Pigeon River in the northeastern part of the report area. They form most of Harmon Den and Hurricane Mountains and extend several miles southwest across the river north of Cove Creek Gap. Good exposures of these rocks can be seen along the road near Shelton Laurel, along the lower part of the road on Cold Springs Creek in the extreme northeast corner of the area, and on an abandoned lumber railroad in the lower part of the valley north of Hurricane Mountain.

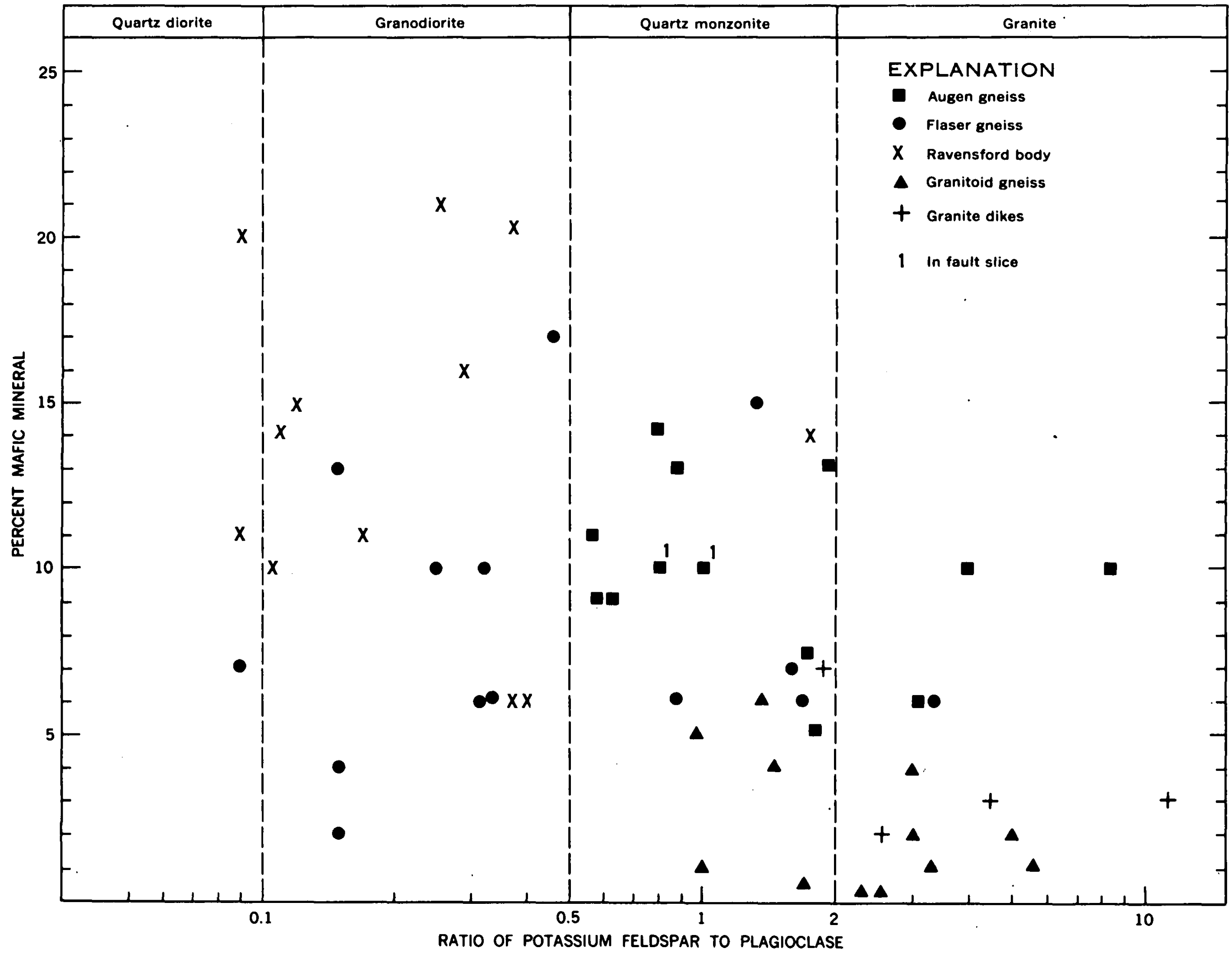


FIGURE 2.—Ratio of potassium feldspar to plagioclase plotted against percent of mafic minerals (biotite, chlorite, epidote, and magnetite) in plutonic rocks, eastern Great Smoky Mountains.

The plutonic rocks in the northeastern part of the report area are continuous with a large area of similar rocks in the adjoining Asheville quadrangle to the east and northeast. This area includes the type locality of the Max Patch granite of Keith, 4 miles northeast of the northeast corner of the report area, as well as considerable areas mapped by Keith as Cranberry granite (Keith, 1904, p. 3–4). On Keith's map both units appear at the west edge of the Asheville quadrangle, where the Max Patch corresponds approximately to the coarser phases and the Cranberry to the finer grained phases of the rocks here described as plutonic rocks of the basement complex.

The northeasternmost plutonic rocks are largely coarse grained and generally gneissic but are varied in texture and composition. In general the rocks contain 5 to 10 percent of dark minerals and their feldspar content falls within the range of granite or quartz monzonite. Most abundant is coarse-grained gneiss characterized by prominent light-gray, greenish, or orange-pink feldspars, bluish quartz, and clots or clusters of fine-grained dark minerals. Most of the feldspars are a centimeter or more in diameter but are rarely euhedral. In most outcrops the rock has distinct but variable foliation marked by crushed and drawn out quartz and mafic clots.

The rocks are composed largely of quartz, potassium feldspar, and saussuritized plagioclase, with minor amounts of biotite, chlorite, muscovite, and epidote, and accessory sphene, apatite, magnetite, and zircon (table 4, analysis 1). Potassium feldspar, commonly microcline, forms large crystals and gives a subprophyritic texture to much of the rock. Plagioclase is mostly gray or greenish white, in smaller grains than the potassium feldspar, and consists of albite with many inclusions of muscovite and clinozoisite. Alteration is also manifest in the biotite, epidote, and sphene, which show large early-formed grains and abundant small secondary grains attached to them or distributed in the dark clots. Apatite and zircon and most of the magnetite seem to be older grains little affected. The dark minerals and most of the accessory minerals are concentrated in aggregates several millimeters long between the larger quartz and feldspar grains. Textures are crystalloblastic and commonly distinctly cataclastic.

Some rocks contain less than 5 percent dark minerals and are characterized by grayish feldspars and abundant intensely blue or purplish quartz or by white feldspars and normal colorless or gray quartz. Locally they are finer grained than most of the complex. These rocks underlie considerable areas, although exposures rarely are such as to reveal their dimensions and relations to adjacent rocks. In part, they grade into the rest of the complex, although locally they appear as irregular dikes cutting coarser or darker rocks.

TABLE 4.—*Modes of the basement complex, Pigeon River area and Straight Fork window, eastern Great Smoky Mountains*

	1	2	3	4	5	6	7	8	9
Quartz	30	50	27.1	24.7	20	2	5	55	12
Potassium feldspar	15	10	23.4	10.6	25	------	2	------	------
Plagioclase	45	32	29.8	39.0	45	13	------	40	[1] 78
Muscovite	([2])	------	4.0	2.0	([2])	------	------	------	------
Biotite and chlorite	7	5	10.0	14.0	6	------	75	3	7
Hornblende	------	------	------	------	------	80	------	------	------
Epidote	3	1	2.3	5.6	2	3	11	1	3
Sphene	.3	.3	1.0	.4	Tr	2	.3	------	1
Apatite	.3	.2	.7	1.5	.4	------	------	Tr	.3
Zircon	Tr	Tr	Tr	Tr	------	------	------	Tr	Tr
Magnetite	.4	------	1.0	1.8	1	------	.5	------	.5
Carbonate	------	------	------	------	------	------	7	------	Tr
Character of plagioclase	([3])	An_{27}	An_{13}	An_{25}	([3])	An_{32}	------	An_{32}	([1])

[1] Two plagioclases: porphyroblasts of oligoclase, An_{20}, and fine granoblastic oligoclase-andesine.
[2] Does not include sericite in saussurite.
[3] Saussurite.

1. Granodiorite, one-half mile north of Shelton Laurel.
2. Biotite flaser (granodiorite) gneiss, Enloe Creek.
3. Coarse augen gneiss, calculated from chemical analysis, table 5 (analysis 2).
4. Dark knotted gneiss of Ravensford body, calculated from chemical analysis, table 5 (analysis 1).
5. Quartz monzonite, 1 mile northeast of Max Patch Mountain, Lemon Gap quadrangle.
6. Amphibolite enclave in Ravensford body, north end of Big Cove.
7. Biotite schist at margin of amphibolite of analysis 6.
8. Medium-grained biotite-epidote-quartz diorite, dikelets in amphibolite of analysis 6.
9. Biotite-plagioclase gneiss adjacent to amphibolite enclave.

Small lenses and pods of granite pegmatite or aplite are fairly common in some places, although they are nowhere abundant. In intensely sheared parts of the complex, such pegmatites remain as thin layers and distinguish mylonitized basement rocks from sheared rocks of the Ocoee series. (Oriel, 1950, p. 33.) Locally in the coarser gneiss and pegmatite, especially where they have been considerably sheared, the potassium feldspar is orange pink (10*R* 7/2 to 10*R* 6/4), similar to that in the "unakite" common in the basement complex farther northeast.

The plutonic rocks of the Pigeon River area have been locally crushed, sheared, and reduced in grain size, especially near faults. In some places the rocks affected have been transformed into mylonites, which occur throughout the narrow fault slice extending across Wading Branch Ridge. Where this slice is best observed, along the east side of the Pigeon River, it consists of dark fine-grained gneiss with abundant knots and rolled porphyroclasts of white or pink feldspar. Strong lineation and accompanying complex foliation indicates intense shearing and rolling. Much of the slice is more mafic than the rest of the basement complex in this area and thus resembles the basement rocks farther southwest.

Smaller bodies of amphibolite, hornblende-biotite schist, quartz-biotite schist, or hybrid gneissic or granular rocks composed of quartz, feldspar, and biotite crop out at several places in this part of the basement complex, notably along the lower part of Hurricane Creek and in the area east of Whiteoak Mountain, southwest of the Pigeon River. All these bodies are small and irregular inclusions in the granitic rocks.

STRAIGHT FORK WINDOW

Plutonic rocks of the basement complex occupy more than half the large window beneath the Greenbrier fault in the south-central part of the eastern Great Smoky Mountains. In the northern part of the window they appear in two fault slices, one above the other. The southern part consists of basement rocks, which seem to represent a thick part of the lower slice.

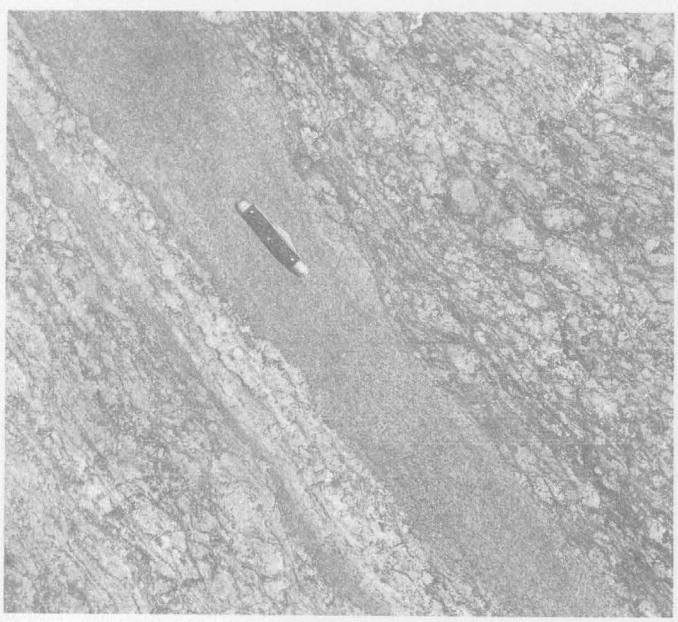
NORTHERN PART

Most of the complex in the northern part of the window consists of coarse augen gneiss, which forms great ledges and stream-bed outcrops along Straight Fork between Hyatt Bald and Beech Gap, in the bed of Straight Fork due west of Beech Gap, and in the bed of Raven Fork in the extreme northeast corner of the Ravensford quadrangle (fig. 3*A*). Typical augen gneiss consists of prominent white or pinkish potassium feldspar in a matrix of foliated quartz, plagioclase, and biotite. Generally the large feldspars are anhedral Carlsbad twins, ½ to 1½ inches long, closely crowded and elongated parallel to a well-developed foliation which bends around them. Quartz occurs as thick curved lenticles between the potassium feldspars; it generally amounts to less than 20 percent of the rock. The dark minerals occur in aggregates, much as they do in the coarser granitic rocks farther east, and commonly include conspicuous grains of magnetite and small bright yellow or white spots of leucoxene.

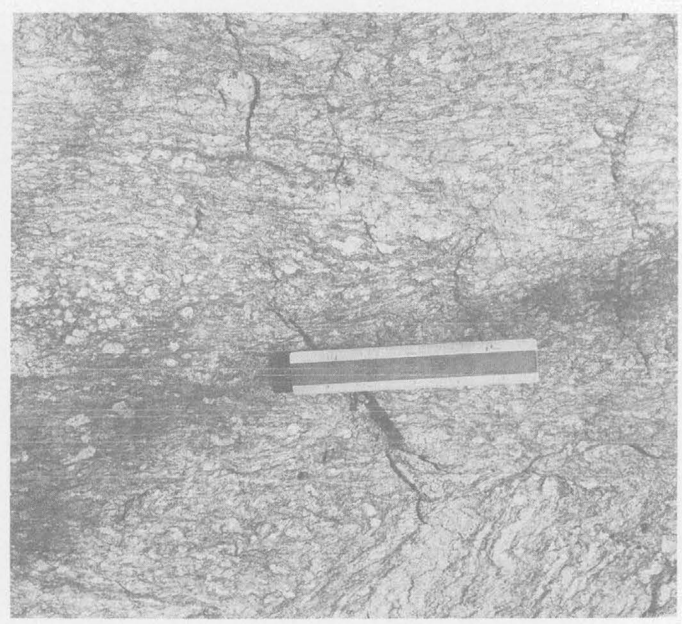
In part of the augen gneiss, notably along Raven Fork, many augen are not wholly feldspar anhedra, but aggregates of feldspar and quartz as much as several inches long. Others are nearly round, as though rolled rather than flattened. They are intercalated with abundant laminae of crushed and mylonitized granite, indicating unusual shearing.

Other rocks associated with the coarse augen gneiss include finer grained biotite-quartz-feldspar gneiss lacking the conspicuous feldspar augen. Some is darker biotite gneiss in which thin biotite-rich layers and small porphyroblasts of white feldspar are sparsely and irregularly distributed. Other parts are lighter colored quartz-rich granitic flaser gneiss of medium or coarse texture. Crudely intercalated mixtures of these rocks form layers or lenses several feet to several tens of feet thick in the augen gneiss, especially in the lower slice and in the lower part of the upper slice southwest of Straight Fork.

Composition of the augen gneiss is much like that of the coarser plutonic rocks on Hurricane Mountain. Potassium feldspar is largely microcline, with lesser amounts of microperthite and much untwinned feldspar. Other feldspar is mainly oligoclase, which is associated with quartz, muscovite, and epidote in grano-



A. Coarse augen gneiss in the bed of Raven Fork below Breakneck Ridge. Knife, 3.3 inches long, lies on metasandstone inclusion; other fine-grained layers are mylonitic.



B. Ridge southwest of Purchase Knob, Dellwood quadrangle. Foliation laminae are folded and sheared apart. Ruler is 6 inches long.

FIGURE 3.—AUGEN GNEISS OF THE BASEMENT COMPLEX

blastic aggregates apparently produced by recrystallization of saussurite. Biotite is the principal dark constituent, but epidote and sphene are abundant. Apatite and zircon are almost always present, and magnetite-ilmenite is common. The bulk composition of most of the augen gneiss is granitic or quartz monzonitic, but it is more mafic than the granite farther east.

Equigranular flaser gneiss intercalated with the augen gneiss in the north part of the window is generally granodioritic, with minor quartz monzonite and coarse-grained granite. It also contains more quartz (35–60 percent) than other gneisses of the complex. The minor constituents are also similar to those in the other gneisses. Biotite is the principal one; muscovite and coarse epidote are always present (1–4 percent), as are sphene, apatite, and zircon. Allanite and garnet are present in a few specimens, but magnetite is absent and the total dark-mineral fraction is relatively low.

RAVENSFORD BODY

The basement complex in the southern part of the Straight Fork window consists largely of distinctive dark gneiss that forms a body ⅓–2½ miles wide, which extends 10 miles from the south end of Hyatt Ridge through Ravensford townsite to near Cherokee, and a related body on the north and west slopes of Becks Bald. The contact between the gneiss in the southern part of the window and the coarse augen gneiss to the north is entirely gradational, but as this part of the complex differs in several respects from the plutonic rocks elsewhere in the area, it is referred to as the Ravensford body.

Characteristic exposures are bold outcrops high on steep slopes and extensive moss-covered outcrops in the beds of steep side streams. Accessible exposures are along the road on the lower part of Tow String Creek, 2 miles north of Ravensford, on U.S. Highway 441, 0.4 mile north of the Oconaluftee Ranger Stations, and in the bed of Oconaluftee River half a mile northeast of the Indian Agency headquarters at Cherokee. Better although less accessible exposures occur along and just above the trail on the northeast side of Big Cove, and exceptionally large and clean outcrops appear in the bed of Raven Fork for a mile or more above Big Cove. The gneiss of the Ravensford body weathers to a thick reddish soil in which very large blocks of gneiss occur in various attitudes. Such blocks, commonly 20 or 30 feet long, are more abundant than outcrops along the lower slopes and crowd even the largest stream courses.

The gneiss is typically a fine- to medium-grained biotite gneiss in which abundant white knots of plagioclase feldspar ⅛–½ inch across are set in a dark matrix. The gneiss is more strongly lineated than foliated, although both features are commonly present and the feldspar knots are flattened or elongated parallel to them. Some foliation laminae bend around the knots, but many are transected by them and impart a knotted rather than an eyed appearance to the rock. The color of the gneiss is governed by the proportion of feldspar knots present, which may range from 5 percent in an unusually dark variety to 80 percent in an unusually light-colored one. These extreme compositions are generally limited to lenses or layers a few inches thick intercalated in gneiss in which the knots range between 20 and 50 percent. The knots are largest and most abundant in the northeastern part of the Ravensford body, along the trail at the south end of Hyatt Ridge, and in the northern part of the exposures on Raven Fork, where the knotted gneiss grades into coarse augen gneiss.

Oligoclase, the most abundant mineral in much of the gneiss, forms anhedral porphyroblasts and aggregates, commonly enclosing quartz and most of the other minerals (table 4, analyses 4). Quartz ranges from 10 to 45 percent and generally forms lenticular aggregates revealing both earlier and later crushing. Potassium feldspar, notably sparse and ranging from none to 10 percent, is present as small grains or as anhedral porphyroblasts generally smaller than those of oligoclase. In the northern part of the Ravensford body, north and northeast of Big Cove, microcline forms locally abundant rounded to subhedral porphyroblasts as much as 1½ inches long. Brownish-green biotite is the principal dark constituent, and minor amounts of muscovite, epidote, and sphene are always present. Accessory minerals are apatite, zircon, magnetite-ilmenite, iron sulfide, and carbonate. Orange-red garnet, although not seen in thin section, is present in some outcrops. The dark minerals and most accessories are largely concentrated in clusters or laminae between quartz-feldspar aggregates and porphyroblasts, much as they are in the coarse augen gneiss in the Cove Creek quadrangle.

The microscopic fabric of the dark knotted gneiss reveals a complex history of metamorphic alteration, cataclasis, and recrystallization, in which deformation and recrystallization have competed for dominance. Quartz, generally a sensitive barometer of deformation, occurs as granoblastic mosaics, largely healed after earlier crushing but generally exhibiting shadowed extinction and slicing due to later stress. Commonly quartz grains have crushed or sutured borders, and locally quartz is found in trains of completely crushed grains with biotite and epidote. In most specimens studied, crystallization was largely synkinematic and took place after an earlier episode of dominant cataclasis. Postcrystalline deformation is limited to microscopic shear zones. All the mineral constituents are involved in this pattern, giving rise to a crystalloblastic texture with unusually varied grain sizes and mineral relationships.

The dark knotted gneiss is the most consistently mafic of the plutonic rocks in the area. The chemical and mineralogical compositions of a representative specimen collected from a cut beside the road just west of Hughes Ridge at the Indian Reservation boundary, 1.2 miles north-northeast of Ravensford townsite, are given in table 5 (analysis 1).

Light-colored weakly gneissic albite granite is well exposed in the bed of the Oconaluftee River just below the bridge on the road just mentioned. Such rock forms bodies less than 100 feet wide at several places along the west margin of the Ravensford body.

TABLE 5.—*Chemical and mineral composition of selected plutonic rocks, eastern Great Smoky Mountains, North Carolina (in percent)*

[L. D. Trumbull, analyst]

Analysis	1	2	3
Laboratory No.	53-2385CD	53-2384CD	53-2383CD
Field No.	218g	217g	221g
Chemical analyses			
SiO_2	62.75	68.15	69.57
Al_2O_3	15.43	14.68	14.88
Fe_2O_3	1.68	2.07	.92
FeO	4.49	1.68	1.96
MgO	1.33	.93	.99
CaO	4.38	2.00	2.54
Na_2O	3.43	3.05	2.98
K_2O	3.21	5.43	4.97
H_2O-	.01	.04	.03
H_2O+	.85	.53	.54
TiO_2	1.18	.78	.40
CO_2	.00	.00	.01
P_2O_5	.66	.28	.14
MnO	.11	.07	.06
BaO	.14	.14	.00
Total	99.65	99.83	99.99
Calculated mineral composition			
Quartz	24.7	27.1	28.5
Orthoclase	10.6	23.4	21.5
Plagioclase	39.0 (An_{25})	29.8 (An_{13})	34.0 (An_{26})
Muscovite	2.0	4.0	4.3
Biotite [1]	14.1	10.0	9.4
Epidote [2]	5.6	2.3	1.2
Sphene	.4	1.0	1.0
Apatite	1.5	.7	.3
Zircon	----------	Tr.	Tr.
Magnetite-ilmenite	1.8	1.0	.0
Allanite	----------	----------	Tr.
Total	99.7	99.3	100.2

[1] Composition of biotite derived from bulk analysis of the rock, in percent:
(1) SiO_2, 34; Al_2O_3, 14.2; Fe_2O_3, 4.2; FeO, 23.5; MgO, 9.4; MnO, 0.8; K_2O, 8.5; TiO_2, 4.2; H_2O, 0.9.
(2) SiO_2, 35; Al_2O_3, 15; Fe_2O_3, 11; FeO, 14; MgO, 9; MnO, 1; K_2O, 10; TiO_2, 4; H_2O, 1.
(3) SiO_2, 34; Al_2O_3, 13.2; Fe_2O_3, 7.6; FeO, 21.8; MgO, 10.6; MnO, 0.6; K_2O, 9.0; H_2O, 3.2.

[2] 15 percent $HCa_2Fe_3Si_3O_{13}$.

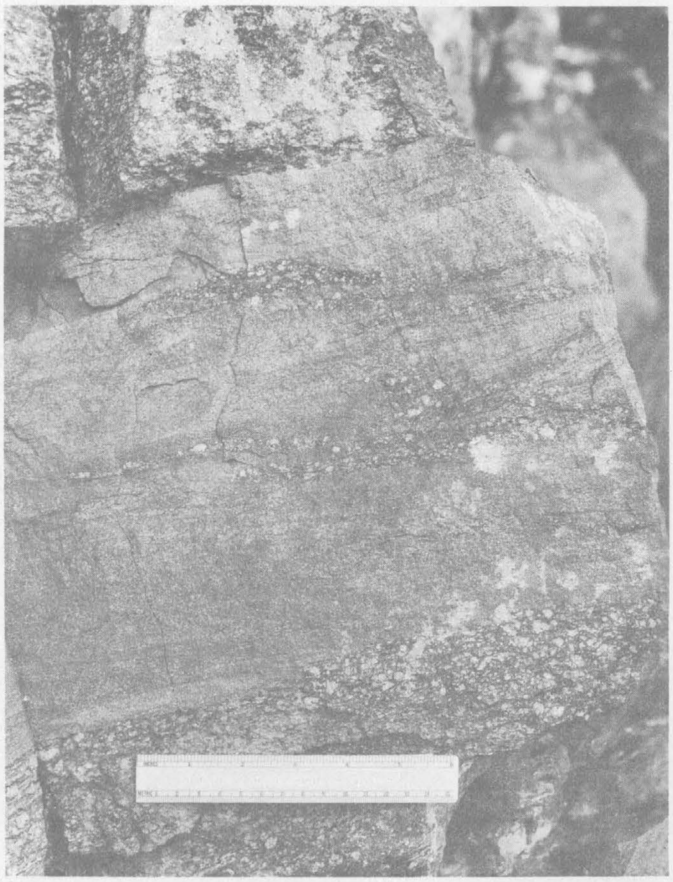
1. Biotite augen gneiss of Ravensford body, from road cut at Indian Reservation boundary, 1.2 miles north-northeast of Ravensford. Alined lenses of felsic minerals with augen-shaped cross sections, mostly less than 5 mm in diameter, set in dark schistose biotitic matrix. Polymetamorphic, inequigranular texture; average grain size, 1.5 mm. Felsic lenses consist of plagioclase with subordinate amounts of quartz and microcline, all flecked with fine-grained mica and epidote. Much epidote also in mafic clusters with olive biotite and sphene. Intersecting zones of sheared quartz and biotite are present.
2. Coarse augen gneiss from abandoned railroad grade 0.2 mile northwest of Beech Gap in Straight Fork window. Augen, with a maximum diameter of 1 in, consists of orange-pink microcline and subordinate amounts of quartz and plagioclase; Greenish-black micaceous matrix consists of biotite, fine-grained quartz, feldspar, and accessory minerals. Microcline encloses all minerals except epidote and sphene which are restricted to the matrix. Muscovite is most abundant near margins of augen. Slight late cataclasis.
3. Coarse aguen gneiss from truck road at 3,520 ft elevation east fork of Evans Branch, near Maggie, Dellwood quadrangle. Microcline augen are 3 cm in maximum dimension, and smaller lenticles and augen of quartz, microcline, and plagioclase are surrounded by streaks and clusters of biotite and epidote. Muscovite occurs mainly with microbrecciated quartz along late shears.

Many outcrops of the Ravensford body contain discontinuous layers of moderately fine-grained rock that represent inclusions of metasedimentary material. Such inclusions, an inch or two thick and several feet long, occur throughout the Ravensford body but are especially common in the western part. Larger inclusions, as much as 25 feet thick and several hundred feet long, are present in several places, notably in large outcrops about 100 feet above the railroad grade 1.6 miles due east of the summit of Becks Bald (fig. 4*A*). Many of these inclusions consist of subequal amounts of quartz and potassium feldspar with minor amounts of biotite or epidote. More quartzose types contain 75 or 80 percent quartz and were probably sandstone; others contain abundant muscovite and may represent sandy shale.

Inclusions of dark amphibolite and biotite schist also are present at several places in the Ravensford body. In an excellent exposure on the west slope of Hyatt Ridge about 500 feet west of the north corner of the Indian Reservation boundary north of Big Cove, a slablike body of amphibolite, 5 feet thick and 25 feet long, is concordantly enclosed in dark knotted gneiss. The amphibolite is composed largely of dark blue-green hornblende smaller than 1 mm (table 4, analysis 6). It is much fractured and the cracks are filled with dikelets of light-colored medium-grained biotite-epidote quartz diorite (analysis 8). Biotite schist (analysis 7) forms a discontinuous shell less than a foot thick between amphibolite and the knotted gneiss and is the only rock present in smaller inclusions within the gneiss. It seems to have been derived from amphibolite by more or less direct conversion of hornblende to biotite. The adjacent knotted gneiss contains much more plagioclase and less quartz than the normal gneiss (analysis 9).

DELLWOOD-CHEROKEE BELT

Plutonic rocks of the southeastern part of the report area, from the Dellwood quadrangle southwestward to the vicinity of Cherokee, are similar to those previously described. They include about equal amounts of coarse biotitic augen gneiss and more evenly textured flaser gneiss, so intermingled in many places that systematic separation on the scale of the geologic map (pl. 1) was not feasible. Some of these rocks also have textures and compositions transitional to the micaceous gneiss of the Carolina gneiss, and the contact between the two units is marked by a transitional zone of varying width containing rocks of doubtful classification.



A. Metasandstone in gneiss of the Ravensford body, north end of Big Cove. Southwestward-facing joint showing tongues of augen gneiss and isolated porphyroblasts of feldspar in metasandstone. The lower part of the ledge is typical of the coarser northern phase of the Ravensford body.

B. Folded metasedimentary layers and pegmatite in augen gneiss, U.S. Highway 19, 3 miles west of Soco Gap.

FIGURE 4.—METASEDIMENTARY INCLUSIONS IN AUGEN GNEISS OF THE BASEMENT COMPLEX

FLASER AND AUGEN GNEISS

The flaser gneiss of the Dellwood quadrangle is medium-grained gray biotite-quartz-feldspar gneiss of somewhat uneven grain. It is characterized by quartz-biotite folia of metamorphic origin separating quartz-feldspar lenticles, 1–6 mm wide and several centimeters to several decimeters long. The lenticles in some rocks are so long as to give them a ribboned appearance. In the more mafic varieties, the folia form a continuous network. In some places the flaser gneiss shows indistinctive layering, probably not metamorphic, resembling layering in the biotite gneisses of the Carolina gneiss. Most flaser gneiss has the composition of granodiorite or quartz monzonite, with varied amounts of mafic minerals (fig. 2).

The augen gneiss is similar to flaser gneiss except for its prominent augen of potassium feldspar enclosed in curved quartzose and micaceous folia. Parts of the gneiss contain few or small augen, but much of it contains such large and abundant augen that it has the appearance of very coarse granite. In typical augen gneiss, cream-colored or white subhedral crystals of potassium feldspar are set in a dark schistose matrix of quartz, plagioclase, and biotite (fig. 3*B*). Most of it represents coarse porphyritic or porphyroblastic rock that has been strongly sheared and recrystallized. In some augen gneiss, however, the augen consist merely of less sheared aggregates of feldspar, quartz, and mafic minerals without conspicuously large feldspar crystals, and these rocks grade into flaser gneiss.

The largest areas of augen gneiss are southeast of Buck Mountain and Setzer Mountain on the high ridge extending southwest from Purchase Knob and on the ridge trending north-northeast from High Top. The augen gneiss is more massive and resistant to erosion than the associated flaser gneiss and crops out in large ledges well up on the slope three-fourths mile southwest of Maggie, on the middle and upper slopes of the high ridge southwest of Purchase Knob, and in the stream at the base of the west slope of Walker Bald. Elsewhere augen gneiss forms scattered ledges among outcrops of flaser and granitic gneisses. In the belt of plutonic rocks northwest of Buck Mountain, augen gneiss occupies long vaguely defined areas in flaser and granitic gneisses and is most abundant along the borders of the belt.

The flaser and augen gneisses of the Dellwood-Cherokee belt consist of quartz, plagioclase, microcline, and biotite with minor epidote, muscovite, and sphene, and traces of apatite, allanite, and magnetite (table 6, analyses 1–8). Plagioclase, ranging from sodic oligoclase to sodic andesine, is the dominant mineral in most specimens studied microscopically. Microcline is abundant in the augen gneiss but varies widely in proportion to plagioclase in the flaser gneiss, some of which contains little potassium feldspar and is similar in composition to some of the biotite gneiss in the Carolina gneiss. Biotite, generally olive-brown, ranges from about 5 percent in the augen gneiss and lighter colored varieties of flaser gneiss to 10 percent or more in the darker flaser gneiss and is accompanied by substantial amounts of epidote.

TABLE 6.—*Modal composition of plutonic rocks, Dellwood-Cherokee belt, eastern Great Smoky Mountains*

	1	2	3	4	5	6	7	8	9	10	11	12	13
Quartz	25	35	44	35	28	25	30	28	35	35	32	30	35
Plagioclase	54	33	25	23	37	32	37	34	30	23	14	15	10
Potassium feldspar	8	19	21	35	17	28	22	21	29	34	47	50	50
Muscovite	-------	Tr.	2	-------	-------	Tr.	1	4	Tr.	2	6	1	1
Biotite	9	8	6	6	13	11	8	9	5	3	1	1	3
Epidote	3	3	Tr.	1	4	2	2	1	Tr.	1	0	1	Tr.
Sphene	1	Tr.	Tr.	Tr.	1	1	Tr.	1	Tr.	1	Tr.	-------	-------
Iron oxide	Tr.	Tr.	1	Tr.	Tr.	-------	-------	-------	Tr.	Tr.	Tr.	Tr.	Tr.
Apatite	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	-------	-------	Tr.
Allanite	-------	Tr.	-------	Tr.	Tr.	1	-------	-------	Tr.	1	-------	Tr.	1
Hornblende	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
Zircon	-------	Tr.	-------	-------	-------	-------	-------	Tr.	Tr.	-------	-------	Tr.	Tr.
Garnet	-------	-------	-------	-------	-------	-------	-------	-------	Tr.	-------	-------	-------	-------
Composition of plagioclase	ol	An_{27}	ol	ol	An_{24}	An_{32}	An_{31}	An_{26}	An_{26}	ol	An_{28}	ol	ol

1. Flaser gneiss, Sugar Cove, Dellwood quadrangle.
2. Flaser gneiss, Fie Creek, Dellwood quadrangle.
3. Light-colored flaser gneiss, Messer Branch, Dellwood quadrangle.
4. Light-colored flaser gneiss, Moody Branch, Dellwood quadrangle.
5. Finer grained augen gneiss, Johnson Gap, Dellwood quadrangle.
6. Finer grained augen gneiss, Moody Branch, Dellwood quadrangle.
7. Coarse-grained augen gneiss, Evans Branch, Dellwood quadrangle.
8. Coarse-grained augen gneiss, Evans Branch, Dellwood quadrangle (weight percent, calculated from analysis 3, table 5).
9. Granitoid gneiss, Johnson Gap, Dellwood quadrangle.
10. Granitoid gneiss, Fie Creek, Dellwood quadrangle.
11. Granitoid gneiss, Wrights Creek, Whittier quadrangle.
12. Dike, Evans Branch, Dellwood quadrangle.
13. Dike, Evans Branch, Dellwood quadrangle.

These minerals are arranged in a dominantly granoblastic and cataclastic fabric revealing complex crushing recrystallization, and replacement. The large microcline crystals in the augen gneiss are commonly carlsbad twins with irregular boundaries and grains of biotite, quartz, plagioclase, epidote, and muscovite included within their margins. Microcline also forms highly embayed grains in the flaser gneiss and in the matrix of the augen gneiss. Plagioclase forms anhedral grains, as much as 2 mm in diameter, enclosing muscovite, biotite, and quartz. Plagioclase adjacent to microcline grains is commonly myrmekitic and more sodic than elsewhere in the rock. In microscopically cataclastic rocks, part of the plagioclase contains patches of microcline suggesting that it has been partly replaced by potassium feldspar. The quartz occurs in several different textural elements, notably granoblastic aggregates with feldspar, fine-grained mosaics produced by crushing of larger grains, and lenticles a few millimeters long of coarser grained quartz. The mafic minerals in the rock together with fine-grained quartz and feldspar, form a network between the larger feldspar grains and the quartz-feldspar aggregates. Biotite, epidote, magnetite, and sphene occur together in mafic aggregates much as in the coarser plutonic rocks in the Pigeon River area. Most of the epidote occurs in relatively large dark grains, many of which are coated with paler epidote probably of later generation. Allanite grains, abundant in some specimens, are similarly coated. Sphene occurs mainly in the mafic aggregates as individual grains and as fine-grained aggregates. Muscovite occurs sparsely in the mafic aggregates, scattered through the feldspars, and in small-scale shear zones.

GRANITOID GNEISS

Medium-grained weakly foliated rocks having granitoid texture and the composition of quartz-monzonite or granite form homogeneous bodies, 250–500 feet wide, and thinner bodies intercalated with flaser and augen gneiss. These rocks are prevalent in the central part of the belt of plutonic rocks northwest of Buck Mountain and in the Soco-Cherokee belt. They are also prominent above the Carolina gneiss along Campbell Creek and in areas near Whittier and Cherokee. They are well exposed in many cuts along the North Carolina Highway 19 west of Soco Gap.

The granitoid gneiss consists largely of microcline, quartz, and oligoclase in order of decreasing abundance, with minor amounts of biotite and muscovite, and traces of epidote, sphene, opaque oxides, apatite, and allanite (table 6, analyses 9–11). Indistinct layers are marked by variations in the amount of biotite, which is generally dispersed through the rock but is locally concentrated in thin discontinuous streaks. Some granitoid gneiss shows indistinct flaser structure and thus grades toward the light-colored varieties of flaser gneiss, and some contains small porphyroblasts of potassium feldspar like those in the augen gneiss. Some contains small clots of biotite, epidote, and magnetite in parallel rows resembling hornblendic quartz-plagioclase geneiss of the Carolina gneiss.

GRANITE AND PEGMATITE

Dikelike bodies a few feet thick of leucocratic granite cut flaser, augen, and granitoid gneisses, especially in the Soco-Cherokee belt and near Maggie. The granite is unevenly grained, locally pegmatitic, and indistinctly foliated. It consists mainly of potassium feldspar and quartz with subordinate amounts of oligoclase and less than 3 percent mafic minerals, mainly biotite (table 6, analyses 12, 13). The walls of these bodies are subparallel to foliation in the enclosing gneiss and their foliation, where present, is continuous with that in the gneiss.

Lenses and irregular bodies of granite pegmatite are common in parts of the basement complex but are nowhere abundant. In the Dellwood area, they range from a few inches to a few feet in width and are generally discordant to the enclosing rocks. Many are weakly foliated and all are deformed concordantly with the surrounding rocks. Potassium feldspar, commonly pink or flesh-colored, is the dominant constituent, with subordinate plagioclase and quartz and scarce biotite and garnet. Secondary epidote is common in some of the more sheared pegmatites.

BOUNDARY RELATIONS

In most places, no sharp or easily determined boundary exists between the plutonic rocks and the Carolina gneiss; rather the plutonic rocks are bordered by a variable zone in which migmatitic and grosser compositional layers become gradually more distinct and the rocks become less granitic and more heterogeneous. In the valley of Campbell Creek in the southwestern part of the Dellwood quadrangle and adjacent areas, augen and flaser gneiss grade downward, through granitoid gneiss with subordinate layers of biotite-quartz-feldspar gneiss, into biotite-quartz-feldspar gneiss and honblendic gneiss of the Carolina (fig. 5). A similar relation exists northeast of Middle Top. In the valley of Hemphill Creek southeast and east of Purchase Knob, plutonic rocks intertongue with the Carolina gneiss. Locally, however, as northeast and east of High Top and between Hemphill Creek and the top of Purchase Knob, augen gneiss cuts sharply across the Carolina gneiss. These crosscutting contacts are probably old faults, as suggested by the nearby presence of dark ribbon gneiss that may represent recrystallized mylonite.

Within the plutonic rocks of the Dellwood-Cherokee area, especially in the belt extending southwest from the vicinity of Purchase Knob, many small bodies of amphibolite, garnet amphibolite, biotite amphibolite, hornblende-biotite gneiss and schist, hornblende-bearing granofels, biotite-epidote gneiss, and mica-quartz-feldspar gneiss represent isolated parts of the Carolina gneiss. They appear as concordant layers, lenses, and pods, as much as several feet thick in the more homogeneous plutonic rocks (fig. 4*B*).

MIGMATITE

Much of the Carolina gneiss, especially near the area of plutonic rocks, contains abundant granitic material or leucocratic mixtures of quartz and feldspar of varying composition and is classed as migmatite. This material generally forms sharply bounded layers or lenses—a few inches to a foot thick—in biotite, hornblende, or quartzose gneiss, but some of it is in irregular bodies with either sharp or gradational contacts against the enclosing rocks. Conversely parts of the plutonic rocks contain abundant inclusions or wisps of preexisting gneiss and are also classed as migmatite. The migmatite was probably produced by a combination of processes including metamorphic differentiation, metasomatism, anatexis, and magmatic injection. The relative importance of these processes varies from place to place, but the migmatite seems to have formed by complex metamorphic processes rather than by simple injection of magma from an outside source.

Most of the granitic layers and lenses in the micaceous gneisses are a few inches to a foot thick and subparallel to foliation in the enclosing rocks. The material in them is leucocratic, coarser grained than the enclosing gneiss, and commonly bordered by selvages of biotite ranging from seams to layers an inch or more thick (fig. 6*B*). More rarely the granitic material occurs as irregular patches with gradational boundaries cutting across the foliation and layering of the enclosing rock. Toward the margins of migmatitic areas, the granitic lenses become smaller and more widespread, similar to quartz-feldspar lenticles that have been produced by mechanical and metasomatic segregation during metamorphism.

The composition of the material in the granitic layers varies with that of the host rock. For example, in hornblende gneiss and amphibolite (fig. 6*C*) it generally consists of about 80 percent sodic andesine and 20 percent quartz with minor biotite, hornblende, and garnet. Similar layers in migmatitic biotite gneiss commonly contain about 30 percent quartz, 35 percent oligoclase,

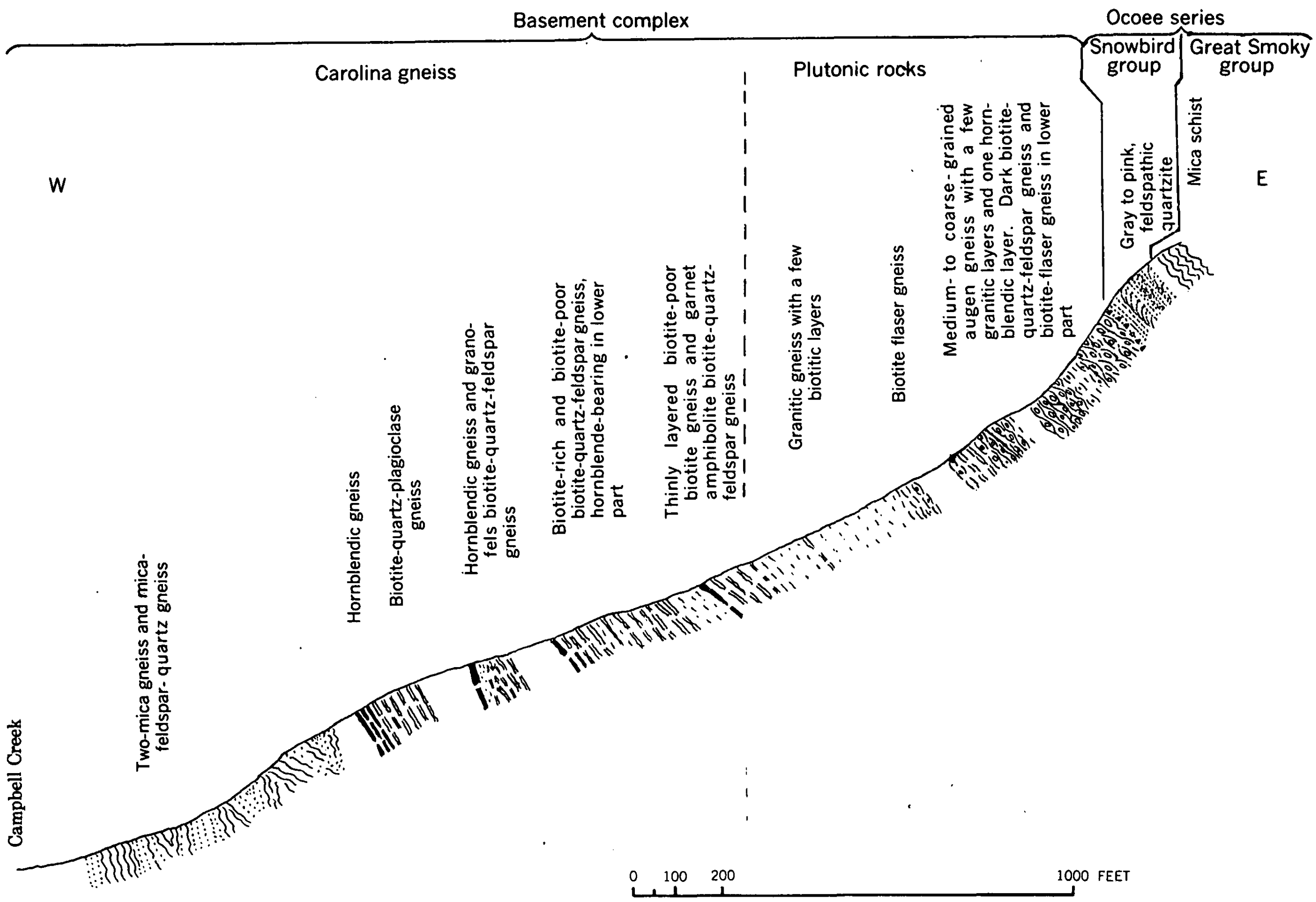


FIGURE 5.—Section of basement complex and overlying rocks east of Campbell Creek, 1.5 miles southwest of Maggie, Dellwood quadrangle.

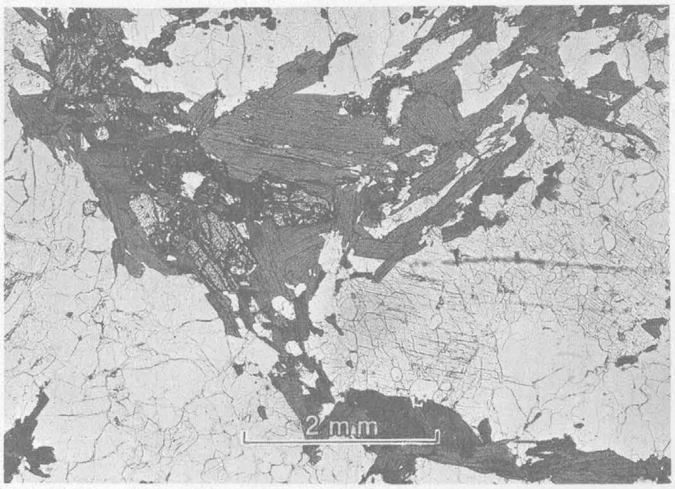
25 percent potassium feldspar, and a little biotite. In mica-feldspar-quartz gneiss the layers consist of about 30 percent quartz, 2 or 3 times as much potassium feldspar as plagioclase, and 2 or 3 percent biotite. This degree of dependence upon the host rock suggests to us that the granitic layers were derived from local sources rather than from a distant common magma, even granting the possible effects of assimilation. Many granitic layers, however, contain sufficiently more potassium feldspar or more albite than their host rocks so that considerable transfer of alkalies must have occurred in their formation.

Granitic layers in migmatites are notably coarser than the enclosing gneisses and many small irregular granitic bodies show a patchy coarsening and irregular distribution of minerals including most of those found in the enclosing rock. This is particularly true of amphibolite, where the spread of granitic material was governed by fractures to a greater extent than elsewhere, and of contorted gneiss where it spread in the crests of minor folds. Such material might be thought to represent a palingenetic liquid that has penetrated the host rock. Such an origin does not seem compatible, however, with the varied composition of the material, which is commonly far from the expected eutectic mixture of quartz and alkalic feldspar.

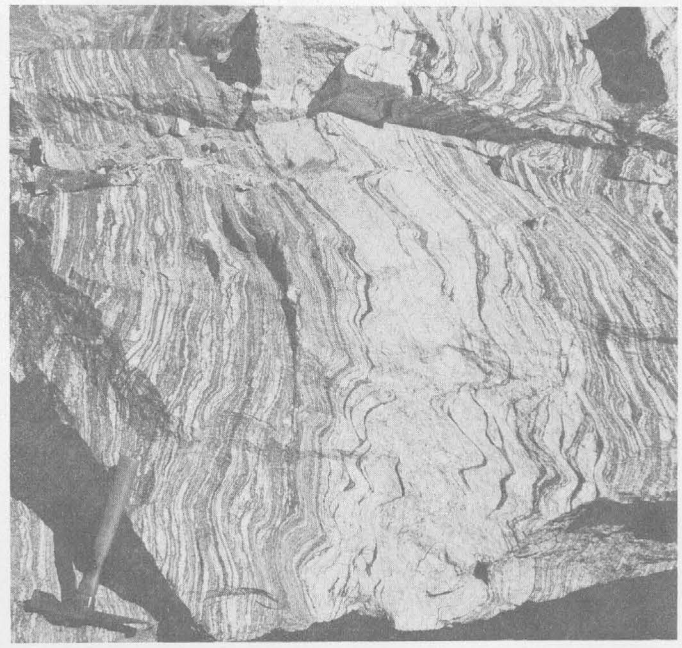
ELA AND BRYSON AREAS

Basement rocks are exposed in an area of 2 by 5 miles near Ela on the Tuckasegee River. Fresh rock and saprolite are well exposed in many places along U.S. Highway 19.

The basement rocks of the Ela area are extremely varied and include almost every type found in the Dellwood quadrangle and the Soco-Cherokee belt. Plutonic gneisses, including biotite flaser gneiss and minor bodies of coarse augen gneiss, are prevalent in the northwestern half of the area, although flaser gneiss is less abundant than farther northeast. Among these rocks are small bodies of hornblende-biotite schist and actinolite schist presumably derived from ultramafic rocks.



A. Photomicrograph of cluster of biotite, epidote, and sphene in biotite-quartz-feldspar gneiss.



B. Migmatitic biotite-quartz-plagioclase gneiss; lightest colored layers are quartz and feldspar of migmatitic origin; darker layers are metasedimentary. Darkest layers, thin and discontinuous, are segregations of biotite marginal to quartz-feldspar layers. Quarry on Pigeon River 2½ miles east of Cove Creek.

C. Migmatitic hornblende gneiss. White plagioclase-rich layers intercalated with dark layers of biotite, hornblende, and small plagioclase porphyroblasts. Purchase Knob, Dellwood quadrangle.

FIGURE 6.—MIGMATITE AND MAFIC CLOTS IN CAROLINA GNEISS

In the eastern part of the area, hornblende and biotite gneisses characteristic of the Carolina gneiss are common and in the vicinity of Birdtown are abundant enough to be shown on plate 1. Many of these rocks are dark layered hornblende gneiss, biotite-quartz-feldspar gneiss, and light-colored quartz-plagioclase granofels containing typical clots of hornblende or biotite and epidote. Less abundant and mostly enclosed within the plutonic gneiss are garnet-biotite gneiss, diopside-bearing hornblende gneiss, and two-mica gneiss, similar to rocks of the Carolina gneiss.

A second area of granitic rocks, larger than the Ela area but of similar shape, occurs near Bryson City on the southwest edge of the report area. These rocks were mapped and studied by Cameron (1951, p. 10) who described them as "fine- to coarse-grained, equigranular to markedly inequigranular, leucocratic and mesocratic gneisses ranging in composition from granitic to granodioritic." Fine- to coarse-grained dark-green to black rocks characterized by hornblende, biotite, or both are described as occurring throughout the granitic complex, and metaperidotite is noted in two thin belts near its margin. A bordering gneiss, 50 to 200 feet thick around the northern part of the complex,

> consists of microcline or composite quartz-feldspar porphyroblasts and augen ⅛ inch to 1½ inches in length set in a medium- or coarse-grained matrix of biotite, quartz, and feldspar * * * Most large outcrops of the granitic gneisses show layers or lenses of material rich in biotite or, less commonly, hornblende. These layers range from biotite-rich granite gneiss to biotite or biotite-hornblende schist. Gradations between the two extremes are exposed in a large number of places * * *. The endless repetition of such features observed * * * indicates that mixed rocks formed from the biotitic and hornblendic gneisses are an important part of the complex.

Small bodies of leucogranite, fine-grained granite, and granite porphyry, as well as a large number of pegmatites are described as cutting both the gneiss of the complex and the surrounding metasedimentary rocks of the Great Smoky group. Because of these relations, Cameron (1951, p. 19) concluded that "the granitic rock of the area are younger than the [surrounding] metasedimentary rocks."

These rocks were examined by us but were not remapped, except for a small modification northeast of Bryson City. Cameron's mapping and description are excellent, and the rocks will not be described again here. When compared with rocks of the basement complex farther northeast, however, it appears to us that much of the granitic rock of the Bryson area belongs to the Precambrian basement complex and is therefore older than the highly metamorphosed Ocoee rocks which surround it. As this conclusion is based partly on considerations of regional structure and metamorphism described in subsequent pages, further discussion of the rocks of the Bryson area is deferred.

PRE-OCOEE HISTORY OF THE BASEMENT COMPLEX

The composition and distribution of the rocks of the basement complex seem to have been well established before the deposition of the Ocoee series, despite the fact that much of their present texture and minor structure resulted from post-Ocoee orogeny. The older features of the complex indicate that a thick sequence of sandy, argillaceous, and in part calcareous or volcanic sedimentary rocks was metamorphosed and transformed progressively northwestward into more granitic rocks. The abundant migmatite and the mobile type of deformation associated with it suggests that the process took place near the zone of remelting. Metamorphic segregation of felsic materials and migration of sodium and potassium seem to have been the dominant processes involved in this phase of reconstitution, to which may be ascribed the prominent biotite, epidote, and sphene in many of the rocks. Zircon, however, seems to be related to the entrance and distribution of granitic materials, for it occurs principally in the plutonic rocks of the complex.

The plutonic rocks, now metamorphosed to augen and flaser gneisses, were originally less gneissic, and some of them may represent intrusions of granitic or quartz-monzonitic magma into the metamorphic and migmatitic rocks. If so, later deformation and metamorphism has obliterated their intrusive contacts, and the only demonstrably intrusive rocks in the complex are the few granite and pegmatite dikes. On the other hand, many features suggest that the plutonic rocks were produced by granitization of preexisting metamorphic rocks. Such an origin is suggested by the porphyroblastic texture and gradational boundaries of the augen gneiss and also by the similarity in composition between parts of the flaser and granitoid gneisses and the biotite-quartz-feldspar gneiss of the Carolina. Most inclusions in the plutonic rocks are delicate concordant bodies whose relation to the enclosing rocks indicates that they have resisted transformation rather than that they are blocks disrupted mechanically from the country rock by intrusion. Thus they may represent the least modified parts of the sedimentary terrain in the area of dominant plutonic rocks; the dark knotted gneiss of the Ravensford body, the coarse augen and flaser gneisses, and the granitoid gneiss represent intermediate stages; and the granite and pegmatite dikes the ultimate of this plutonism.

The age of the pre-Ocoee metamorphism and plutonic crystallization of the basement complex is known only from studies of radioactive minerals and so far is beset with a good deal of uncertainty. Evidence available at present, mostly from the Blue Ridge province considerably northeast of the Great Smoky Mountains, suggests that the basement rocks throughout a large area were formed about a billion years ago (Davis, and others, 1958), or about the same time as the metamorphic crystallization of the Grenville series in the Adirondack Mountains (Engel and Engel, 1958, p. 1044). The attempt to fix this date and to define the rocks that were formed then is, however, complicated by widespread effects of post-Ocoee (early Paleozoic) regional metamorphism upon the indicator minerals, mainly zircon and micas.

A few lead-alpha measurements made on zircon samples from the Great Smoky region indicate ages ranging from 535 to 1,140 million years. A zircon sample from the plutonic rocks of the basement complex (Max Patch granite of Keith) on Max Patch Mountain a few miles northeast of the present report area was estimated to be 880 million years old (Carroll, Neuman, and Jaffe, 1957, table 5, 187). Another sample, collected by us from granitoid gneiss in the Dellwood quadrangle and analyzed in the Survey laboratory, was estimated to be 535 million years old (457–472 alphas per mg per hour; 102–205 ppm Pb). Lead-alpha measurements made on samples of several different morphological types of zircon recovered from sandstones of the Great Smoky group in the western Great Smoky Mountains and analyzed in the Geological Survey laboratory indicated ages ranging from 620 to 1,140 million years (Carroll, Neuman, and Jaffe, 1957, p. 187). These zircon samples presumably were derived from basement rocks similar in age to those now exposed in the area, which therefore may contain rocks more than a billion years old. The lower figures may be due to varied loss of lead caused by regional metamorphism or to other factors as yet unknown. Unfortunately no studies were made of the isotopic ratios in the zircon samples from the Great Smoky Mountains, and the significance of the lead-alpha measurements is debatable.

OCOEE SERIES

The metasedimentary rocks of the eastern Great Smoky Mountains belong mainly to the Ocoee series of late Precambrian age, a thick mass of clastic rocks which occupy large areas in eastern Tennessee, western North Carolina, and northwestern Georgia and were first described by Safford (1856, p. 151–152; 1869, p. 183–198). Although first subdivided into formations by Keith (1895), further study of the lithology and stratigraphic succession of the Ocoee series has been a major part of the present investigations, the stratigraphic results of which are summarized by King and others (1958). The Ocoee series is now divided into three major groups, each including a number of formations (table 1). Two of these groups, the Great Smoky and Snowbird Groups, are prominent in the present report area, and rocks of the third, the Walden Creek group, appear at its north edge.

In the northern part of the foothill belt, formations of the Ocoee series are overlain by the Chilhowee group of Cambrian and Cambrian(?) age. These rocks appear only at the north edge of the area of this report, where they are in fault contact with the Ocoee series.

The rocks of the Ocoee series are variably metamorphosed. Argillaceous and other pelitic rocks have become slate, phyllite, or fine- to medium-grained micaceous schist; finer grained sandstone and the matrix of coarser sandstone and conglomerate have been thoroughly recrystallized. Nevertheless, many sedimentary features of bedding and texture remain and are the most useful means of classifying and describing the rocks in much of the area. Therefore, such sedimentary rock terms as "sandstone," "arkose," "graywacke," "conglomerate," and "pelite" are used, especially in the stratigraphic sections of the report. The prefix "meta" is used, however, where the metamorphic nature of the rock needs to be emphasized, as in "metapelite" or "biotitic metasandstone" (to indicate that the biotite is metamorphic rather than detrital). Because the finer grained and argillaceous rocks are more completely reconstituted, the metamorphic terms "slate," "metasiltstone," "phyllite," "argillite," and "schist" are generally used for them. The term "quartzite" is used for metamorphosed quartz sandstone in which the matrix is dominantly silica rather than a mixture of quartz, feldspar, and mica. The prefix "meta" is omitted from the formal name Pigeon siltstone to keep a simpler nomenclature.

SNOWBIRD GROUP

DEFINITION

The Snowbird group corresponds to the Snowbird formation of Keith (1904, p. 5), named for Snowbird Mountain in the northeastern part of the present report area. The formation is described by him as consisting of

> fine and coarse quartzite with interstratified beds of quartz-feldspar conglomerate and arkose and subordinate layers of gray and black slate. Throughout the region it rests in its normal position on the Archean rocks and is the first sedimentary deposit thereon. Materials derived from the granite make up the formation to a large extent.

Rocks of the Snowbird group appear in a broad belt extending from the type area on Snowbird Mountain westward along the front of the Great Smoky Mountains and southward into the eastern part of the report area. This belt includes the type localities of the four formations among which the rocks of the Snowbird are now divided and will be referred to as the type belt of the Snowbird group. Rocks of the group are also exposed in the Straight Fork window and in four other belts in the southeastern part of the area. The largest belt extends 20 miles from the northern part of the Dellwood quadrangle southwestward along the Cataloochee Divide and the north side of the valley of Soco Creek to the village of Cherokee. Another well-defined belt extends from Shelton Laurel at the east edge of the map area southwestward across the Pigeon River, along Stevens Creek and the southeastern slopes of Piney Mountain, and across North Carolina Route 284 northwest of Cove Creek Gap. Two much smaller belts are on Hurricane Mountain north of Shelton Laurel.

The stratigraphic succession of the group in the type belt is best observed in the vicinity of the Pigeon River where a complete and easily accessible section is exposed along the road and the river from Harmon Den Mountain to Waterville and along Big Creek from Waterville to Mount Sterling village. Four formations are recognized in this section, from oldest to youngest, the Wading Branch formation, Longarm quartzite, Roaring Fork sandstone, and Pigeon siltstone. These formations are closely related in lithology, stratigraphic relations, and origin both to each other and to the basement rocks from which, as Keith observed, they have been directly derived.

WADING BRANCH FORMATION

DEFINITION

The name Wading Branch formation is given (King and others, 1958, p. 954) to a distinctive unit in the lowermost part of the type belt of the Snowbird group. The formation is named for Wading Branch Ridge northwest of Walters Lake, and the 1,500 foot interval of dark fine- to coarse-grained poorly sorted clastic rocks exposed in road cuts along the Pigeon River just west of Harmon Den Mountain constitute the type section. The Wading Branch formation is also well exposed along the east bank of the Pigeon River southeast of the narrow belt of basement rocks and along various lumber roads west of the river and north of Wading Branch Ridge.

TYPE AREA

The main part of the Wading Branch formation in the type area consists of medium- to dark-gray clastic rocks ranging from sandy slate to very coarse pebbly sandstone. The coarse beds contain abundant quartz and feldspar sand and small pebbles in a dark micaceous matrix. The finer beds and the matrix of coarser beds consist of recrystallized quartz and feldspar sand and silt, together with abundant metamorphic muscovite and biotite. Except where strongly folded, individual beds are fairly distinct and range in thickness from a few inches to several feet. Thick beds are irregularly graded, coarse-sandstone grading upward into finer sandstone and metashale; however, the coarser fraction may be more sparsely and irregularly distributed throughout individual beds. Rarely lenses or pockets of coarse well-sorted sandstone are enclosed in slate or metasiltstone, and small detached slabs or lenses of argillite occur in the sandstone. Such contrasts of texture are exceptional, however, and gradual changes in grain size and composition characterize the transition between most beds.

The basal part of the formation in the type section consists of pale-green quartz-sericite schist or phyllite, rather uniform in composition but commonly revealing thin indistinct sandier layers. This rock is resistant to erosion and forms prominent outcrops by which the unit can be traced in much of the area. The quartz ranges from fine sand to granule size and at one place abundant quartz pebbles occur in a matrix of schist (fig. 7*A*). Alkalic feldspar is present also, but the basal schist is distinctly less feldspathic than other parts of the formation. Moderate amounts of chlorite color the rock green, and, locally, small porphyroblasts of chloritoid, garnet, or magnetite are present.

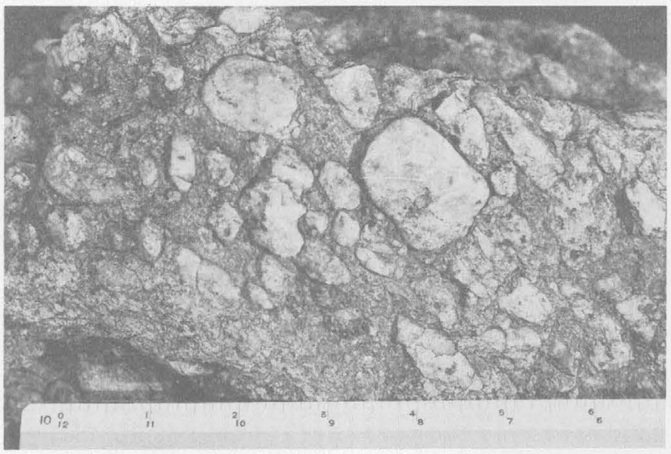
OTHER AREAS

The Wading Branch formation is especially prominent in the belts of the Snowbird group south of the Greenbriar fault near Hurricane Mountain and Piney Mountain. Two of the belts on Hurricane Mountain consist entirely of rocks of the Wading Branch; the basal phyllite, much repeated by minor folding, occupies nearly all the eastern belt and much of the western. Coarser clastic rocks higher in the formation occur in both belts, but most of the higher beds in the formation have been cut out by the adjacent faults.

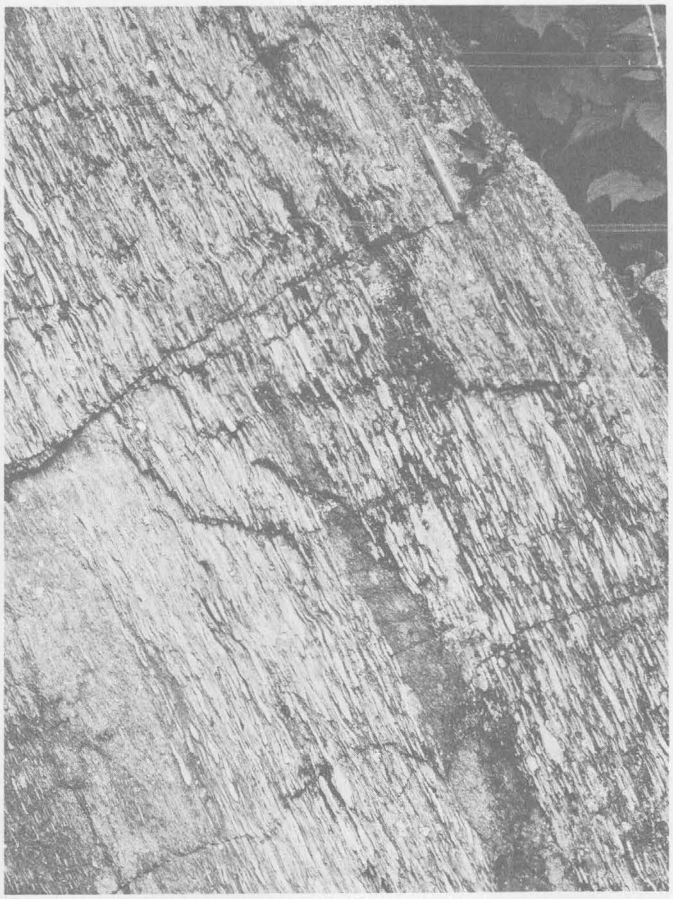
More of the Wading Branch is preserved in the third belt, extending southwestward from Shelton Laurel. In this belt the basal phyllite forms conspicuous outcrops adjacent to the gneiss of the basement complex. The phyllite is typically light greenish gray with sandy laminae and contains a few lenses of quartz-pebble conglomerate near its base. Small porphyroblasts of chloritoid or garnet appear in it here and there, and porphyroblasts of chlorite or magnetite locally give the rock a spotted appearance.

Darker and coarser clastic rocks similar to those in the type area occur above the basal phyllite in the Shelton Laurel belt. Exposures on the southeast side of Stevens Creek, 1½ miles southwest of the Pigeon River, show several hundred feet of dark-gray biotitic metasandstone, fine to very coarse grained, with lenses, 1–3 feet thick, of quartz pebble conglomerate (fig. 7*B*). The conglomerate beds and lenses consist of abundant white quartz pebbles in a matrix of coarse quartzose metasandstone; the pebbles are very much flattened but their intermediate diameters, mostly 2 inches or less, are probably close to the original diameters of the pebbles. Similar conglomerate and dark sandstone is exposed in the bed of Stevens Creek near its confluence with Walters Lake.

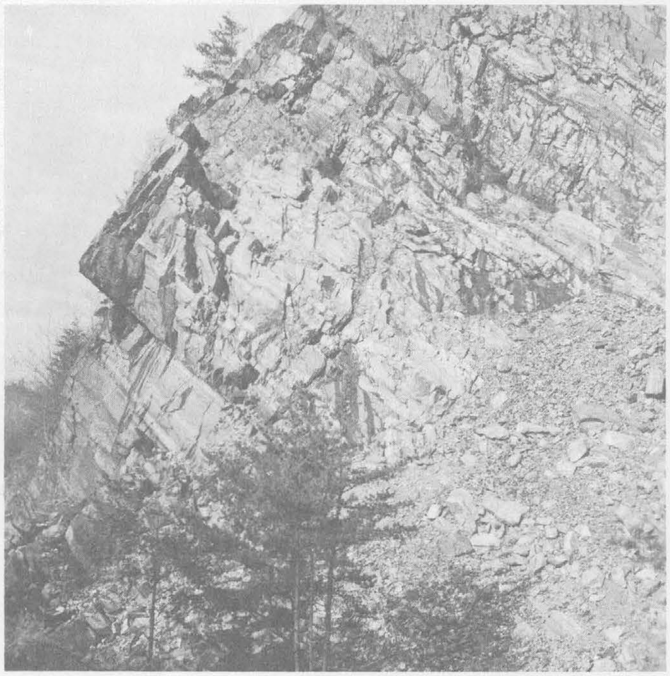
The Wading Branch formation in the Dellwood-Cherokee belt is a rather coarse silvery-gray quartz-mica schist that is dominantly muscovitic with a small amount of biotite. Quartz is abundant and commonly appears in small pods and lenses. Porphyroblasts of garnet and kyanite are commonly present and, more rarely, staurolite. In some places porphyroblasts of oligoclase have formed in such abundance that the rock is more gneissic than schistose. The schist forms moderate ridges where it is sufficiently thick, and it is so different from the adjacent basement rocks that it is an excellent marker of the base of the Snowbird group, even in this highly metamorphic terrane.



A. Quartz-pebble conglomerate, basal Wading Branch formation, southeast slope of Piney Mountain.



B. Quartz conglomerate in Wading Branch formation, showing extreme flattening of quartz pebbles. Knife in upper right is 2.2 inches long. Southeast of road, 1½ miles southwest of Walters Lake.



C. Longarm quartzite. View northeast showing light-colored feldspathic quartzite interbedded with dark metasandstone and metasiltstone in exposure 45 feet high. Quarry at Walters Dam.

FIGURE 7.—WADING BRANCH FORMATION AND LONGARM QUARTZITE

On Jenkins Divide, 5 miles east of Cherokee, the rocks of the Wading Branch resemble those on Stevens Creek, except that they are still more metamorphosed. About 200 feet of interbedded quartz conglomerate, quartzose metasandstone, and subordinate quartz-mica schist occur above the basal schist, which is here about 50 feet thick. Metasandstone beds, 8 inches to 2 feet thick, are dark biotitic and sparsely garnetiferous. The coarser beds are poorly sorted, but the coarser material commonly forms lenses in finer grained sandstone. As elsewhere, most of the pebbles are quartz, considerably flattened, and have a maximum original diameter of about an inch. Feldspar is scarce in the lower beds, but becomes more abundant in higher ones, which are more even grained, lighter colored, and resemble beds in the lower part of the overlying Longarm quartzite. West of Jenkins Divide, biotitic metasandstone is common in the Wading Branch formation, although the beds are thinner and conglomerate is absent.

The two belts of Wading Branch in the northwest part of the Straight Fork Window area contain rocks like the coarser clastic rocks in the Wading Branch of the Dellwood-Cherokee belt. Most of the belt exposed in Raven Fork at the foot of Enloe Ridge and between Highland Ridge and Breakneck Ridge is interbedded quartz-mica schist and biotitic quartzose metasandstone that locally contain quartz pebbles ½–¾ inch across. Muscovite-quartz schist with prominent porphyroblasts of garnet, staurolite, and biotite resembles the basal schist of other areas but here does not occupy the normal position next to the basement rock.

THICKNESS

In its type area between Harmon Den Mountain and the south end of Mine Ridge, the Wading Branch formation is repeated twice by folding and its thickness, estimated from structure sections, is about 1,500 feet. In this belt the folded basal phyllite forms an outcrop about 500 feet wide, but it is probably less than 100 feet thick.

The Wading Branch is much thinner in the belts southeast of the Greenbrier fault. In the Shelton Laurel area, as exposed on the road one-fourth mile west of the Redmond mine, about 250 feet of dark metasandstone interbedded with quartz-feldspar-mica schist overlies 170 feet of basal phyllite. Where the formation crosses North Carolina Route 284, the phyllite is about 300 feet wide, but the overlying beds are represented by only 100 feet of coarse pebble feldspathic sandstone. On Stevens Creek the apparent thickness of the formation is 700 feet, but the rocks are too much deformed for this estimate to be reliable.

In most of the Dellwood-Cherokee belt, along Soco Creek and Cataloochee Divide, the Wading Branch is between 50 and 100 feet thick; southeast of this belt, on Setzer and Buck Mountains, and the lower slopes of Walker Bald Mountain, it is less than 10 feet thick. It persists as a unit a few feet thick as far southeast as Dellwood, beyond which no Snowbird is present.

STRATIGRAPHIC RELATIONS

The Wading Branch formation lies directly on the basement rocks nearly everywhere in the report area. The contact between the basal phyllite and the basement complex is generally sharp; but locally in the Shelton Laurel belt south of the Pigeon River and in the Dellwood quadrangle northeast of Maggie, the basement complex and basal phyllite are separated by a few inches to a few feet of rock interpreted as remnants of regolith. This rock is dark, micaceous, medium to fine grained, generally finer than the basement gneiss but distinctly coarser than the overlying phyllite, with large grains of quartz and feldspar irregularly scattered through it. Although it contrasts sharply with the overlying phyllite, it grades into adjacent augen gneiss and flaser gneiss.

The contact between the Wading Branch formation and the overlying Longarm quartzite is gradational over several tens of feet in most places but is more abrupt than most of the formation boundaries in the Snowbird group. It is unusually so on the Pigeon River road near the south end of Mine Ridge, where the uppermost beds of the Wading Branch consist of fine-grained sandstone considerably different from the beds that normally occur at the top of the formation. Elsewhere the dark sandstone of the Wading Branch gradually becomes lighter colored and more feldspathic or is interbedded with light-colored arkose of the basal Longarm.

LONGARM QUARTZITE

DEFINITION

The Longarm quartzite (King and others, 1958, p. 954), which conformably succeeds the Wading Branch formation in the eastern part of the report area, consists of several thousand feet of clean feldspathic quartzite and arkose. It is named for Longarm Mountain in the northeastern part of the report area, and its type section is at the north end of the mountain where the formation is well exposed along the Pigeon River.

The Longarm quartzite is the most resistant of the formations of the Snowbird group and forms ridges such as Longarm, Whiteoak, and Noland Mountains, and much of Snowbird Mountain. Both the Longarm

Mountain belt and the Whiteoak Mountain belt are typical of the formation, and some of the best exposures are in the Whiteoak Mountain belt along the Pigeon River below Walters Dam. More weathered exposures are easily accessible along North Carolina Route 284 between Mount Sterling Gap and Cove Creek Gap.

TYPE AREA

The Longarm quartzite in the Longarm Mountain and Whiteoak Mountain belts consists largely of light-colored feldspathic quartzite and arkose; it is medium to very coarse grained and almost everywhere current-bedded. On fresh surfaces it is light to medium greenish gray (5*GY* 7/1 to 5*GY* 5/1) or light pinkish gray (5*YR* 7/1). It is conspicuously light colored in weathered outcrops and forms a distinctive light-colored sandy soil.

The coarser rocks of the formation consist of moderately well sorted arkose and feldspathic quartzite ranging in grain size generally from 1 to 4 mm, with grains as large as 10 mm in the coarsest beds. The conspicuous mineral components are subangular to well-rounded grains of colorless or bluish quartz and white or pink feldspar. Minor amounts of magnetite and metamorphic biotite are concentrated in thin bedding layers or seams parallel to current bedding. The finest fraction consists of recrystallized quartz and feldspar with few dark minerals.

Stratification in these rocks consists of multiple sets of cross beds ranging in thickness from a few inches to 3 feet (fig. 8, *A* and *B*). The sets range from tabular to wedge shaped and the cross strata from straight to concave (McKee and Weir, 1953). More rarely sets of convex cross strata occur. The sets combine to form bedding units which range in thickness from 1 or 2 feet to 50 feet, and which are separated from one another by finer grained commonly darker strata, in which current bedding is inconspicuous or absent (fig. 7*C*).

Current ripple marks are rarely present in the Longarm quartzite. In an exposure on the old railroad grade in the Pigeon River gorge 2,000 feet northwest of Walters Dam, ripples are preserved as molds in the overlying sandstone. They trend north-northeastward and have steeper sides toward the northwest.

Subordinate amounts of darker finer grained rocks are interbedded with quartzite and arkose throughout the formation (fig. 7*C*). These rocks are more abundant in the upper part of the formation than the lower and more abundant in the Longarm belt than in the Whiteoak belt. They range from fine-grained biotitic metasandstone to progressively darker metasiltstone, sandy slate, and feldspathic quartz-mica schist. They occur generally as regular beds less than a foot thick and locally in thicker units which are relatively massive or indistinctly layered. Boundaries between lighter and darker beds are gradational rather than sharply defined, a characteristic feature of the Snowbird group.

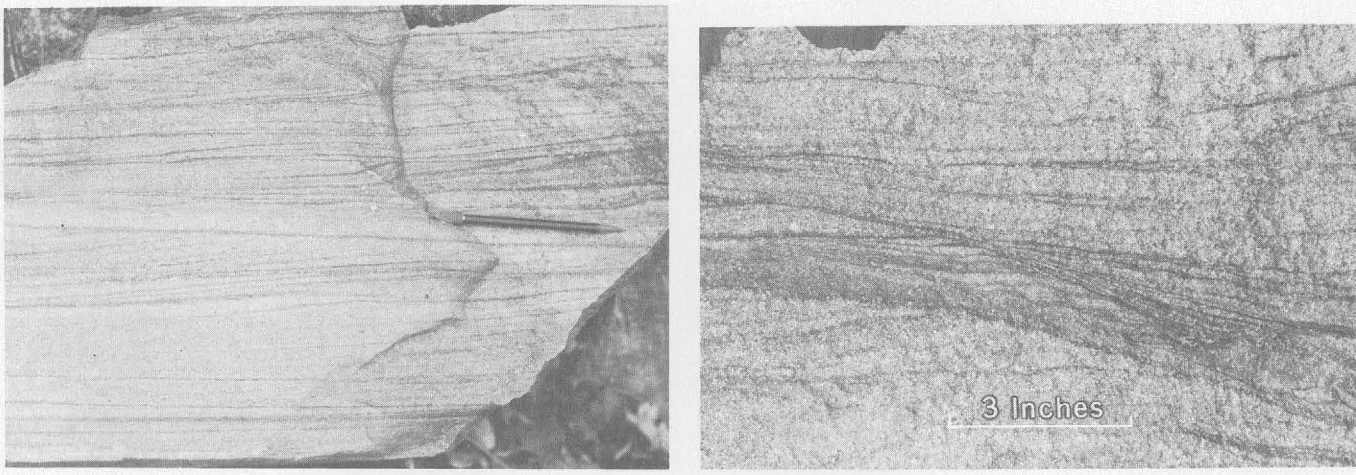
Folded bedding caused by slumping of the sediments before consolidation occurs here and there in the Longarm quartzite of the type area, especially in the Pigeon River gorge below Walters Dam. Small asymmetrical or overturned folds in thin-bedded sandstone were produced by higher beds sliding over lower ones in a westward or northwestward direction (figs. 8*C* and 9*A*).

In the thicker coarser grained rocks, especially in the Longarm Mountain belt, crossbeds are inclined 60°–80° to the normal bedding, which may or may not be folded (fig. 9*B*). In parts of the Longarm Mountain belt such steep crossbedding is much more apparent than the normal bedding and can be easily mistaken for it, especially in small outcrops. At many other places in the type area of the formation, the inclination of crossbeds, though not so steep, is considerably more than that considered normal for coarse to medium sand deposited under water (McKee, 1957, p. 130). The excessive steepness of these beds appears to be due to sliding in unconsolidated sand similar to that which produced folding in finer grained less homogeneous strata.

OTHER AREAS

The Longarm quartzite is prominent in three other areas—the Straight Fork window, Shelton Laurel belt, and Dellwood-Cherokee belt. In the Straight Fork window area and the lower part of the valley of Raven Fork, typical light-colored crossbedded feldspathic quartzite and arkose belong to the sequence exposed beneath the Greenbrier fault in the type areas to the east. Interbeds of darker biotitic metasandstone and feldspathic quartz-mica schist are abundant in the upper part of the formation and are well exposed on the road between Straight Fork and Pin Oak Gap. Below Big Cove, typical beds of the Longarm are prominently exposed in road cuts and in outcrops in the bed of Raven Fork. The rocks of this belt become more recrystallized toward the south so that in the old quarry northeast of the abandoned townsite of Ravensford they are strongly foliated quartz-feldspar gneiss with minor pegmatite lenses. Rock from this quarry showing deformed but recognizable crossbedding was used in the outer walls of buildings at Park Service headquarters near Gatlinburg and at the Oconaluftee Ranger Station near Ravensford.

Most of the Shelton Laurel belt of the Snowbird group, southeast of the Greenbrier fault, is occupied by Longarm quartzite that is more deformed but otherwise



A (left), *B* (right). Slabs of coarse arkose showing current bedding in quarry at Walters Dam.

C. Vertical face of feldspathic quartzite dipping southeastward showing both current bedding and slump folding. Current direction and overfolding are toward left (northwest). Light-colored layer at lower left is 2 inches thick. Old railroad grade about 500 feet north of Walters Dam.

FIGURE 8.—CURRENT BEDDING AND SLUMP STRUCTURE IN LONGARM QUARTZITE

similar to that in the areas to the north and west. Pelitic interbeds are abundant, but they are notably lighter colored and more muscovitic than similar interbeds elsewhere in the formation. Bedding is generally indistinct, much folded, and masked by strong foliation.

Throughout the Dellwood-Cherokee belt and elsewhere in the Dellwood quadrangle, the Longarm consists largely of light-gray to pink gneissic arkose and feldspathic quartzite. Minor amounts of darker schistose biotitic metasandstone and feldspathic quartz-mica schist become thicker and more abundant in the upper part of the formation as in the type area. Current bedding and other bedding features are recognizable at many places, although they are generally so deformed as to prevent interpretations regarding current directions or the tops and bottoms of beds. Recrystallization, at least as intense as that in the vicinity of Ravensford, has obscured in varying degree sedimentary textures and structures and has been sufficient to give parts of the arkose a granitic appearance.

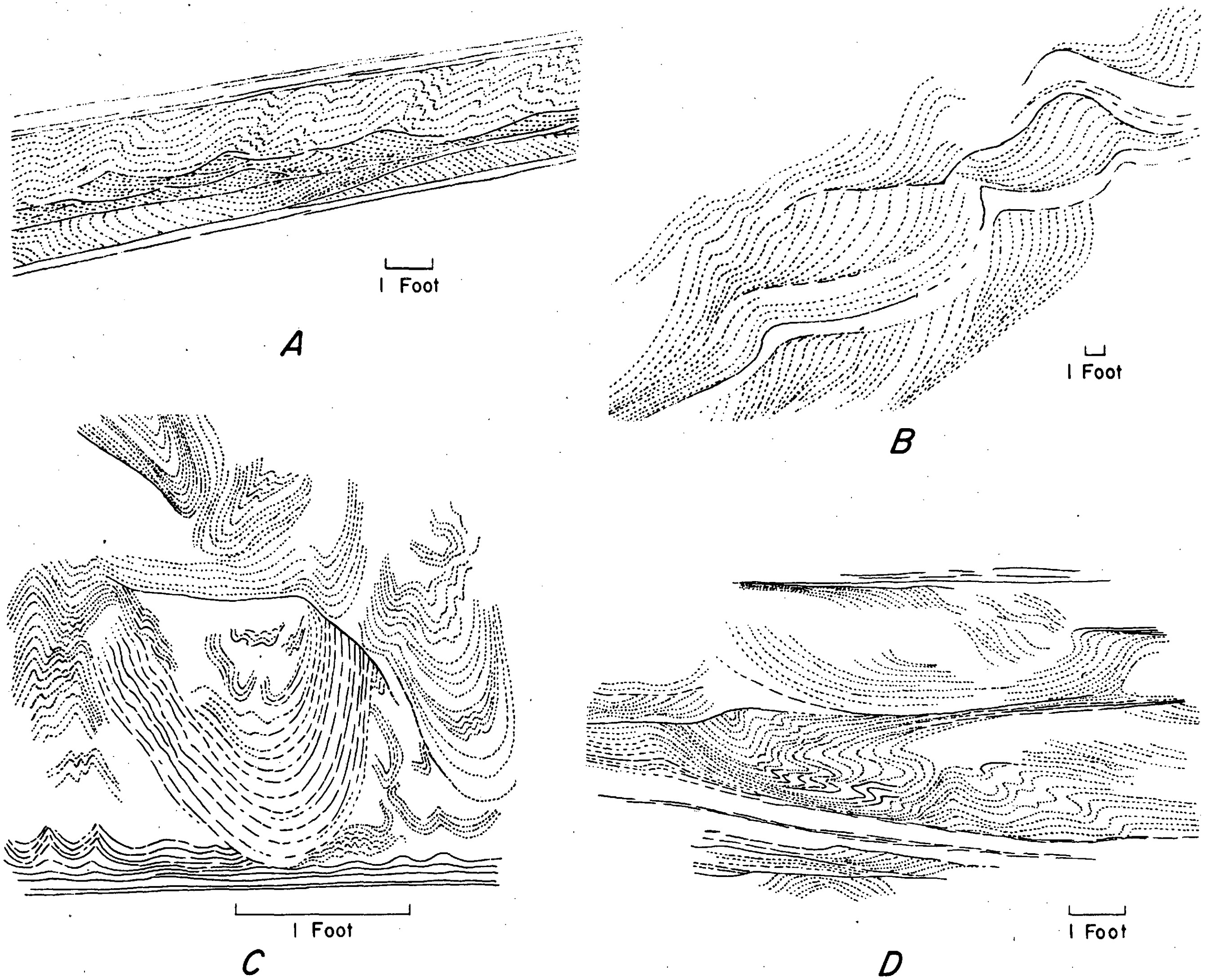


FIGURE 9.—Current bedding and slump folds in Snowbird group. *A*, Longarm quartzite on old railroad grade on Pigeon River 1 mile below Walters Dam. Direction of slumping and major currents was toward right. *B*, Very coarse current bedding deformed by slump movements toward left (northwest). Longarm quartzite dipping 30° NW., northwest slope of Longarm Mountain, 2 miles south of Pigeon River. *C*, Intricate folding and faulting due to sliding in very fine sandstone of the Pigeon siltstone. Folds trend N. 65° E.; sliding is toward left (north). North slope of Greenbrier Pinnacle. *D*, Slump folds in light-colored fine-grained sandstone in the Roaring Fork sandstone. Sliding was toward left (north). West slope of Gabes Mountain.

THICKNESS

The Longarm quartzite is estimated to be about 5,000 feet thick in the type section at the north end of Longarm Mountain, where both base and top of the formation are exposed. Because the measurement is made normal to the major fold axes and in the direction of the regional cleavage, it may be considerably greater than the original stratigraphic thickness, as pointed out by Cloos (1947, p. 910–911). Nevertheless, the Longarm is about this thick in the Whiteoak belt to the southeast, where the beds dip generally to the southeast, appear to be less deformed, and are less subject to systematic thickening of the sort described by Cloos.

The Longarm is much thinner in the southeastern belts of outcrop. Its outcrop width in the Shelton Laurel belt ranges from 500 to 3,500 feet; but much of this variation is due to repetition by folding and to tectonic thinning. Along North Carolina Route 284 possibly 1,200 feet of Longarm is present, and on Stevens Creek about 800 feet is present. At Shelton Laurel, where the Wading Branch is estimated to be about 450 feet thick, the Longarm is so folded that no reliable estimate of its thickness can be made. The Longarm quartzite has an apparent thickness of about 1,000 feet throughout most of the Dellwood-Cherokee belt, although it thins to about 500 feet southwest of

Jenkins Divide, probably by intertonguing with the overlying Roaring Fork sandstone. At the extreme southwest end of the belt, in the vicinity of Cherokee, the Longarm is absent, and sandstone of the Wading Branch is directly overlain by the Roaring Fork.

Still farther southeast in the Dellwood quadrangle, the Longarm is the principal and most easily recognizable unit between the basement and the overlying Great Smoky group. Its thickness decreases southeastward from 500 feet on Buck and Setzer Mountains to 50 feet near Walker Bald and to a foot or two at the eastern limit of the Snowbird group, a little more than a mile west of Dellwood (pl. 2).

STRATIGRAPHIC RELATIONS

In most places the Longarm quartzite rests on dark sandstone and graywacke of the Wading Branch formation and the relations are gradational, the rocks becoming better sorted, lighter colored, and eventually crossbedded as the Longarm is reached. In some places in the Dellwood-Cherokee belt, however, the Longarm lies directly on the basal schist of the Wading Branch, and here the contact is sharp, and basal Longarm unusually coarse. Owing to deformation, metamorphism, and inadequate exposures, other details of the contact relations at the base of the Longarm could not be seen.

The contact between Longarm quarzite and the overlying Roaring Fork sandstone is everywhere gradational and characterized by intertonguing between the two formations. In the type section on the Pigeon River near the mouth of Mount Sterling Creek, the proportion of finer grained darker sandstone and metasiltstone characteristic of the Roaring Fork gradually increases, and the proportion of light-colored beds of Longarm aspect decreases over a stratigraphic interval of 2,000 feet. The formation boundary is located where the beds change from dominantly light-colored feldspathic quartzite and arkose to darker and finer sandstone and interbedded metasiltstone containing only minor beds of Longarm aspect. Even so, owing to the extremely gradational character of the boundary and inadequate exposures in many places, only the larger tongues of Longarm could be mapped and these in somewhat generalized fashion, as on the northwest side of Longarm Mountain. Similar tongues in the northern part of the Straight Fork window and the southern part of the Ravensford anticlinorium are so obscured by folding and lack of exposure that the mapped boundary in these places is even more generalized.

The top of the Longarm quartzite is considerably sharper in the Dellwood-Cherokee belt, where the transitional rocks are generally less than 200 feet thick.

ROARING FORK SANDSTONE

DEFINITION

The Longarm quartzite is overlain by and grades laterally into a thick unit of finer grained clastic rocks, named the Roaring Fork sandstone (King and others, 1958, p. 954–6). This formation is thickest and most typical in the northern belt of the Snowbird group, along the north side of the mountains. It is named for Roaring Fork, a tributary of the West Fork of the Little Pigeon River southeast of Gatlinburg, at the west edge of the report area and is typically exposed in natural outcrops along Roaring Fork for 3 miles southeast of the town. A better exposed but thinner section is exposed in road cuts along the Pigeon River a short distance south of Hartford, Tenn., and a complete but still thinner and less characteristic section is excellently exposed along the river 1–2 miles southeast of Waterville, N.C., adjacent to the type section of the Longarm.

TYPE AREA

The Roaring Fork sandstone of the type area consists of moderately metamorphosed medium- and fine-grained feldspathic sandstone, metasiltstone, and minor amounts of slate and muscovite phyllite. The color of the fresh rocks depends on the amount of dark mica present and varies with the grain size from light greenish gray (5*GY* 7/1) in the coarser rocks to medium and dark greenish gray (5*GY* 4/1) in the finer. Where biotite rather than chlorite is the principal dark constituent, the rocks are more neutral gray of similar values. On weathering, the coarser sandstone becomes various shades of yellowish brown or tan, and it disintegrates into pale-yellowish sandy soil with few rock fragments. The finer grained rocks weather to dark-red or yellow clayey soil containing more fragments than soil derived from coarser sandstone.

Sandstone, siltstone, and finer grained pelitic rocks are interbedded throughout the formation in varying proportions. In the better exposed sections along the larger streams, it is possible to divide the formation into units of varying thickness in which either sandstone or siltstone and finer grained rocks are dominant. Such units grade into one another, both vertically by interbedding and laterally by intertonguing and can be traced with difficulty across interstream areas, in which exposures are relatively few. In some places they are abruptly cut off by faults; elsewhere they disappear, presumably by lensing of coarser beds into finer ones and vice versa. Rarely are exposures good enough to show this clearly.

Thick-bedded feldspathic sandstone constitutes a third to a fourth of the formation in this area. It appears in beds that range in thickness from 1 to 80 feet but that are commonly between 5 and 10 feet thick. Most beds cannot be traced far enough to determine their lateral extent, but several thick cliff-forming beds just southeast of Gatlinburg can be followed for at least 2 miles and suggest a length-to-thickness ratio of 150 or more. The coarser and thicker beds are generally massive without noticeable internal structure. In some, however, indistinct internal layers form sharply truncated crossbeds several feet long, and more rarely they are contorted by sliding as illustrated in figures 9*C* and *D*. Thinner beds, less than a foot thick, contain thin parallel layers of darker or finer grained sandstone, particularly where interbedded with metasiltstone. The standstone is notably uniform and well sorted although most of it contains micas and recrystallized quartz and feldspar less than 0.1 mm in size, representing original silt and clay. The maximum grain size in the coarsest beds in the type area is a little less than 0.5 mm.

Much of the Roaring Fork sandstone in the type area consists of sandy schistose metasiltstone and very fine-grained sandstone that ranges from thick massive beds to thinly layered and current-bedded rocks. Parts of the finer grained rocks form relatively massive beds, but most of the coarser siltstone and finer sandstone is current bedded on a small scale. Individual current-bedded lenses are ¼–½ inches thick and several inches long. They form units generally not more than 2 or 3 feet thick interbedded with thicker units of nonlayered or more evenly layered siltstone. The coarser beds grade symmetrically into finer beds above and below; asymmetrical graded bedding is virtually absent.

The presence of more argillaceous material is accompanied by lenticular-laminate bedding in which the fine-sand fraction occurs in discrete lenses separated by very thin but more continuous pelitic laminae. Most commonly such sand lenses are 0.5–3 mm thick and several inches long and are intercalated between slightly wavy laminae which form ½ or ⅔ of the rock. In some places, the sand lenses are thicker and more abundant and are minutely crossbedded. Rarely, where the sand lenses amount to 80 percent of the rock, they were thickened and deformed by sliding before consolidation of the sediments.

At the few places where bedding surfaces of lenticular-laminate beds are exposed they are ripple marked. Such surfaces are well exposed on the under side of a large overhanging ledge on the east bank of the Little Pigeon River three-fourths mile north of the bridge at Greenbrier Cove. The ripples here are about 1 inch in wavelength and one-eighth inch in amplitude; they trend N. 20° E. on a bedding surface that dips 10° S. 55° E. and indicate a westward current direction.

Thin very even and continuous layers of fine sand, siltstone, and metapelite indicate still more argillaceous material and grade vertically into beds consisting largely of slate or phyllite.

Highly argillaceous rocks, found only in the upper part of the Roaring Fork sandstone, consist of silvery, pale-green phyllite or slate composed largely of muscovite and quartz, with small porphyroblasts of biotite and ilmenite. Foliation is conspicuous and commonly bent or crinkled. At some places weathered outcrops contain small rectangular or discoid molds a few millimeters in diameter thought to have contained porphyroblasts of chloritoid, although no specimen was found in which this mineral was preserved. Most of the phyllite lacks visible bedding, although here and there thin layers differ slightly in color and in proportions of mica and quartz. In general, the phyllite forms homogeneous units 10–100 feet thick, grading into metasiltstone by interbedding and by gradual increase in grain size.

The phyllite is notably resistant to weathering, yields abundant and distinctive fragments in the float, and forms ridges or steep cliffy slopes. It also contains large masses of white vein quartz that accumulate in the surficial mantle. By means of these features one phyllite unit about 100 feet thick was mapped for more than 3 miles. Several similar beds in the upper part of the Roaring Fork on the north slopes of Mount Winnesoka and north of Potato Ridge can be traced eastward and northward across the crest of the Copeland Creek anticline, where they are less metamorphosed and pass into olive slate.

Some beds of the Roaring Fork sandstone are notably calcitic, particularly beds of fine current-bedded sandstone, in which the carbonate is commonly revealed by selective weathering of the sandy lenses between slaty laminae. Similar calcitic layers occur sporadically in massive metasiltstone. In both types of rock, carbonate occurs in the coarsest parts and is erratically distributed in them; this evidence suggests that it has been introduced along permeable layers.

BUCKEYE LEAD-CHESTNUT MOUNTAIN BELT

The Roaring Fork sandstone appears again farther east in a belt extending from near the Sevier-Cooke County line across Buckeye Lead and Chestnut Mountain to the Pigeon River. The top of the formation is marked by the contrast between dominant sandstone in the Roaring Fork and finer grained rocks in the overlying Pigeon siltstone. The rocks are similar to those farther west but are considerably sandier, as about two-thirds of the formation is sandstone.

On Buckeye Lead, Gabes, and Round Mountains the formation consists in part of light-colored slightly coarser sandstone like that in the Longarm quartzite. These beds, individually ranging in thickness from 1 to 20 feet or more, are composed of medium- or coarse-grained feldspathic quartzite containing sporadic grains of quartz and pink feldspar as much as 6 mm in diameter. Internal bedding is generally indistinct, but on favorably weathered surfaces coarse crossbedding and large-scale slump folds are seen (fig. 9*D*). This type of sandstone, grading into and interbedded with finer and darker sandstone of typical Roaring Fork aspect, is prominent in the middle 2,000 feet of the formation in this part of the belt. It tongues out abruptly along the strike both to the east and to the west, only a few thin beds extending west of the county line and none at all east of Cosby Creek.

The upper part of the Roaring Fork sandstone at the east end of the Buckeye Lead-Chestnut Mountain belt is exposed where the Pigeon River cuts through Chestnut Mountain, just south of Hartford. It consists of thick layers of medium- to fine-grained sandstone interbedded with relatively thick and massive units of dark metasiltstone. A few thin lenses of coarser sandstone containing sporadic grains as large as 3 mm occur in the lower part of the section. Farther south, near the prominent **U**-bend of the river, dark very fine-grained sandstone and metasiltstone, distinctly and evenly bedded, make up about 35 percent of the middle and upper parts of the formation, and medium-grained sandstone in beds 2–8 feet thick makes up about 25 percent. The remainder is weakly schistose very fine-grained sandstone that is intermediate in texture between the more distinct sandstone beds and the siltstone. The uppermost 700 feet of the formation is largely fine-grained sandstone and siltstone, dark gray or green, and thinly bedded, with several more massive sandstone beds 4–6 feet thick. The highest of these marks the top of the formation in this section.

OTHER AREAS

Half a mile southeast of the State line at Waterville, the Roaring Fork is a succession of thick sandstone beds marked by conspicuous large-scale crossbedding and interbedded darker evenly layered sandstone in beds 1–3 feet thick spaced 1–10 feet apart. A few beds, 1–2 feet thick, of typical Longarm aspect appear about midway in the section, and similar beds occur here and there with finer light-colored sandstone and subordinate dark beds throughout most of the lower part. The formation is nearly all sandstone at this place and appears to represent a transition from the rocks of the type area to the Longarm quartzite at the southeast.

The Roaring Fork sandstone in the Cataloochee anticlinorium and Straight Fork window in the upper part of the formation in the Dellwood-Cherokee belt is largely dark-gray biotitic metasandstone and garnetiferous feldspathic quartz-mica schist, in which bedding and textures are obscured by deformation and recrystallization.

The lower part of the formation in the Dellwood-Cherokee belt is predominantly light- to dark-gray medium- to fine-grained current-bedded metasandstone, similar to the lighter colored beds of the Longarm except for a greater abundance of biotite and a slightly great percentage of feldspar, some of which is probably of metamorphic origin. Dark laminae marking the crossbedding are composed primarily of heavy minerals as in the Longarm quartzite. Most dark laminae are rich in magnetite, but sphene is abundant in some, and orthite, apatite, epidote, and metamorphic biotite are common. Other thin dark seams are composed largely of biotite, especially in metasandstone beds high in the sequence. Interbeds several feet thick of light-colored gneissose quartzite are present in the lower part of the formation transitional to the Longarm, and the formation boundary is mapped where the lithologic aspect changes from dominantly light-colored to dominantly dark-colored metasandstone.

THICKNESS

About 7,000 feet of the Roaring Fork sandstone is present in the type area along Roaring Fork, from the fault along Dudley Creek to the highest beds exposed just east of Piney Mountain. Still higher beds appear farther east in the vicinity of Copeland Divide, where the upper part of the formation consists largely of metapelite and its top is placed for convenience at the top of the uppermost mappable sandstone. Correlation of this section with that on Roaring Fork by means of traceable units within the formation indicates that about 1,000 feet must be added to give 8,000 feet as the partial thickness of the formation exposed in the type area, where its base is concealed.

A maximum of 5,600 feet of the formation is exposed in the Buckeye Lead-Chestnut Mountain belt, where the base is likewise cut off by faults. Farther east where the first complete sections of the formation are exposed, it is considerably thinner than in the type area, but the thickness varies greatly because of intertonguing with overlying and underlying formations. Still farther southeast in the Dellwood-Cherokee belt, the Roaring Fork is only a few hundred feet thick.

STRATIGRAPHIC RELATIONS

The Roaring Fork sandstone is recognized in these various belts as a rock-stratigraphic or lithogenetic unit in sequence above the Longarm quartzite, yet its stratigraphic position varies widely. For example, a structure section along the Pigeon River (section *A–A′*, pl. 1) shows that most of the Roaring Fork southeast of Waterville is stratigraphically higher than that south of Hartford and that at the latter place the Roaring Fork is actually the northwestern equivalent of a large part of the type Longarm; these relations are shown somewhat diagrammatically in figure 10. The transition between the two formations occurs on Snowbird Mountain where reconnaissance traverses indicate that they intertongue extensively. Evidence of the intertonguing was also found within the mapped area—particularly where rocks similar to the Roaring Fork and the Longarm are interbedded—with consequent difficulty in establishing a formation boundary—and in the local appearance of beds of Longarm aspect within the Roaring Fork on Gabes Mountain.

The upper boundary of the Roaring Fork sandstone in the type area is characterized by a very gradual upward transition from sandstone with interbedded finer grained rocks to dominant metasiltstone of the Pigeon. Prominent and persistent sandstone beds, 10 feet or more thick, occur at intervals of 50–100 feet throughout the upper part of the Roaring Fork, and the top of the formation is placed generally at the top of the highest of these sandstone beds in any locality. As these marker beds pinch out, generally westward and northward, the upper limit of the Roaring Fork sandstone descends in much the same manner as the base of the formation. In some places, notably on Gabes Mountain, the overlying beds classed as Pigeon are succeeded by recurrent beds of sandstone that pinch out both westward and eastward and represent detached tongues of the Roaring Fork sandstone.

PIGEON SILTSTONE

DEFINITION

The Pigeon siltstone (King and others, 1958, p. 956–957; King, 1949, p. 639–640) is adapted from the Pigeon slate of Keith (1895) and named for exposures along the Little Pigeon River a few miles north of the present report area. The formation is a sequence of metasiltstone and interbedded slate, 10,000–15,000 feet thick, in the type area. It has now been traced eastward to the Pigeon River where it overlies the Roaring Fork sandstone in the type Snowbird sequence and is considered the uppermost formation of the Snowbird group.

As exposed in the area of this report, the Pigeon siltstone is limited to the northern belt of outcrop of the Snowbird group and has a maximum thickness of 7,000 feet. In most of the belt, it lies conformably upon the Roaring Fork sandstone. Although it is the uppermost formation of the group, its top is exposed only at the eastern end of the belt, where it is overlain by the Rich Butt sandstone.

WESTERN AREA

The Pigeon siltstone in the western part of its outcrop belt consists of clastic rocks ranging from fine-grained sandstone and metasiltstone to argillite or slate. All these rocks have undergone low-grade regional metamorphism with recrystallization of the silt-size particles and reconstitution of the clay fraction to mica. The rocks classed as sandstone are composed largely of quartz and feldspar grains between 0.1 and 0.35 mm in diameter. Most of them contain more than 10 percent argillaceous material, represented by mica, and were originally muddy sandstones. Metasiltstone is characterized by a preponderance of recrystallized detrital grains less than 0.1 mm in size and generally contains 30 percent or more of recrystallized argillaceous material. Rocks termed "argillite," "slate," or "phyllite" are composed dominantly of mica, with recrystallized detrital grains generally less than 0.1 mm.

Where fresh, these rocks range from medium to dark greenish gray, with exception of the slate, which is dark grayish olive. The characteristic green color is due largely to metamorphic chlorite and partly to epidote. In the southern part of the belt, however, biotite locally supplants chlorite as the principal dark mineral, and the rocks are darker and less green. Deeply weathered rocks are medium yellowish or reddish brown, and their soils are clayey.

Although the rocks of the Pigeon fall within rather narrow limits of grain size, they exhibit a notable variety of bedding structures and textural variations. Metasiltstone is an abundant type grading to and hardly distinguishable from sandstone. It forms uniform massive beds, 1–30 feet thick, with little or no internal structure. The rocks are moderately feldspathic and were originally argillaceous, for their mica content, including nearly as much chlorite as muscovite, ranges from 20 to 50 percent. Prominent flakes of detrital muscovite are moderately abundant.

Much metasiltstone and fine sandstone shows current bedding on a small scale as shown in figure 11A. Individual current-bedded lenses, ¼–1 inch thick, form units as much as 2 or 3 feet thick, generally interbedded with thicker units of massive or evenly bedded metasiltstone.

Slaty metasiltstone with lenticular-laminate bedding like that in the Roaring Fork sandstone is abundant in the Pigeon and likewise grades to laminated slaty siltstone or to sandy siltstone with current-ripple-bedding. Such rocks seem to represent a form of deposition transitional between fine current-bedded sandstone and more argillaceous and evenly bedded rock. In some places lenticular-laminate beds appear in which the sand lenses are thicker and more abundant in proportion to argil-

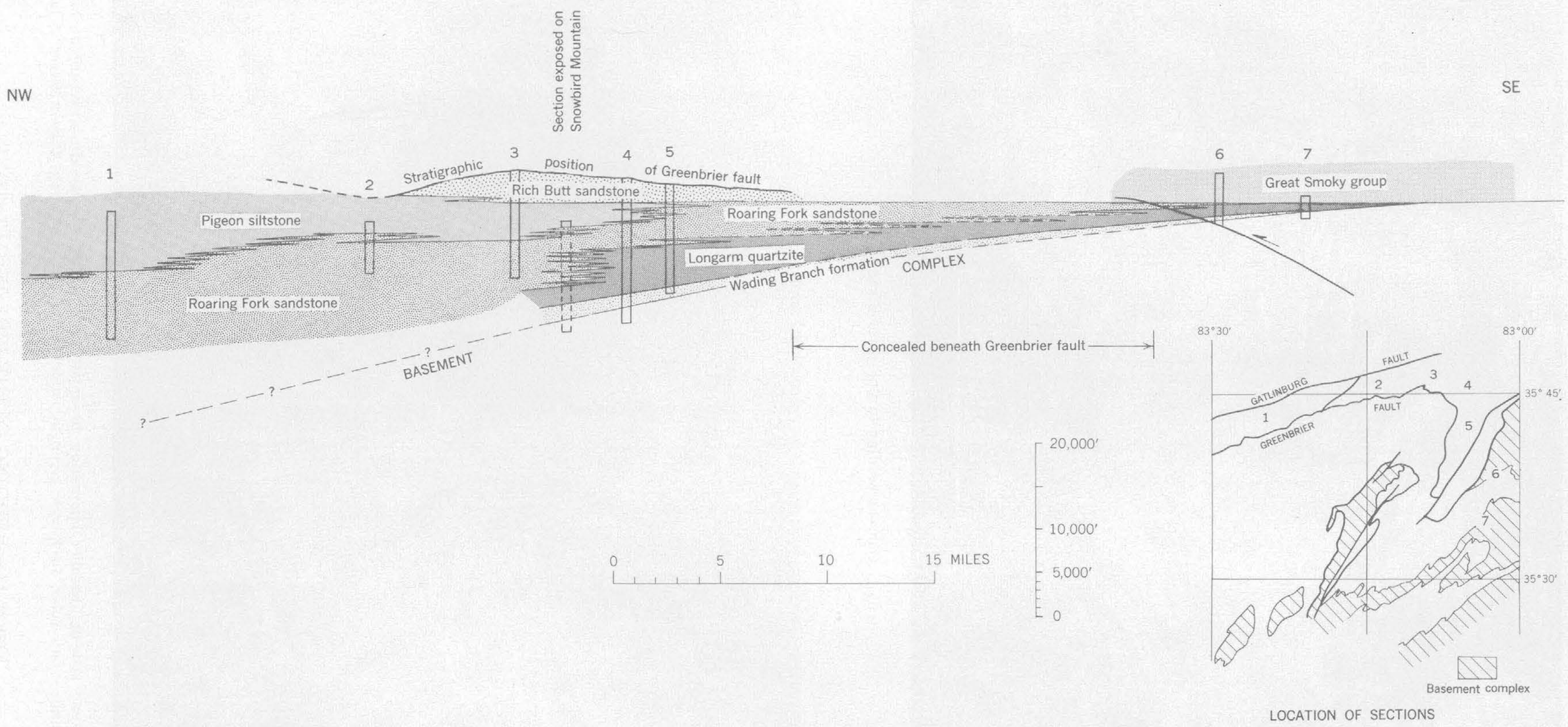
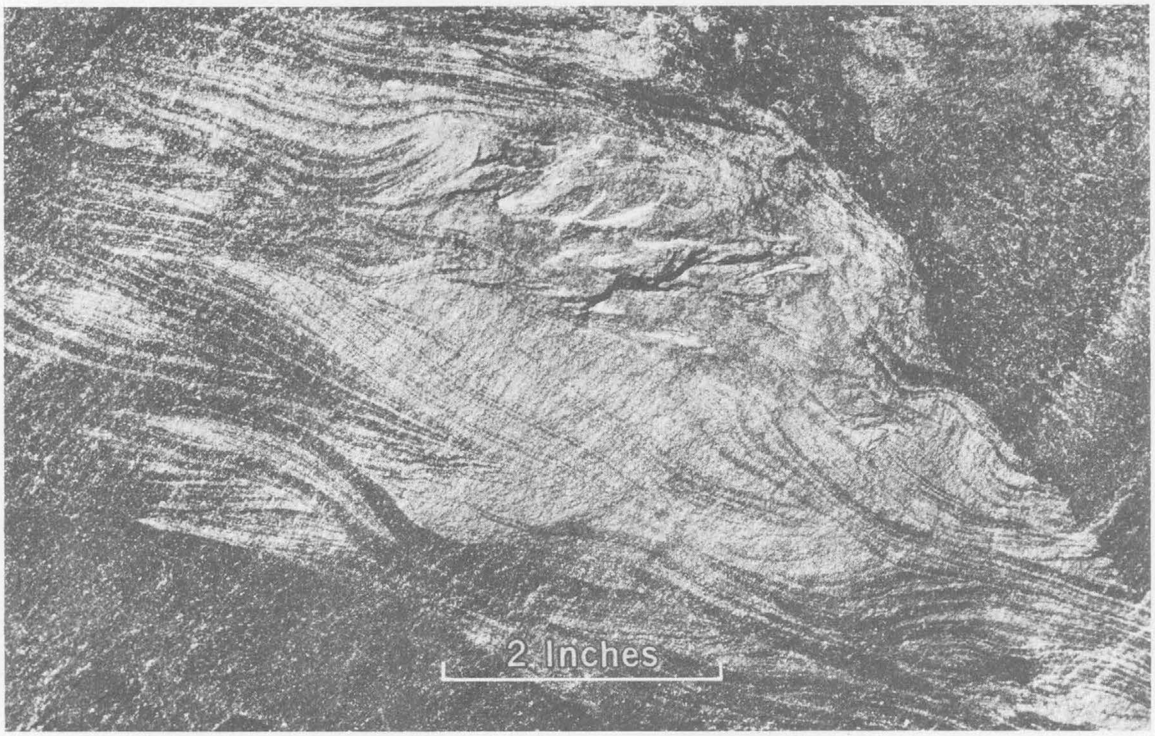


FIGURE 10.—Stratigraphic relations of the Snowbird group and overlying rocks, eastern Great Smoky Mountains.



A. Current bedding in fine-grained sandstone.

B. Argillitic metasiltstone showing parallel lamination in upper part, lenticular-laminate structure at lower left, fine current bedding and slump folds in 3-inch layer in middle. Roadcut on Little Pigeon River 2 miles north of Emerts Cove.

FIGURE 11.—BEDDING IN THE PIGEON SILTSTONE

laceous material. Sandstone constitutes as much as 80 percent of some of these beds, and ultimately this type of rock grades into fine-grained sandstone marked by wispy argillaceous laminae.

A much larger proportion of the Pigeon siltstone than of the Roaring Fork sandstone consists of alternate silty and argillaceous layers characterized by very regular lamination (fig. 11*B*). Individual layers are 0.5–3 mm thick but become considerably thicker with increase in grain size. As in the Roaring Fork, bedding surfaces are not sharply defined and the rocks rarely part along them, so that the slight differences between layers are commonly visible only in weathered rock and saprolite.

Feldspathic sandstone, recognizable by its relatively light color and absence of schistosity, forms beds ½–20 feet thick but mostly less than 5 feet thick. They are homogeneous in texture and composition, without internal layering except for indistinct parallel lamination at their margins. A few sandstone beds show large-scale cross lamination similar to that in the Roaring Fork. These relatively massive sandstone beds are associated with massive metasiltstone or with evenly bedded sandstone and siltstone but not with current-bedded siltstone or slate. They resemble sandstone beds in the Roaring Fork sandstone but are thinner, less abundant, and not persistent.

The finest grained rock in the Pigeonsiltstone is grayish-olive slate, altered in places to silvery phyllite like that in the upper part of the Roaring Fork sandstone. It is characterized by thin bedding laminae, 0.2–4.0 mm thick, differing slightly in color or texture and generally obscured by slaty cleavage. These laminate are very even, as they are neither lenticular nor ripple marked, and grade imperceptibly into laminated slaty siltstone. Units consisting largely of slate are as much as 100 feet thick in the northwest part of the mapped area, where they are relatively resistant to erosion and form minor ridges traceable for considerable distances. Like the argillaceous rocks of the Roaring Fork, they are commonly invaded by vein quartz and can be traced by the abundance of quartz fragments in the colluvial mantle.

EASTERN AREAS

The Pigeon siltstone becomes increasingly coarse grained from Gabes Mountain eastward to the vicinity of Waterville. On the northwest slope of Rich Butt Mountain and in adjacent areas, much of the formation consists of fine to very fine grained sandstone with abundant laminae of argillaceous metasiltstone; the usual siltstone and slate are much less abundant than farther west. Near Waterville, the Pigeon includes several thick sandstone beds which eventally form mappable tongues of Roaring Fork sandstone (pl. 1). These increase abruptly southeast of Big Creek, so that the Roaring Fork takes over the stratigraphic interval occupied by the Pigeon a few miles to the northwest (fig. 10).

THICKNESS

The Pigeon siltstone is thickest in the northern part of the map area where it forms large parts of both the Cartertown and Copeland Creek anticlines. Exposures most amenable to measuring the thickness of the formation in this area are on the crest and north flank of the Copeland Creek anticline; at this place 7,000 feet of Pigeon siltstone is exposed south of the southern strand of the Gatlinburg fault, but minor folds and faults and tectonic thickening may have increased the original thickness by 1,000 feet or more. Hamilton (1961, p. A–9) reports the formation to be between 10,000 and 15,000 feet thick north of the Gatlinburg fault, but only the lower 3,000 or 4,000 feet of this section is exposed in the present map area.

To the east, on the south flank of the Chestnut Mountain anticline, the Pigeon is thinner, as it is 4,600 feet thick on the northwestern slope of Rich Butt Mountain and 3,500 feet thick on Turkey Knob. Still farther east in the section of Big Creek, less than 3,000 feet of Pigeon siltstone is present.

STRATIGRAPHIC RELATIONS

Intertonguing of the Pigeon siltstone and Roaring Fork sandstone near Waterville and from Gabes Mountain to the vicinity of Gatlinburg indicates that the base of the Pigeon appears at progressively lower stratigraphic levels toward the north and west. Several unmapped standstone beds that wedge out abruptly in the Pigeon on the south flank of the Cartertown anticline just north of Dudley Creek may represent the edges of sandstone units in the uppermost Roaring Fork in the Copeland Creek anticline south of the fault. Similarly the uppermost sandstone beds of the Roaring Fork north of Gatlinburg pinch out westward in Pigeon siltstone a short distance west of the quadrangle boundary.

The top of the Pigeon siltstone is exposed only in the northeastern part of the report area, where it is overlain by the Rich Butt sandstone. The contact between the two formations is everywhere gradational and is marked by dominantly sandy rocks with bedding and other features unlike those of the Snowbird group.

PETROGRAPHY OF THE SNOWBIRD GROUP

Discussion of the composition and texture of the rocks of the Snowbird group has been deferred until this point for two reasons: (1) duplication of rock types among the several formations would make detailed description for each formation unnecessarily repetitive and (2) variations of texture and composition involve the group as a whole and are best understood if presented in that context. Petrographic information about the sedimentary character of the Snowbird group was drawn almost entirely from rocks of the northern belt of outcrop, where changes resulting from metamorphism, although considerable, are less than elsewhere in the area. Laboratory study of 140 specimens included 100 specimens sectioned and studied microscopically, 12 specimens analyzed chemically, and 30 stained with hydrofluoric acid and sodium cobaltinitrite to indicate their potassium feldspar content.

TEXTURES

Microscopic sedimentary textures of many of the medium and coarser grained rocks in the northern belt of the Snowbird group are preserved in spite of regional metamorphism. Most grains larger than 0.1 mm appear to retain approximately their original sizes, although their shapes have been much modified by recrystallization (fig. 12*A*). Smaller grains are thoroughly recrystallized. Within these limits of observation, clastic quartz and feldspar grains making up the bulk of the sandstones of the group appear to be subangular to rather well rounded. The larger heavy mineral grains such as epidote, sphene, and magnetite also tend to be subangular to well rounded; an exception is apatite which is generally well rounded. The small grains of zircon do not appear to be recrystallized and may be either sharply euhedral or distinctly rounded, possibly as a result of processes within the parent rock.

Excepting the Wading Branch formation, the sandstones of the group are at least as well sorted as normal near-shore marine sands.

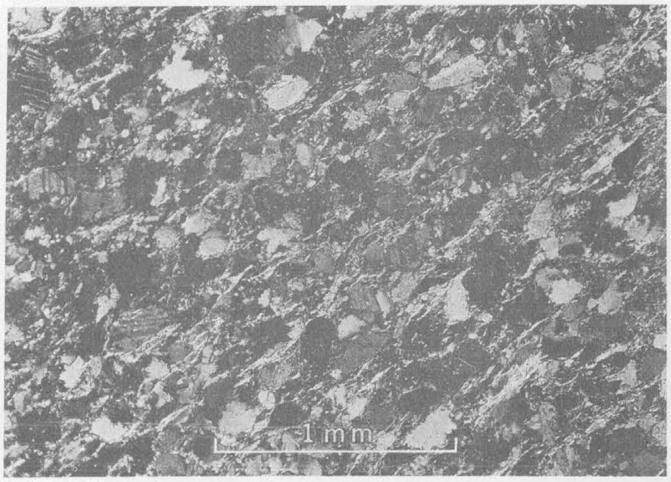
MINERAL COMPOSITION

The rocks of the Snowbird group are notably uniform in mineral composition. Major constituents of detrital origin are quartz, potassium, feldspar, and plagioclase; minor detrital minerals include epidote, sphene, biotite, magnetite, apatite, and zircon. Minerals of metamorphic origin include muscovite, paragonite, biotite, chlorite, chloritoid, ilmenite, and garnet, and also some epidote, sphene, and magnetite. Carbonate and pyrite may have been syngenetic but have been introduced in most rocks where they were observed.

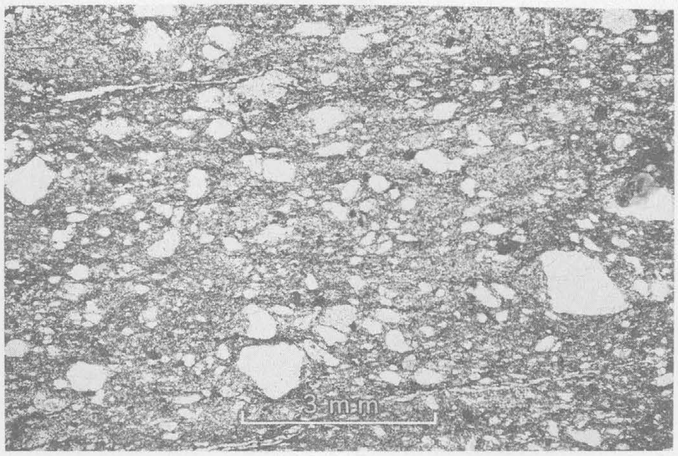
All the rocks of the group are notably feldspathic, as illustrated by figure 13, which shows estimated proportions of quartz, feldspar, and metamorphic mica. The metamorphic mica presumably represents the clay fraction of the original sediments. Most of these points are plotted according to visual estimates made from thin sections; several, however, were determined semiquantitatively from thin sections and corrected from chemical analyses. Most of the chemically determined compositions show more feldspar than those visually determined, probably because part of the very fine grained feldspar in thin sections was mistaken for quartz. Even so, many rocks of the group fall into the arkose or muddy arkose field of the diagram. The diagram also shows the presence of subarkose or feldspathic quartzite in the Longarm, as well as the fact that the rocks of the Wading Branch formation are somewhat less feldspathic than most other rocks of the group.

The term "graywacke" has been used for the rocks of the Ocoee series (Stose and Stose, 1949, p. 632–643; King, 1949, p. 633, 642–643), but it does not seem appropriate for most of the Snowbird group. Most definitions emphasize clayey matrix, poor sorting, and lithic fragments as distinguishing features of graywackes, yet none of these features are prominent in the sandstones of the group. Some rocks of the Wading Branch formation contain coarse angular particles with abundant recrystallized clayey matrix, but, in general, the argillaceous components increase with decrease in maximum grain size (figs. 12*B* and 14); moreover, detrital fragments of fine-grained igneous or metamorphic rocks do not amount to as much as 1 percent in any rocks of the group. Some petrographers (Pettijohn, 1957, p. 307) classify plagioclase-bearing sandstone as graywacke rather than as arkose or subarkose, and much of the Roaring Fork sandstone would be graywacke by this classification. Nevertheless, we prefer to restrict the term to conspicuously muddy or poorly sorted sandstone, reflecting processes of erosion and deposition rather than a particular type of source rock.

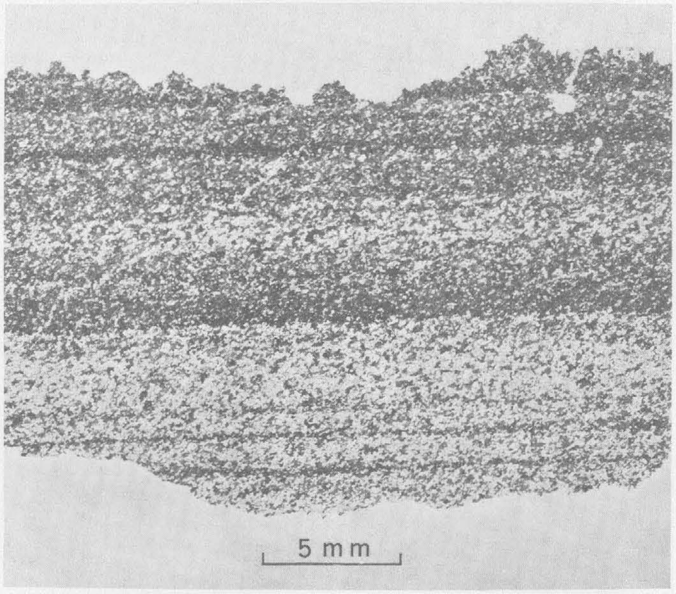
Several kinds of potassium feldspar and plagioclase are widespread in the rocks studied. Microcline is the most abundant, but several varities of microperthite and some untwinned potassium feldspar also occur. Plagioclase ranges from nearly pure albite to An_8; some of it occurs as clear twinned grains and some is untwinned and either clear or clouded with sericite. Untwinned feldspar is difficult to determine in the finer grained rocks, but chemical analyses showed that most of it is sodic plagioclase rather than orthoclase.



A. Fine-grained feldspathic sandstone in Pigeon siltstone. Composition: 40 percent quartz, 40 percent plagioclase, 5 percent orthoclase, 8 percent metamorphic mica, and 7 percent heavy minerals, largely epidote. Cleavage slopes left. Crossed nicols.



B. Graywacke, Wading Branch formation. Large subangular grains are mostly quartz. Chemical and mineral composition given in table 7, analysis 14.



C. Heavy mineral layers in Roaring Fork sandstone. Most dark grains are metamorphic biotite or chlorite, but thin layers contain as much as 50 percent detrital sphene, epidote, magnetite, and apatite.

FIGURE 12.—PHOTOMICROGRAPHS OF GRAYWACKE AND SANDSTONE, SNOWBIRD GROUP

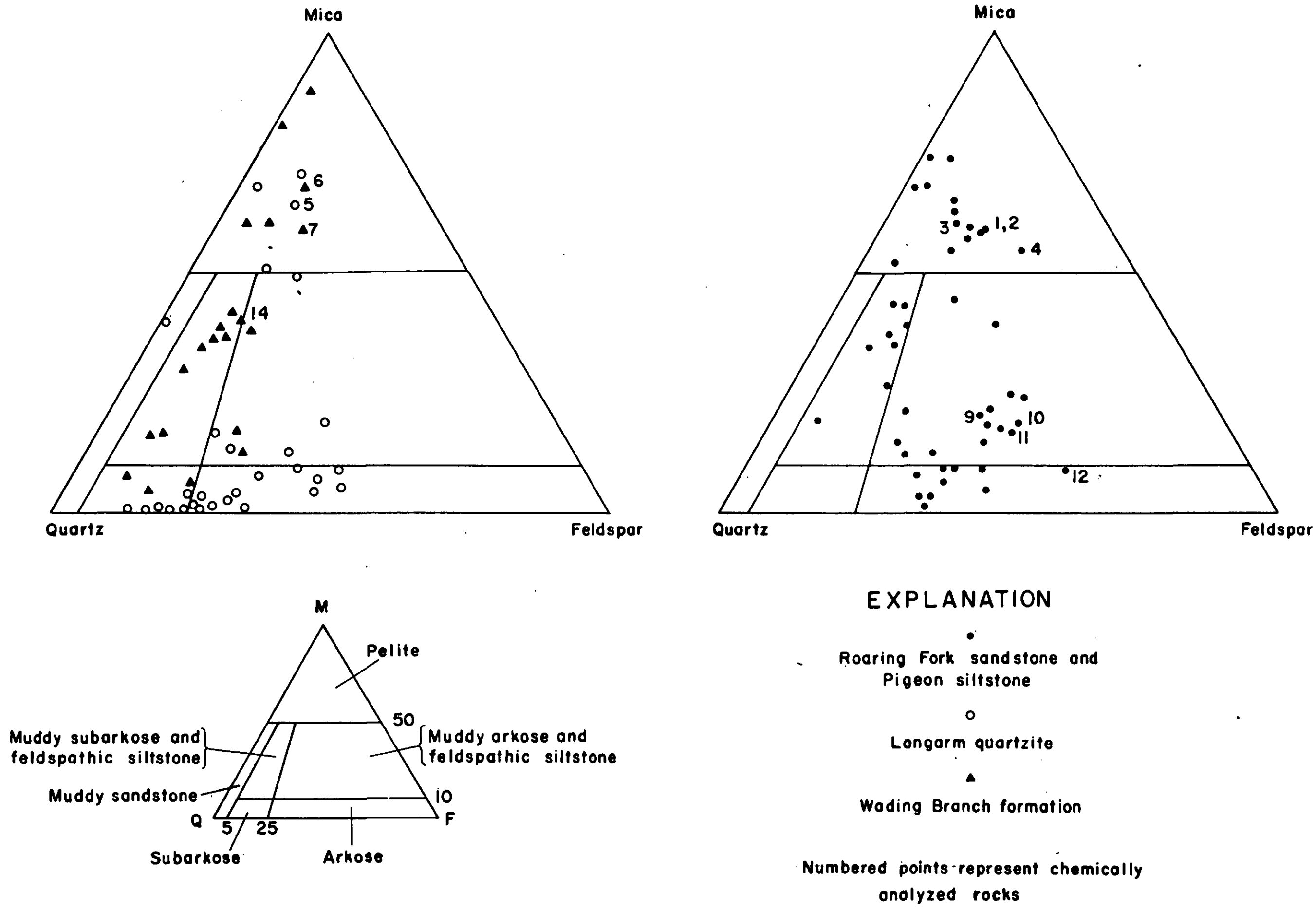


FIGURE 13.—Composition and classification of rocks of the Snowbird group, northern outcrop belt, eastern Great Smoky Mountains. Numbered points represent chemically analyzed specimens given in table 7.

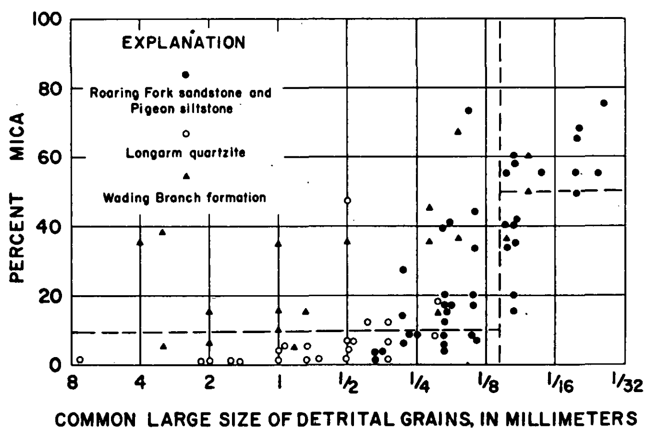


FIGURE 14.—Sorting in rocks of the Snowbird group, northern belt of outcrop, eastern Great Smoky Mountains.

The plagioclase is distinctly finer grained than the potassium feldspar, and is increasingly abundant relative to potassium feldspar in the finer grained rocks. Most medium- and fine-grained sandstones contain more albite than potassium feldspar, whereas in most coarse sandstones this proportion is reversed (fig. 15). Many finer grained sandstones contain very little potassium feldspar, as indicated by study of thin sections and by chemical analyses of two specimens (table 7, analyses 10, 11). Feldspar is not easily recognized in thin sections of the most argillaceous rocks so that visual estimates of the feldspar ratio in these rocks are mostly not available.

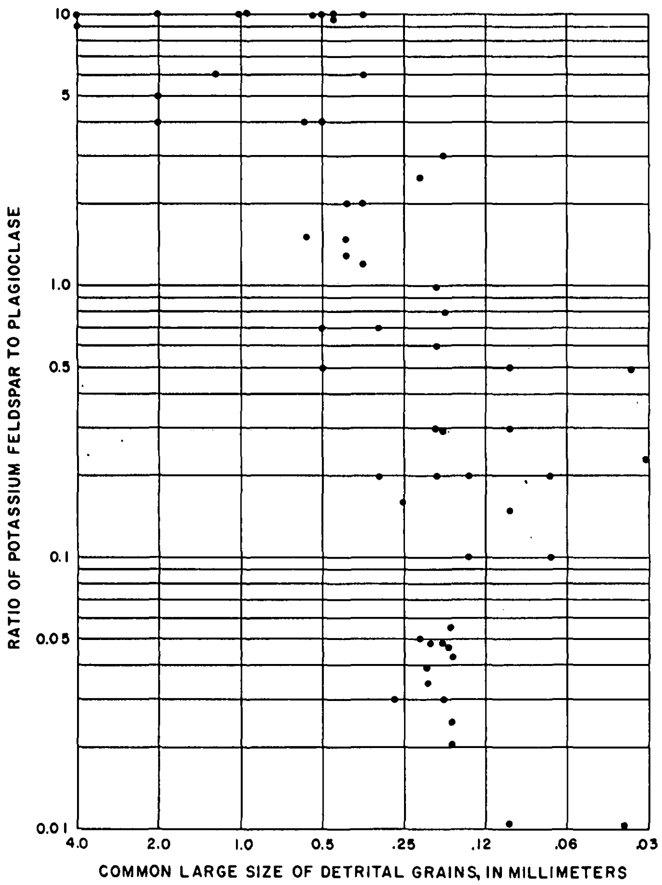


FIGURE 15.—Ratio of potassium feldspar to plagioclase compared to grain size in the Longarm quartzite, Roaring Fork sandstone, and Pigeon siltstone, in the northern belt of outcrop eastern Great Smoky Mountains.

The formations are not wholly alike in their feldspar ratios, however. For example, 7 of 15 samples of sandstone with common large grain sizes between 0.1 and 0.5 mm in the Longarm quartzite contain more potassium feldspar than albite; whereas among sandstone of this grain-size range in the Roaring Fork, only 6 of 25 samples contain more potassium feldspar than albite. In the Wading Branch formation where coarse and fine materials are mixed together, there is no consistent relation between the grain size and the feldspar ratio.

A convenient explanation of the relative distribution of feldspar in the Snowbird group is that potassium feldspar was furnished to the sediments in larger sizes than plagioclase, a disparity that can be traced to the basement complex where potassium feldspar normally occurs in much larger grains that plagioclase. Thus it lagged behind plagioclase during transport and was deposited in greater abundance in the coarser layers nearer the source. No such systematic dispersal of the feldspars is found in the poorly sorted rocks of the Wading Branch, because such a winnowing process did not occur in their deposition. This mechanism does not explain, however, why the finer sandstone in the Longarm contains relatively more potassium feldspar than corresponding fine sandstone of the Roaring Fork. Perhaps this is due to comminution of the potassium feldspar while in transport, the plagioclase having been previously swept out.

Figure 13, although indicating the relative proportions of clastic quartz and feldspar to argillaceous components of the sediments, does not indicate variations in grain size; consequently, fine, medium, and coarse sandstone and siltstone are all represented in the lower half of the diagram. In most of the Snowbird group a normal relation exists between the size of the clastic components and the proportion of mica, representing the argillaceous fraction (fig. 14). Most medium and coarser grained sandstones of the Longarm, Roaring Fork, and Pigeon contain less than 10 percent argillaceous material, and the most argillaceous rocks, containing more than 50 percent argillaceous material, rarely contain quartz or feldspar grains larger than 0.1 mm.

Most of the Wading Branch formation, on the other hand, is less well sorted, so that some very coarse sandstones contain nearly 40 percent of argillaceous material (fig. 12*B*). This poor sorting is associated with graded bedding, also not found in other parts of the Snowbird group, and seems to indicate turbulent transport and rapid deposition in contrast to the gradual movement and reworking of the typically current-bedded deposits of the other formations.

Various clay minerals and probably other very fine grained detritus in the original sediments are now recrystallized to white mica and ferromagnesian minerals in nearly all the rocks of the group in variable proportions. White mica in these rocks is largely muscovite, but the chemical composition of some specimens indicates that it contains considerable sodium, and paragonite may be present. Paragonite was tentatively

TABLE 7.—*Chemical analyses and calculated mineral composition of rocks of the Snowbird group in the northern belt of outcrop, eastern part of the Great Smoky Mountains*

[Analysts: L. D. Trumbull, analyses 1, 2, and 9; M. Balazs, analyses 3-7, 10-12, and 14]

Analysis	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Laboratory No.	52-1493CD	52-1492CD	C470	C479	C477	C475	C476	----	52-1499CD	C467	C469	C478	----	C474
Field No.	RC-299	CT-298	W-513	W-525	W-523	CC-521	CC-521A	----	GB-305	CT-487	W-512	W-524	----	CC-520
Chemical analyses														
SiO_2	56.28	55.85	58.46	57.55	56.59	54.47	55.72	56.65	74.19	67.60	72.75	72.43	71.90	69.97
Al_2O_3	21.36	20.78	18.22	18.90	18.77	21.20	20.31	19.92	12.52	10.90	13.88	12.87	13.07	14.23
Fe_2O_3	.94	1.44	1.97	1.76	2.08	2.41	5.09	1.77	1.27	.92	1.06	.39	.91	1.11
FeO	6.04	6.20	5.18	5.31	5.77	5.30	2.75	5.65	1.67	3.13	1.62	.94	1.85	3.46
MgO	2.21	2.35	2.34	2.37	2.60	1.88	1.90	2.30	.74	1.17	.75	.37	.76	1.21
CaO	1.16	1.30	1.71	1.07	2.08	1.50	2.18	1.47	1.10	4.38	1.82	2.36	2.42	1.10
Na_2O	1.52	1.38	1.23	2.51	1.55	.93	1.47	1.52	2.57	4.17	4.57	4.82	4.04	1.39
K_2O	4.92	5.11	6.41	6.26	5.91	7.37	5.41	6.02	4.17	1.07	2.02	3.14	2.61	4.45
H_2O-	.07	.08	.03	.08	.06	.15	.07	----	.01	.00	.00	.02	----	.05
H_2O+	4.12	4.08	2.60	2.32	2.63	3.08	2.97	3.15	.89	1.35	.85	.41	.87	1.75
TiO_2	.81	.86	1.05	1.18	1.06	.90	1.14	.98	.42	1.01	.26	.17	.47	.82
CO_2	.03	.01	.01	.09	.07	.00	.00	.03	.09	1.50	.18	1.74	.88	.01
P_2O_5	.24	.27	.32	.51	.29	.34	.40	.33	.12	.36	.05	.09	.16	.16
S	----	----	Trace	.01	Trace	.02	.01	Trace	----	Trace	Trace	----	----	Trace
MnO	.11	.14	.10	.07	.13	.11	.10	.11	.05	.09	.05	.06	.06	.07
BaO	----	----	.03	.15	.08	.16	.09	.10	----	.02	.13	----	----	.08
Total	99.81	99.85	99.66	100.14	99.68	99.82	99.61	100.00	99.81	99.67	99.99	99.81	100.00	99.86
Calculated mineral composition														
Quartz	22.2	21.2	25.0	18.5	23.7	18.7	20.5	----	41.9	33.6	35.6	31.9	----	43.1
Potassium feldspar	2.5	5.7	----	2.7	1.3	2.6	6.2	----	11.8	1.4	1.7	13.6	----	2.1
Plagioclase	13.3	12.1	11.1	22.6	8.7	8.7	14.2	----	23.6	37.4	40.7	42.1	----	11.8
Epidote	2.2	2.9	3.9	----	3.0	2.2	2.0	----	.9	3.8	3.9	----	----	2.1
Chlorite	18.6	20.2	----	----	1.0	2.0	12.2	----	----	9.5	----	----	----	2.0
Biotite	----	----	22.7	24.1	24.8	21.1	----	----	8.9	----	8.0	4.2	----	11.8
Muscovite	38.1	35.0	34.5	29.1	[1] 34.4	42.6	37.1	----	11.2	7.1	8.7	3.8	----	24.3
Apatite	.6	.6	.8	1.2	.7	.8	1.0	----	.3	.9	.1	.2	----	.4
Sphene	.7	.7	1.4	----	1.7	1.2	2.8	----	1.0	2.50	.6	----	----	1.3
Leucoxene	.5	.6	----	.7	----	----	----	----	----	----	----	----	----	----
Magnetite	.5	.5	.2	----	----	----	4.0	----	----	.5	----	----	----	----
Calcite	.1	.0	----	.2	.2	----	----	----	.2	3.6	.4	4.0	----	----
Total	99.3	99.5	99.6	99.1	99.5	99.9	100.0	----	99.8	100.3	99.7	99.8	----	99.5
Character of plagioclase	An_3	An_3	An_6	An_6	Ab_{100}	An_{10}	An_{12}	----	An_8	An_5	An_5	An_3	----	Ab_{100}

[1] Includes 6.50 percent paragonite molecule.

1. Pigeon siltstone. Green foliated metasiltstone from road cut 0.2 mile north of bridge at Laurel, Richardson Cove quadrangle, 2 miles north of report area. Bedding laminae, 2-5 mm thick, differ mainly in proportions of quartz and feldspar to mica and chlorite. Sphene, epidote, and leucoxene are concentrated in some laminae. Grain size is 0.02 mm for both detrital and metamorphic minerals. Potassium feldspar not recognized in thin section. Rock analysis indicates that chlorite contains about 2 iron chlorite (daphnite and ferroantigorite) molecules to 1 magnesium chlorite (amesite or antigorite) molecule. It may be less aluminous and all the K_2O in muscovite.
2. Pigeon siltstone. Green slaty metasiltstone from cut on Tennessee Highway 73, 2 miles east of Gatlinburg, Tenn. Grain size, 0.02-0.05 mm. Otherwise similar sample given in analysis 1.
3. Roaring Fork sandstone. Medium-dark-gray foliated metasiltstone from roadside quarry on east side of Pigeon River, ½ miles south of Hartford, Tenn. Strongly sheared. About 15 percent fine quartz and feldspar sand and 85 percent recrystallized mica and quartz and feldspar silt. Biotite is olive green; rock analysis indicates 65 percent annite, and 35 percent phlogopite. Epidote and sphene, 0.1 mm in diameter, are variably concentrated in bedding laminae.
4. Roaring Fork sandstone. Medium-dark-gray foliated metasiltstone containing fine sand from near top of formation on Pigeon River road, 0.6 mile southeast of Tennessee-North Carolina State line. Quartz is crushed and elongated; mica well is oriented. Biotite is dark olive brown; rock analysis indicates 65 percent annite and 35 percent phlogopite.
5. Longarm quartzite. Medium-dark-gray argillaceous metasiltstone from Pigeon River road, 1 mile above mouth of Mount Sterling Creek. Grain size is 0.04 mm for both detrital and metamorphic minerals. Epidote and sphene occur in uniformly disseminated subhedral to rounded grains, 0.01-0.08 mm in diameter. Biotite is olive green; rock analysis indicates 68 percent annite and 32 percent phlogopite.
6. Wading Branch formation. Medium-dark-gray slaty metasiltstone from Pigeon River road, 1.7 miles below Cold Springs Creek. Grain size 0.06 mm (quartz and feldspar) to 0.03 mm (mica). Biotite is brownish olive; rock analysis indicates 90 percent annite and 10 percent phlogopite. Chlorite is yellow green with high birefringence, probably iron rich.
7. Wading Branch formation. Basal schist from Pigeon River road at Cold Springs Creek. Moderate-greenish-gray finely sandy metapelite. Grain size is 0.1 mm (quartz and feldspar) to 0.5 mm (mica). Quartz is elongated and mica well oriented. Chlorite, probably ripidolite, is blue green with very low birefringence and yellow-brown extinction colors. Plagioclase is largely untwinned, and its composition is assumed. Nearly all the magnetite occurs as octahedral porphyroblasts about 1 mm in diameter.
8. Average of analyses 1-6, recalculated less uncombined water.
9. Roaring Fork sandstone. Medium-grained feldspathic sandstone from quarry near U.S. Highway 441, 1 mile southeast of Great Smoky Mountains National Park Headquarters, 1¾ miles west of report area. Average grain size is 0.15 mm. Moderately sheared. Micas occur largely in recrystallized interstitial material; sparse detrital muscovite. Biotite is dark olive green. Composition of plagioclase determined from thin section.
10. Roaring Fork sandstone. Greenish-gray fine-grained sandstone from cut on Tennessee Highway 73, 1½ miles east of Gatlinburg. Average grain size is 0.7 mm. Moderately sheared. Plagioclase is slightly cloudy; composition determined from thin section. Chlorite, probably penninite, is all metamorphic and emerald green with low birefringence and blue extinction colors.
11. Roaring Fork sandstone. Greenish-gray fine-grained feldspathic sandstone from roadside quarry on east side of Pigeon River, 1½ miles south of Hartford, Tenn. Moderately sheared. Plagioclase is somewhat altered; composition determined from thin section. Biotite is green; rock analysis indicates 65 percent annite and 35 percent phlogopite.
12. Roaring Fork sandstone. Medium-gray fine-grained feldspathic sandstone from Pigeon River road, 0.6 mile southeast of Tennessee-North Carolina State line. Average grain size is 0.13 mm. Strongly sheared; grains are partly crushed. Potassium feldspar mostly untwinned; composition of plagioclase determined from thin section. Biotite is brownish olive.
13. Average of analyses 9-12, recalculated less uncombined water.
14. Wading Branch formation. Olive-gray argillaceous graywacke from Pigeon River road, 1.7 miles below Cold Springs Creek. About 15 percent clastic grains are 0.2-0.3 mm diameter; metamorphic mica is 0.03 mm in diameter. Composition of plagioclase determined from thin section. Both detrital and secondary epidote and sphene are abundant, and magnetite grains are coated with sphene. Biotite is olive brown; analysis indicates 65 percent annite and 35 percent phlogopite.

identified by X-ray diffraction in two pelites of the Snowbird group but could not be identified in thin section. The ferromagnesian minerals include either biotite or chlorite or both, depending largely on the degree to which the rocks have been affected by regional metamorphism. Nearly all the mica seen in thin section is of metamorphic origin; detrital muscovite and chlorite (probably originally biotite), although recognizable in some rocks, are quantitively insignificant.

White mica predominates over biotite and chorite in coarse sandstone of the Longarm and the more argillaceous rocks of the other formations. It is also much more abundant than biotite and chlorite in graywacke of the Wading Branch and in muddy sandstone of the Longarm. Proportions of white mica to ferromagnesian minerals are distinctly varied in fine-grained sandstone and coarser siltstone of the Roaring Fork and Pigeon, ranging from 3:1 to entirely ferromagnesian; ferromagnesian minerals also dominate in rocks of similar size range in the Longarm.

Carbonate appears in many of the rocks of the Snowbird group in amounts ranging from a trace to 5 percent, but it is a major constituent of only a few of them. Some carbonate layers in finer metasandstone and metasiltstone of the Roaring Fork sandstone and Pigeon siltstone in the northwestern part of the area contain as much as 25 percent of calcite or dolomite or mixtures of the two. Such carbonate is distributed in thin layers, and is abundant in very fine current-bedded material. In thin section the carbonate occurs in rather coarsely crystalline untwinned anhedral aggregates associated with the finer or argillaceous parts of the rock. Where it is most abundant, these aggregates have coalesced in most of the space normally occupied by the argillaceous components and replace part of the coarser quartz and feldspar. In the Roaring Fork sandstone in the eastern part of the area, the carbonate has strong external and internal fabric orientation and abundant lamellar twinning, indicating that it was present before the rock was deformed.

The iron-bearing carbonate, ankerite, although abundant in other rocks of the Ocoee series, scarce in the rocks of the Snowbird group. It appears sporadically in the Longarm quartzite as small disseminated grains generally represented by limonite-filled pores in weathered rock.

Pyrite occurs as euhedral crystals in sandstone of the Roaring Fork and Pigeon and seems to have been introduced locally into the more permeable parts of these formations.

The Snowbird group contains a remarkably constant suite of detrital heavy minerals which duplicates that in the basement rocks of the area. Epidote is the most abundant, followed by sphene, magnetite, apatite, and zircon in order of decreasing abundance. Heavy minerals average more than 4 percent of all rocks of the group and as much as 7 percent of some; nevertheless proportions differ widely among different rock types (fig. 16). They are most abundant in the Wading

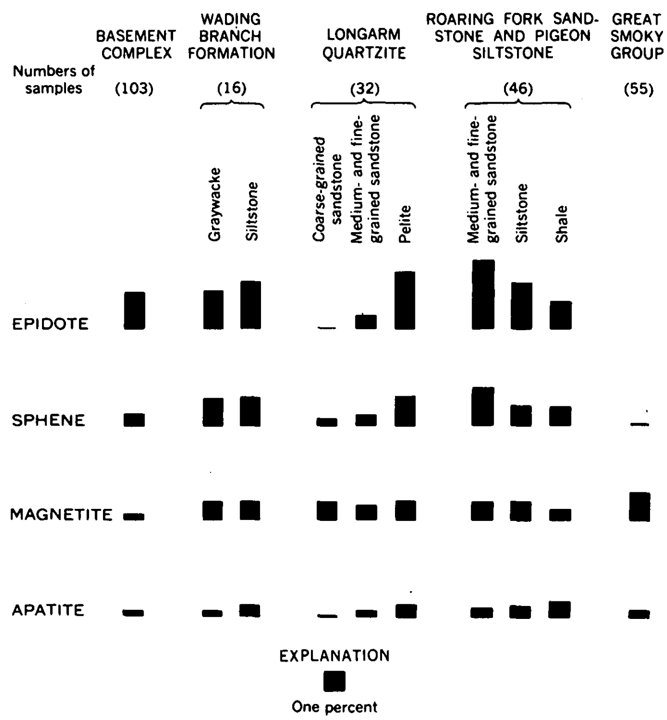


FIGURE 16.—Heavy minerals in rocks of the basement complex, Snowbird group, and Great Smoky group, eastern Great Smoky Mountains.

Branch formation, the sandstones of the Roaring Fork and Pigeon, and pelitic interbeds in the Longarm quartzite; they are least abundant in the coarser quartzite and arkose of the Longarm and in the argillaceous rocks of both the Roaring Fork and Pigeon. Thus the heavy minerals appear to have been winnowed from the coarser parts of the current-bedded rocks but not sufficiently comminuted to appear in the finest sediments.

Grains of epidote and sphene have about the same size, shape, and distribution and appear to have been derived in large part directly from the basement rocks. They are moderately rounded, similar in shape to those of quartz, but somewhat smaller in proportion to their greater specific gravity. The grains are largely detrital as shown by their size relation to detrital quartz and feldspar and by the fact that they are locally concentrated in bedding layers along with apatite and magnetite (fig. 12*C*). In some rocks, epidote appears in detrital polycrystalline grains either alone or with quartz or plagioclase. In some, the larger grains of

678-811 O—63——4

sphene are strongly pleochroic in pink and yellow or have lamellar twining, in both respects like sphene found in much of the basement complex.

Some of the epidote and sphene in these rocks is distinctly finer grained than the rest and is probably secondary. Some specimens, for example, show fine granular coatings of epidote or sphene on larger detrital grains of the same mineral, and similar material is commonly disseminated in the finer grained rocks. Much of this finer epidote and sphene probably represents recrystallized detrital material, although some may be metamorphic epidote derived from calcic plagioclase and sphene derived from sedimentary leucoxene. Such processes may explain, in part, why both minerals are so abundant in the finer grained rocks; nevertheless, the greater part of them was probably ultimately derived from disintegration of the basement rocks.

Apatite is entirely detrital. It occurs as much-rounded grains about the same size as those of quartz, and its distribution is like that of epidote and sphene, at least in the coarser rocks. Chemical analyses (table 7) and visual estimates show that apatite is very widespread and that very fine grained apatite amounts to 1 percent in some of the darker finer grained rocks. As apatite in the basement complex is fairly coarse and euhedral, its roundness and its abundance in the finer sediments derived from the complex presumably resulted from low resistance to abrasion as compared with other transported minerals of the sediments.

Whereas epidote, sphene, and apatite follow a common distribution pattern in rocks of the Snowbird group, magnetite and zircon show different frequency relations. Magnetite occurs both as obviously detrital grains and as anhedral aggregates of smaller recrystallized grains. It is commonly intergrown or coated with authigenic sphene. It is also especially conspicuous in the light-colored quartzite of the Longarm, where it commonly is concentrated in thin discontinuous layers.

Zircon of varied habit is widespread in the Wading Branch and Longarm and somewhat less widespread in the Roaring Fork and Pigeon; as it rarely occurs in more than trace amounts (less than 0.1 percent), its relative abundance is not adequately known. Zircon grains range from 0.02 to 0.1 mm in the Roaring Fork and Pigeon and may be as large as 0.2 mm in the Longarm quartzite. They range in shape from rather well rounded fragmental or subhedral grains to sharply euhedral grains, commonly in the same specimen. Like magnetite, zircon is concentrated in heavy-mineral layers, especially in the Longarm quartzite. Rarely zircon grains are found enclosed in detrital quartz or potassium feldspar.

Tourmaline occurs in only 2 of the 100 sections studied. These are from siltstone and metashale of the Roaring Fork and Pigeon, in which tourmaline grains are very few and appear to be angular detrital fragments.

CHEMICAL COMPOSITION

Chemical compositions of some rocks of the Snowbird group are given in table 7, along with calculated mineral compositions in terms of somewhat idealized modal minerals. Although such attempts are at best approximations, they serve as a partial control on mineral identification and composition and on quantitative estimates of rock composition made from thin sections.

The chemical composition of the sandstones of the group obviously differs widely from that of average sandstone, as cited by Clarke (1924, p. 34) which includes many calcareous sandstones of the shelf type. The sandstones of the Snowbird group are much richer in alumina and alkalies because of their large feldspar content; they are also richer in lime, iron, and titania because of the epidote and sphene present. In general, their composition is much more nearly that of granodiorite than average sandstone, and in this respect they resemble graywackes cited by several authors. Compared to Archean graywackes (table 8, analysis 6) cited by Pettijohn (1943, p. 250), sandstones of the Roaring Fork and Pigeon differ in that they are more siliceous and low in iron, magnesia, and lime, although they are similar in the ratios of sodium to potassium and alkalies to alumina. Feldspathic sandstones of the Franciscan series (table 8, analysis 7) cited by Taliaferro (1943, p. 134, 136) contain amounts of silica, alumina, alkalies, and lime comparable to the Snowbird rocks, but notably more iron and magnesia, apparently due to a large proportion of ferromagnesian minerals and mafic rock fragments.

The more pelitic rocks of the group depart less widely from the composition of Clarke's average shale; nevertheless, the Snowbird rocks contain distinctly more alumina and potassium, and their ferrous iron greatly exceeds ferric iron presumably because of long burial and metamorphism. As compared to an Ordovician shale of the shelf type (table 9, analysis 3), the Snowbird pelites have closely similar silica and alumina contents but greater iron, magnesia, lime, and sodium, reflecting presumably larger proportions of detrital feldspar, epidote, and other ferromagnesian constituents. Two rocks rather similar chemically to average Snowbird pelite are the older Precambrian Knife Lake slate (table 9, analysis 4) and glacial varved clay derived from the Precambrian crystalline rocks of Finland (table 9, analysis 5) cited by Pettijohn (1949, p. 285). Both of them are probably products of rapid erosion and sedimentation from little-weathered plutonic-igneous and metamorphic rocks. The composition of the Snowbird pelites departs from that of the rocks cited mainly in that they are lower in sodium, lime, and magnesia—the relatively soluble constituents—and higher in potassium and alumina—both likely to be retained during weathering and sedimentation; thus it may be concluded that weathering of the source terrane was a more important factor in producing the Snowbird rocks. Deep weathering of the source area, at least at the beginning of Snowbird time, is suggested by the high alumina and low feldspar content of the basal schist of the Wading Branch formation (table 10).

TABLE 8.—*Chemical composition, in percent, of sandstone and graywacke, Ocoee series, Great Smoky Mountains area, and of comparable rocks*

	1	2	3	4	5	6	7	8
SiO_2	66.6	73.37	75.99	70.09	68.85	61.96	69.69	75.5
Al_2O_3	14.6	13.33	13.28	14.26	16.73	14.31	13.53	11.4
Fe_2O_3	1.9	.93	.81	1.11	1.16	1.14	.74	2.4
FeO	3.3	1.89	1.27	3.47	1.31	4.53	3.10	--------
MgO	2.0	.80	.63	1.21	1.22	3.45	2.00	.1
CaO	3.2	1.28	.56	1.10	.52	4.07	1.95	1.6
Na_2O	3.2	4.15	3.07	1.40	1.88	3.20	4.21	2.0
K_2O	3.8	2.66	2.60	4.46	3.71	2.37	1.71	5.6
H_2O-	--------	--------	--------	--------	--------	--------	.26	} .6
H_2O+	.5	.89	.98	1.76	2.03	1.94	2.08	
TiO_2	.7	.48	.55	.82	.62	.56	.40	tr
CO_2	--------	--------	--------	.01	.17	2.17	.23	.4
P_2O_5	.2	.16	.14	.16	.21	--------	.10	--------
MnO	--------	.06	.05	.07	.03	--------	.01	.2
BaO	--------	--------	.07	.08	.04	--------	--------	--------
S	--------	--------	--------	tr	.99	--------	--------	--------
C	--------	--------	--------	--------	.53	--------	--------	--------
Total	100.0	100.0	100.0	100.0	100.0	99.70	100.04	99.8

1. Average composition of basement rocks calculated from modal and chemical analyses of specimens from the Dellwood quadrangle and adjacent areas. Plutonic rocks and Carolina gneiss weighted equally.
2. Sandstone, average of four analyses, Roaring Fork sandstone, eastern Great Smoky Mountains (table 7, analysis 13); recalculated omitting $CaCO_3$.
3. Sandstone, average of three analyses, Rich Butt and Thunderhead sandstones, eastern Great Smoky Mountains (table 11, analysis 9).
4. Graywacke, Wading Branch formation, eastern Great Smoky Mountains (table 7, analysis 14).
5. Graywacke, Anakeesta formation, eastern Great Smoky Mountains (table 11, analysis 10).
6. Archean graywackes, average of six analyses, from Pettijohn (1949, p. 250, table 64, cols. A and B).
7. Franciscan (Jurassic) graywackes, average of three analyses, from Taliaferro, as cited in Pettijohn (1949, p. 250).
8. Arkose, average of three analyses, from Pettijohn (1949, p. 259).

ORIGIN AND MANNER OF DEPOSITION

The mineralogical and chemical compositions of the rocks of the Snowbird group indicate that their source was remarkably similar to the basement complex as it exists today in the southeastern Great Smoky Mountains area; the conditions of erosion and sedimentation by which this material was made over into the sedimentary rocks of the Snowbird group still remains to be considered. The closely interrelated Longarm quartzite, Roaring Fork sandstone, and Pigeon siltstone represent the dominant mode of sedimentation; the distinctive character of the Wading Branch formation, on the other hand, suggests that the earliest phases of this process were considerably different and offers some clues as to the nature of the surface and the materials on which the Snowbird rocks were laid.

The notably high alumina and low feldspar content of the basal phyllite and schist of the Wading Branch (table 10) and the predominance of quartz fragments in its lower beds suggest that these rocks were formed from residual soil produced by prolonged weathering of the basement rocks. Comparison with the chemical composition of modern residual clay formed on gneisses similar to those beneath the Snowbird (table 10, analysis 4) shows, however, that magnesia, lime, and alkalies are more abundant in the Wading Branch, either as a result of incomplete weathering or as restorations during sedimentation, diagenesis, and metamorphism. The original sediment was deposited, in part at least, in quiet water; nevertheless, quartz granules and pebbles are commonly mixed with argillaceous material.

Distribution of rocks of the Snowbird group in much of the Dellwood quadrangle, where they are relatively thin, suggests that they were deposited on a surface of low but significant relief. In a few places, the basal phyllite and other rocks of Wading Branch type are absent, and very coarse pebbly quartzite of Longarm aspect lies directly on the basement. This evidence, together with the irregular distribution (p. B27) of the coarser clastics in the Wading Branch and their variation in thickness, suggests filling of lower areas on an uneven topographic surface or, alternatively, the presence of old river-channel deposits. Subsequent

TABLE 9.—*Chemical composition in percent, of pelitic rocks of the Ocoee series, Great Smoky Mountains area, and comparable rocks*

	1	2	3	4	5
SiO_2	56.65	53.96	56.29	60.88	54.76
Al_2O_3	19.92	24.23	19.22	17.78	17.65
Fe_2O_3	1.77	1.73	} 4.39	1.94	5.46
FeO	5.65	3.65		4.07	2.88
MgO	2.30	1.93	1.65	3.53	3.45
CaO	1.47	.39	.09	2.77	1.96
Na_2O	1.52	1.33	.19	2.65	2.80
K_2O	6.02	6.11	10.85	3.16	3.00
H_2O-	--------	--------	3.54	.13	2.44
H_2O+	3.15	3.61	2.04	1.91	3.01
TiO_2	.98	.87	.64	.62	1.16
CO_2	.03	--------	--------	--------	--------
P_2O_5	.33	.19	--------	.29	.15
MnO	.11	.32	--------	--------	.10
BaO	.10	--------	--------	--------	--------
SO_3	--------	--------	.72	--------	--------
S	Tr	.73	--------	.10	--------
C	--------	.95	--------	1.70	1.18
	100.00	100.00	99.62	101.53	100.00

1. Average pelite of Snowbird group (table 7, analysis 8).
2. Average pelite of Great Smoky group (table 11, analysis 5).
3. Glenwood feldspathic shale, Ordovician, Minneapolis, Minn.; R. B. Ellestad, analyst; (Gruner and Thiel, 1937).
4. Knife Lake slate, Archean, Minn., F. F. Grout analyst; average of three analyses; (Grout, 1933, p. 997).
5. Late-glacial varved clay, Leppakoski, Finland; L. Loka analyst; equal parts summer silt and winter clay (Pettijohn, 1949, p. 285).

TABLE 10.—*Chemical and mineral composition in percent, of basal part of the Wading Branch formation, and of residual clay*

[Analysts: L. D. Trumbull, analyses 1, 2, 3; S. S. Goldich, analysis 4]

Analysis	1	2	3	4
Laboratory No	53-2389CD	53-2390CD	53-2388CD	--------
Field No	220g	241g	219g	--------
Chemical analyses				
SiO_2	50.57	54.46	55.77	55.07
Al_2O_3	28.06	25.06	25.39	26.14
Fe_2O_3	1.57	1.62	1.49	3.72
FeO	6.39	5.59	6.80	2.53
MgO	1.57	1.91	1.93	.33
CaO	.42	.87	1.19	.16
Na_2O	1.07	.46	1.04	.05
K_2O	4.28	5.66	3.33	.14
H_2O-	.08	.06	.06	.64
H_2O+	4.65	2.75	1.52	9.75
TiO_2	.84	.90	.74	1.03
CO_2	.00	.02	.00	.36
P_2O_5	.41	.37	.34	.11
MnO	.13	.11	.17	.03
SO_3	--------	--------	--------	Tr
BaO	--------	--------	--------	.01
S	--------	--------	--------	.04
Total	100.04	99.84	99.77	100.11
Mineral composition				
Quartz	17.4	23.0	25.9	--------
Plagioclase	4.0(An_0)	.0	11.5(An_{23})	--------
Muscovite	[1] 47.0	[2] 52.6	18.4	--------
Paragonite	7.2	.0	.0	--------
Biotite	.0	9.8	[3] 13.3	--------
Chlorite	[4] 7.1	.0	.0	--------
Chloritoid	12.9	.0	.0	--------
Staurolite	.0	.0	6.0	--------
Kyanite	.0	3.2	14.6	--------
Garnet	Tr	[5] 10.6	[6] 6.7	--------
Ilmenite	1.6	--------	0.7	--------
Magnetite	2.3	.4	1.6	--------
Apatite	.7	.4	.8	--------
Allanite	.0	.1	.0	--------
Total	100.2	100.1	99.5	--------

[1] Sericite—$K_2O \cdot 4Al_2O_3 \cdot 8SiO_2 \cdot 3H_2O$ (Shannon, 1926, p. 372).
[2] Includes 1.0 percent Na_2O by volume.
[3] Composition of biotite, in weight percent: SiO_2, 34; Al_2O_3, 16; Fe_2O_3, 2; FeO, 20; MgO, 13; K_2O, 8; TiO_2, 3; H_2O, 3.
[4] Composition of chlorite: $9MgO \cdot FeO \cdot 2Al_2O_3 \cdot 6SiO_2 \cdot 8H_2O$.
[5] Composition of garnet, in weight percent: almandine, 74; pyrope, 12; grossularite, 8; spessartite, 6 (n=1.802, A=11.548).
[6] Composition of garnet, in weight percent: almandine, 63; pyrope, 20; grossularite, 5; spessartite, 2 (n=1.794, A=11.542).

1. Chloritoid phyllite, Wading Branch formation, North Carolina Highway 284, a mile northwest of Cove Creek Gap. Thinly layered pale-greenish-gray and greenish-gray phyllite with small chlorite, chloritoid, and garnet porphyroblasts in sericite and fine-grained quartz and feldspar. Average grain size is 0.1 mm. Slight slip cleavage; deformed garnets. Garnet zone, albite-epidote-amphibolite facie
2. Garnet mica schist, Wading Branch formation, road cut on U.S. Highway 19, 0.6 mile southwest of Soco Gap. Light-gray, silvery crinkled muscovite schist, with grain size ranging from 1.5 mm (mica) to 0.2 mm (quartz). Kyanite is mostly about 1 mm in longest dimension. Muscovite is segregated in foliated lenticles, quartz is in knots. Garnet porphyroblasts, 3 mm in diameter, show two stages of growth. Micas show slight postcrystalline deformation but no cataclasis. Kyanite is somewhat altered to sericite. Kyanite zone; amphibolite facies.
3. Oligoclase-kyanite-mica gneiss, Wading Branch formation, southwest end of Buck Mountain, Dellwood quadrangle. A foliate fabric of quartz (0.1–0.5 mm) and muscovite (1 mm) is interrupted by irregular patches and lenticles of oligoclase and porphyroblasts of kyanite (14 mm), staurolite (1.5 mm), oligoclase (5 mm), and almandine. Oligoclase encloses all other minerals except kyanite. A small amount of moderate-brown biotite occurs mostly near garnet. Slight late cataclasis. Kyanite zone; staurolite-kyanite subfacies of amphibolite facies.
4. Residual clay from Morton gneiss of Thiel and Dutton (1935), Ramsey Park, Redwood Falls, Minn.

deformation has been so great that more details of the nature of the pre-Snowbird topography and its relation to the basal sediments are not available.

The distribution and variation in thickness suggest that the basement rock was covered by a deeply weathered residual mantle at the beginning of Snowbird deposition and that most of it, at least in the area of the present study, was reworked before being incorporated in the Wading Branch formation. The general paucity of coarse sediments and indeed the complete absence of larger fragments of the basement rocks, as such, show that no vigorous erosion or wave action occurred during reworking. In fact, the lowermost part of the formation may have been deposited under terrestrial conditions or under marine conditions along a very sheltered part of the coast. The poorly sorted graywacke higher in the formation, especially farther northwest where it is thicker, shows that large quantities of less completely weathered regolith were removed at a rate that for some time kept pace with weathering in the source area. This material was laid down rather rapidly in water that was relatively quiet and, if marine, must have been at least below the reach of wave action.

The deposition of the Longarm quartzite signifies a marked change from the previous manner of sedimentation to transport by bottom currents in an extensive body of water, in which the Longarm and the other two formations of the group were deposited. Widespread current bedding shows that in the Longarm of the northern belt, at least, the direction of transport was dominantly toward the west and northwest. Not much was learned about current directions in the Roaring Fork and Pigeon in the report area. Immediately to the north, however, current directions in the Pigeon siltstone were predominantly west-southwest (Hamilton, 1961, p. A-14). Such currents were rather strong in the Longarm quartzite and parts of the Roaring Fork sandstone, where coarse sand and fine gravel were carried and crossbedded strata several feet thick were formed. They were much weaker in the Roaring Fork, generally, and in the Pigeon siltstone, where fine sand and coarse silt were the coarsest material carried and individual current-bedded layers are rarely more than an inch thick.

Along with the apparent decrease in current energy, as revealed by crossbedding, there was a systematic northwestward decrease in grain size throughout the upper three formations of the group. The coarsest rocks are limited to the Longarm quartzite in the southeastern part of the group (fig. 10); farther northwest in the Roaring Fork, the sandstone becomes progressively finer, and siltstone and shale are dominant in the northwesternmost exposures of the group. At some places, tongues of coarser rocks projected farther than others, as in the Roaring Fork on Gabes Mountain and in scattered beds of relatively coarse sandstone in the lower part of the Pigeon. Both slackening of currents and the presence of finer sediments toward the northwest are probably due to deepening water in that direction; they also indicate that the currents were most active in shoreward areas to the southeast and east, as would be true if they were tidal or deltaic currents.

A record of northwestward tilting of the region during deposition is evident in southeastward convergence of the three lower formations of the Snowbird group in the Dellwood quadrangle and adjacent areas. The Longarm quartzite thickens northwestward from a featheredge near Dellwood to about 200 feet on Buck Mountain and about 1,000 feet on the Cataloochee Divide in a distance of 10 miles measured along the bedding. In the same way, the Wading Branch formation thickens to 50 or 100 feet on the Cataloochee Divide and 300–400 feet in the Shelton Laurel belt. The Roaring Fork standstone thickens similarly, but westward rather than northward, from its eastern limit near Cove Creek Gap to 1,500 feet thick at the southwest end of the Dellwood-Cherokee belt. These rates of westward and northwestward thickening, extrapolated to the observed thicknesses of the Snowbird group in the type belt of outcrop, are shown in the right half of the stratigraphic diagram (fig. 10). The Wading Branch formation persists as a basal unit a few feet thick as far as the Longarm quartzite can be recognized, and the Roaring Fork sandstone wedges out somewhat farther northwest than the two lower formations.

The Wading Branch formation, composed of the muddy sediments derived from the newly eroded land, may be to some extent transgressive toward the southeast, and its upper beds overlapped by the basal part of the Longarm quartzite; however, the time-rock boundaries of figure 10 are probably more nearly parallel to the base of the Wading Branch than is suggested by the vertical exaggeration of the diagram. Thus, the thinness of the Snowbird group in the Dellwood quadrangle probably resulted from the fact that this was a bypass area during deposition of the rocks to the northwest rather than from a shorter period of submergence or from erosion before deposition of the overlying Great Smoky group.

We infer, therefore, that the land area during Snowbird time lay not far to the southeast and east, while the deeper part of the sedimentary basin sank as much as 2½ miles as indicated by the thickness of the Snowbird group in the northern part of the report area. The source area must have been uplifted concurrently to provide material for the sedimentary rocks, gradually keeping pace with mechanical disintegration and partial chemical weathering of the basement rocks, but never producing relief enough to yield really coarse material to the basin.

RICH BUTT SANDSTONE

DEFINITION

The Pigeon siltstone in the northeastern part of the report area is overlain by sandstone and other rocks named the Rich Butt sandstone (King and others, 1958, p. 906) for Rich Butt Mountain, a prominent spur on the north side of Mount Cammerer. Characteristic rocks of the formation are exposed along the southeast side of Big Creek above the bridge at the community of Mount Sterling, and this section is regarded as the type locality. The rocks lie conformably on the Pigeon siltstone and are the highest unit in the sequence in the foothill belt beneath the Greenbrier fault in the report area. They could be included in the Snowbird group, but features of composition and bedding in the Rich Butt suggest rather a transition in sedimentary character from the Snowbird to the Great Smoky group, and the formation is at present included in neither group.

TYPE AREA

The most characteristic rock of the Rich Butt sandstone in the type area is medium- to fine-grained feldspathic sandstone with sharply contrasting dark argillaceous layers and laminae. The laminae are spaced a millimeter to a foot apart; thicker sandstone beds range in thickness from 1 foot to at least 20 feet, and some of these beds contain sparse chips and slabs of dark slate or metasiltstone. In the laminated sandstone the sandstone layers are, in part, lenticular between thinner but more continuous argillaceous laminae (fig. 20*A*); but where the argillaceous layers are most abundant, the beds are more regular. Where the argillaceous layers are least abundant, they trail out in thin wisps in sandstone resembling that in the Pigeon and Roaring Fork. Current bedding is less distinct than in the Snowbird group, but it is probably responsible for much of the lenticular bedding of the Rich Butt sandstone.

The argillaceous layers are medium-dark-gray argillite or slate commonly containing abundant angular sand grains. Where interbedded with lenticular sandstone, they are current bedded on a small or minute scale; elsewhere the dark layers are thin and evenly bedded, probably as a result of settling from suspension. They locally contain load casts, in which the overlying sand has worked its way into the underlying mud before consolidation (fig. 17). These features occur principally where the contrast between sandstone and argillite layers is marked, and this may be the reason why load casts are not found in the less contrasting beds of the Pigeon siltstone. Their strongly cuspate

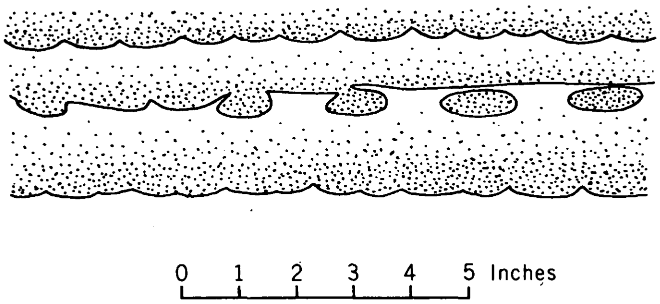


FIGURE 17.—Graded bedding and load casts in interbedded argillite and standstone, Rich Butt sandstone, south slope of Rich Butt Mountain.

shape suggests that they were induced by current oscillation of unconsolidated sand over a weak but coherent layer of mud.

A distinctive rock, exposed on the trail to Mount Sterling northeast of the footbridge across Big Creek opposite the park gate, consists of many alternate layers of light-gray fine-grained ankeritic sandstone and darker argillaceous siltstone. The sandstone consists of highly angular quartz and feldspar contains as much as 25 percent ankerite (see chemical analysis, table 11, analysis 7), which weathers to various shades of orange brown. Sandstone layers, a few millimeters to 2 feet thick, are interbedded with argillaceous layers, as much as half an inch thick; and the bedding is similar to that in the laminated sandstone previously described. These ankeritic rocks, although conspicuous, are not abundant; they seem to be associated with lateral transition from dominantly sandy to dominantly argillaceous parts of the formation.

Beds and lenses of very coarse sandstone or fine conglomerate, 1 to 10 feet thick, occur in a few places northwest of Big Creek. They consist of grayish or bluish quartz and white feldspar grains, 6 mm or less in diameter, and are well sorted in some places and distinctly muddy in others. Some beds contain intraformational fragments of argillite. These coarse beds are scattered throughout the vertical extent of the formation: near its base, on Rich Butt Mountain and east to Turkey Knob; near the middle, east of Mount Cammerer; and in the upper part, on Big Creek.

The Rich Butt sandstone becomes dominantly pelitic south of Big Creek, the change taking place abruptly west of Ivy Gap. On the southeast side of Mount Sterling Ridge and east of Indian Ridge, most of the formation is dark well-bedded argillite or slate containing contrasting layers, 2 inches or less thick, of lighter colored fine-grained sandstone. The argillite forms generally carbonaceous and pyritic homogeneous units, as much as 50 feet thick, resembling pelitic rocks of the Anakeesta formation in the Great Smoky group. These argillaceous rocks of the Rich Butt mainly intertongue with the sandstone in the type area farther northwest; in part, however, they may be stratigraphically lower beds.

OTHER AREAS

Rocks assigned to the Rich Butt sandstone on the basis of lithologic character and bedding features occur in two areas on the north side of Greenbrier Pinnacle and in a third area just north of Gatlinburg. The rocks in the first two areas are mainly sandstone with minor amounts of argillite, separated from the Pigeon siltstone by low-angle thrust faults beneath the Greenbrier fault. The rocks north of Gatlinburg are dark-gray thin-bedded sandy argillite and siltstone resembling the pelitic rocks of the Rich Butt east of Mount Sterling. They are part of a larger body to the west, interpreted by King (1963) as occupying a structural position similar to the two fault slices farther east.

PETROGRAPHY

Studies of 20 specimens from the Rich Butt sand stone show that potassium and plagioclase feldspar occur in much the same amounts and proportions to quartz as in the Roaring Fork sandstone. Plagioclase is everywhere albite and considerably exceeds potassium feldspar in all but a few specimens. The proportion of metamorphic mica in most specimens of sandstone is less than 10 percent; but it is considerably more than that in others, which are less well sorted than the sandstone of the Roaring Fork and Pigeon. Muscovite predominates generally over biotite and chlorite.

Greater differences appear in the accessory minerals of the Rich Butt sandstone. Epidote and sphene are virtually absent, in marked contrast to their abundance in the Snowbird group. Tourmaline, scarce in the Snowbird, occurs in nearly half the sections from both sandstones and argillite of the Rich Butt. Finely disseminated carbon is also present, especially in the more argillaceous parts of the formation, and magnetite, apatite, and zircon, are widespread.

THICKNESS

The Rich Butt sandstone has a maximum exposed thickness of 4,000 feet just east of Mount Cammerer fire tower. It thins westward as the upper 800 feet of the formation is cut off by the Greenbrier fault and the lower part tongues out in the Pigeon siltstone; thus on Rich Butt Mountain the formation is only 1,800 feet thick, and farther west the entire formation disappears beneath the Greenbrier fault. About 3,000 feet of beds constitute the type section on Big Creek, where part of the rocks exposed near Mount Cammerer are cut out by the Greenbrier fault. West of

Mount Sterling Gap, the formation is also reduced to about 2,000 feet largely by the Greenbrier fault and possibly by minor faulting within the Rich Butt and between it and the Roaring Fork sandstone.

STRATIGRAPHIC RELATIONS

The boundary between the Rich Butt sandstone and the underlying Snowbird group is gradational and indefinitely located in most places. It is mapped from the point where sandstone with contrasting dark laminae or intraformational fragments first appears, but this occurs at varying stratigraphic positions in different sections. The change is least definite in the southeastern part of the outcrop belt, where the formation is fine grained throughout. Farther northwest, on Rich Butt Mountain, where massive coarse-grained sandstone occurs low in the formation, the base, and even tongues of the Rich Butt in the underlying Pigeon, can be located more exactly.

The Rich Butt standstone seems to have been deposited on the Snowbird group without important interruption, but its accessory minerals and type of bedding, as well as the presence of intraformational and arkosic conglomerates, suggest that gradual changes occurred both in the source from which sediments of the Rich Butt were derived and in the manner of their transportation and deposition. In general, these lithologic features indicate a closer affinity with the Great Smoky group than with other rocks of the region and therefore suggest a vertical transition between the Snowbird and Great Smoky groups.

GREAT SMOKY GROUP

DEFINITION

The main part of the Great Smoky Mountains consists of a very thick sequence of clastic rocks to which Keith (1895) gave the name Great Smoky conglomerate. Where he first found these rocks in the Knoxville quadrangle, he divided them into four formations, from oldest to youngest, Cades conglomerate, Thunderhead conglomerate, Hazel slate, and Clingman conglomerate. In subsequent work in the Great Smoky area and farther east, Keith (1904, p. 6; 1907) found that this subdivision could not be maintained and he called the equivalent rocks Great Smoky conglomerate because of "its notable development in the Great Smoky Mountains southwest of Pigeon River." The current study has resulted in subdividing the Great Smoky conglomerate in the area of Keith's original work but in a somewhat different manner than his; accordingly, the term "Great Smoky" is elevated to the status of a group which includes the Elkmont sandstone followed in ascending order by the Thunderhead sandstone and the Anakeesta formation (King and others, 1958, p. 957). The Thunderhead sandstone is by far the most extensive of these formations, for it occupies about half of the eastern part of the Great Smoky Mountains and forms all the higher parts of the range. The Elkmont sandstone and Anakeesta formations are more restricted units intertonguing with the lower and upper parts of the Thunderhead, respectively.

ELKMONT SANDSTONE

DEFINITION

The Elkmont sandstone forms a belt of varied width extending from Greenbrier Pinnacle westward across Mount Winnesoka and into the adjacent report area where it was named for exposures in the vicinity of Elkmont, Tenn. (King and others, 1958, p. 958). The formation in the eastern Great Smoky Mountains consists of medium- to coarse-grained feldspathic sandstone and interbedded sandy slate; no conglomerate is present, the lowest mappable beds containing quartz-feldspar conglomerate being regarded as either the basal part or tongues of the overlying Thunderhead sandstone. The formation in the report area ranges in thickness from 800 to 3,000 feet; near Elkmont it is as much as 4,000 feet thick; and father west, where it includes conglomerate beds, it is even thicker (Neuman and Nelson, written communication).

LITHOLOGY

The Elkmont sandstone on Bald Top Ridge, 7 miles east of Gatlinburg, consists of 3,000 feet of interbedded medium- and fine-grained highly feldspathic sandstone and gray fine-grained argillaceous sandstone and slate. Units, 100–200 feet thick, are dominantly either sandstone or argillaceous rocks, the argillaceous units more abundant in the lower part of the formation and the sandstone in the middle and upper parts.

The sandier parts of the formation consist of massive sandstone beds, 2–15 feet thick, with little or no internal structure, except for occasional coarse cross lamination. Such beds are separated from one another by darker finer grained interbeds that range from a few inches to 2 or 3 feet thick; they commonly diminish to thin seams or pass laterally into layers of dark argillaceous chips similar to those in the Rich Butt sandstone. Grains in the sandstone beds are rarely as great as 1 mm, but a few beds contain grains as large as 2 or 3 mm.

The argillaceous units contain much slate and fine-grained argillaceous metasandstone characterized by alternate sandy layers generally less than an inch thick. More sharply defined sandstone beds, a foot or two thick, are commonly interbedded with thinner bedded more argillaceous rocks. The argillaceous units are not well exposed, so that the proportion of sandstone in them can only be estimated, but it is probably close to 50 percent.

Argillaceous rocks dominate the lower part of the Elkmont throughout, but the upper part becomes increasingly sandy and thicker bedded toward the west. On Mount Winnesoka the formation consists almost wholly of sandstone beds, 5–20 feet thick in the lower part and thinner in the upper part. The exposed thickness of the formation is here reduced to 2,200 feet mainly because the lower beds, which dip somewhat less steeply than the underlying Greenbrier fault, are cut out updip on Mount Winnesoka.

STRATIGRAPHIC RELATIONS

The upper part of the Elkmont sandstone intertongues westward with the lower part of the Thunderhead sandstone to a large extent. This is well shown southwest of Mount Winnesoka, where the top of the Elkmont descends westward about 1,500 feet stratigraphically in 3 miles. Thus at the west edge of the report area most of the Elkmont has passed laterally into coarser beds mapped with the Thunderhead sandstone, and the remaining Elkmont consists of 800 feet of dark sandy slate.

The base of the Elkmont is not known in the northern part of the report area, as its lower beds are cut out by the Greenbrier fault. To the southeast, where the Great Smoky group conformably overlies the Snowbird group, pelitic rocks several hundred feet thick commonly form the basal part of the Great Smoky group; however, as such pelitic rocks are abundant throughout the Thunderhead sandstone in the southern part of the report area, a specific correlation of the basal beds with the Elkmont is not justified.

As noted earlier, the Elkmont lithologically resembles the Rich Butt sandstone; in fact, except on a structural basis, it was difficult to distinguish between the Elkmont southwest of Greenbrier Pinnacle and the faulted slices of Rich Butt to the east. Moreover, as the Great Smoky group is known to succeed the Snowbird above the Greenbrier fault and as the Rich Butt appears in the same stratigraphic position beneath it, the two formations may possibly be essentially the same. They are, however, separated by a structural break of many miles and, in the absence of more definite evidence of their identity, they are treated as separate though possibly equivalent units.

THUNDERHEAD SANDSTONE

DEFINITION

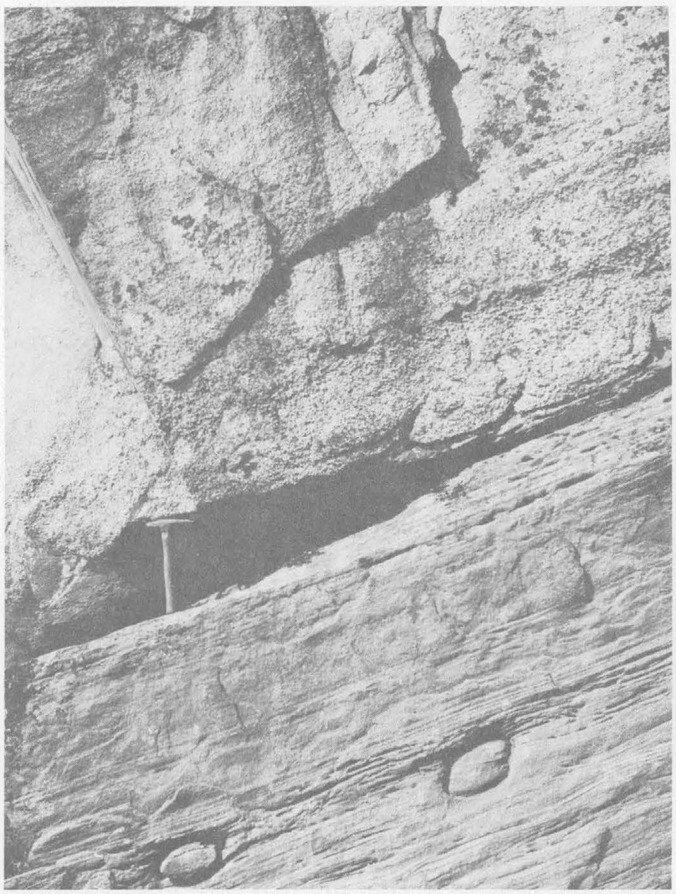
The Thunderhead sandstone is equivalent to the Thunderhead conglomerate of Keith (1895, p. 3), named for Thunderhead Mountain on the crest of the Great Smoky Mountains west of the area of this report. In the eastern part of the Great Smoky Mountains, the Thunderhead sandstone, 6,000–12,000 feet thick, is a most impressive unit. It makes up the bold north-facing slope and much of the high crest of the range from Mount LeConte eastward to Mount Guyot and Mount Cammerer. Rugged topography and extensive cliffy outcrops characterize the formation throughout the mountains, and many waterfalls, such as Rainbow Falls and Ramsey Cascade, adorn the streams which flow across it. It is abundantly exposed on roads and trails in the northeastern part of the Great Smoky Mountains National Park, especially in the vicinity of Bull Head and Mount LeConte. The most accessible exposures are on U.S. Highway 441 between Chimneys Campground and "The Loop."

The Thunderhead sandstone in the northeastern part of the mountains consists of lower, middle, and upper parts, distinguished by different lithologic features and relations to the overlying Anakeesta formation. These units are recognized only on the north slope of the mountains and are not mapped elsewhere in the formation. They are not the same as the three members described by Stose and Stose (1949, p. 280), which are in the lower part of the Thunderhead as defined in this report.

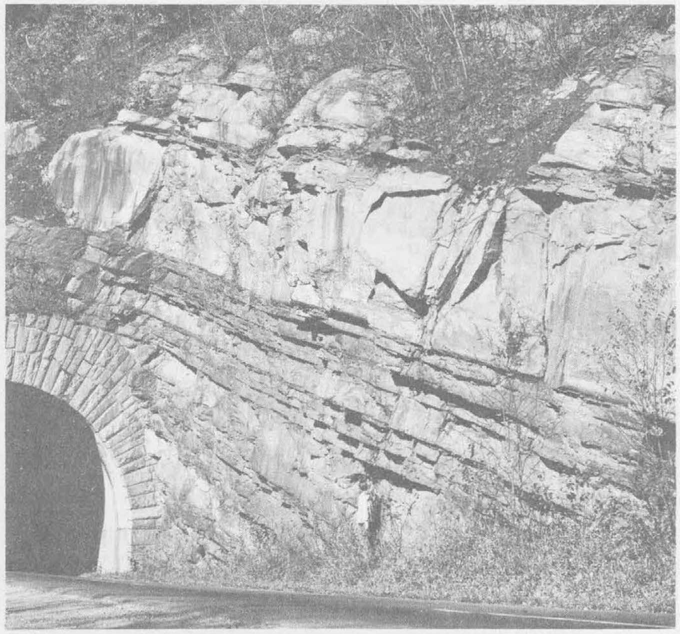
GENERAL LITHOLOGIC FEATURES

The Thunderhead sandstone is least deformed and altered along the crest and north slope of the range; its principal lithologic features and stratigraphic relations therefore have been determined here, and the following descriptions apply primarily to the formation as seen in that part of the report area. Farther southeast the formation occupies large areas, but it is more intensely folded, its internal stratigraphic continuity is more obscure, and the increasing regional metamorphism masks its original lithologic character. The southeastern rocks are described in the section on metamorphism.

The Thunderhead sandstone is distinguished from the Roaring Fork, Rich Butt, and Elkmont sandstones by the greater thickness and coarseness of its beds (fig. 18). The most abundant rock in the formation is medium- to coarse-grained feldspathic sandstone or arkose, but this is interbedded with various amounts of arkosic pebble conglomerate, finer grained feldspathic sandstone, argillaceous metasandstone, and dark-gray slate. All the rocks contain metamorphic biotite and their color, where fresh, ranges from light salt-and-pepper gray to darker gray depending upon the amount of biotite and other dark constituents. The finest grained rocks are dark neutral-gray slates, which form thin interbeds between much thicker sandstone beds.



A. Lower part of quartz-feldspar conglomerate bed, 35 feet thick, overlying thinner bedded calcareous sandstone with calcareous concretions. Shows typically sharp contact at base of conglomerate and small channel at left of hammer.

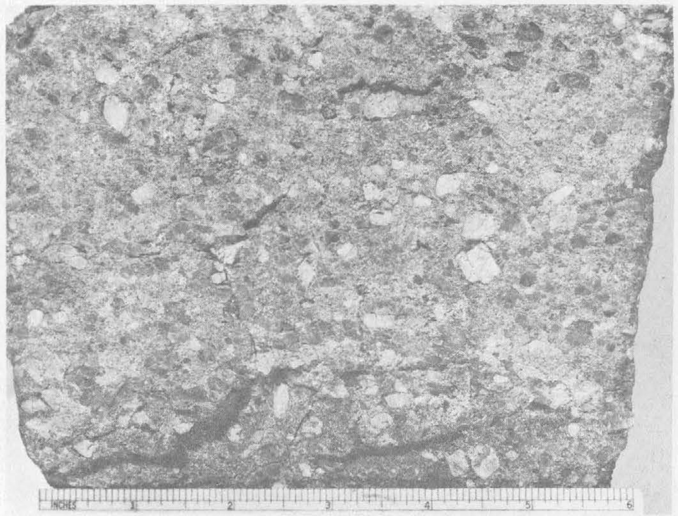


B. Thick graded sandstone beds in Thunderhead sandstone with thin interbeds and partings of slate and fine argillaceous sandstone. East portal of highway tunnel east of Chimneys Campground, Great Smoky Mountains National Park.

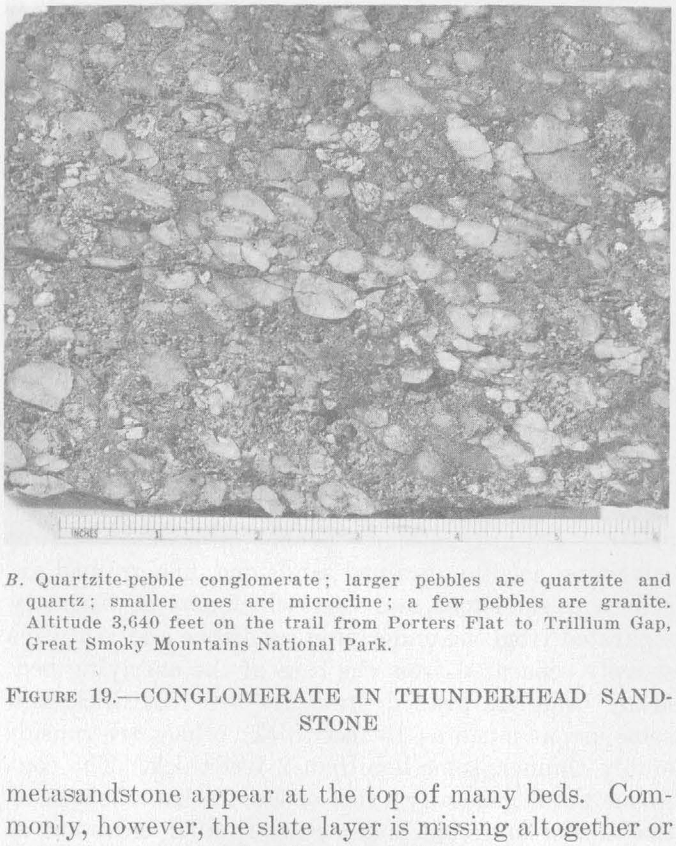
FIGURE 18.—GRADED SANDSTONE AND FINE CONGLOMERATE, THUNDERHEAD SANDSTONE

The coarser rocks are poorly sorted and contain granules and pebbles scattered through a sandy matrix in which the larger fragments are well separated. These fragments are uniform throughout thousands of feet of strata. Most abundant are grains of whitish glassy quartz that are moderately well rounded and as large as one-half inch. Grains of white feldspar are almost as large and abundant as quartz, but are not so well rounded, and the shapes of cleavage fragments are commonly preserved. Smaller grains of glassy blue quartz, rarely more than one-fourth inch in diameter, are also abundant in many of the coarser beds throughout the formation. A few unusually coarse and isolated beds contain pebbles of quartz, feldspar, and other rocks as much as three-fourths of an inch across, but most pebbles in the vicinity of Mount LeConte are between $1/4$ and $3/8$ inch (fig. 19*A*). These beds contain very few rock fragments, although pebbles of white quartzite, dark siliceous or slaty rocks, and fine-grained leucocratic granite occur here and there.

Thick graded beds are characteristic of the Thunderhead sandstone throughout the area. A typical bed consists of a basal layer of small-pebble conglomerate grading upward to coarse pebbly or granule-bearing sandstone, medium-grained sandstone, fine-grained argillaceous sandstone, and slate, which may be distinctly separated from the underlying sandstone and is always sharply separated from the base of the overlying bed. Many complete graded units are 5–8 feet thick and some are as much as 15 feet thick; others are considerably thinner, some less than 2 feet thick. The conglomerate is generally a foot or less thick at the base of the thicker units but is generally thinner or absent in the thinner beds, which begin with coarse granule-bearing sandstone. Fine-grained sandstone, generally argillaceous, is almost universal, its thickness ranging from $1/10$ to $1/4$ of the total thickness of the bed. The slate is relatively thin, generally 1–3 inches thick, although some slate beds as much as 2 feet thick were seen. Several thin alternations of slate and argillaceous



A. Normal quartz-feldspar conglomerate: prominent white pebbles are microcline, more abundant quartz is gray.



B. Quartzite-pebble conglomerate; larger pebbles are quartzite and quartz; smaller ones are microcline; a few pebbles are granite. Altitude 3,640 feet on the trail from Porters Flat to Trillium Gap, Great Smoky Mountains National Park.

FIGURE 19.—CONGLOMERATE IN THUNDERHEAD SANDSTONE

metasandstone appear at the top of many beds. Commonly, however, the slate layer is missing altogether or is represented only by disrupted chips and slabs. Conglomerate-filled channels ranging from several inches to 2 feet deep are fairly abundant at the bases of the thicker graded units (fig. 18*A*).

Where graded bedding is not conspicuous, the rocks are medium-coarse or granule-bearing sandstone beds, 3–20 feet thick, with interbeds, 1 or 2 feet thick, of thin-bedded fine-grained sandstone, argillaceous sandstone, and slate. Some sandstone, however, is as much as 60 feet thick without noticeable interbeds. Conglomeratic parts of the thick sandstone beds are commonly lenticular without sharp boundaries and occur at various places above the base within a single bed. Some beds, as much as 35 feet thick, especially in the eastern part of the formation, consist entirely of quartz-feldspar conglomerate with abundant pebbles ¼–½ inch in diameter.

In the vicinity of Mount LeConte, coarser beds are scarce, nevertheless one such bed is exposed at 3,640 feet altitude on the trail from Porters Flat to Trillum Gap in the eastern part of the Cartertown quadrangle (fig. 19*B*). The bed is 15 feet thick and contains unusually abundant well-rounded pebbles with a common large size of 1½ inches and a maximum size of 2 inches. The rock is well sorted, with a minimum of sandstone matrix. Many pebbles are rock fragments rather than the usual quartz and feldspar and include the following types in order of decreasing abundance: white quartzite, white quartz, feldspar, dark argillaceous siltstone, fine granular biotite-feldspar gneiss, coarse calcareous sandstone, and fine light-colored granite.

Current-bedded sandstone appears at a few places, even in sequences dominated by graded bedding, but it is very scarce. An unusual example of current bedding with prominent scour-and-fill structure is exposed on U.S. Highway 441 at the first overlook above Chimneys Campground.

Because of the heavy forest and colluvial cover, the lateral extent of beds could not be widely observed, but the beds extend without great changes in thickness for hundreds of feet and are not noticeably lenticular.

The section of nearly 1,000 feet of beds on U.S. Highway 441 above Chimneys Campground was measured and studied in detail as a representative sample of the Thunderhead sandstone in the western part of the report area (see partial geologic section). The rocks here are midway in the formation, beginning about 2,500 feet above the base. Of a total thickness of 964 feet in the measured section, 785 feet is exposed. Many graded beds are present, as well as thicker beds of granule-bearing and conglomeratic sandstone, but there is no coarse pebble conglomerate. Of the rocks exposed in the section, 6 percent is fine arkosic conglomerate, 24 percent is very coarse granule-bearing sandstone, 50 percent is medium- or coarse-grained sandstone, 19 percent is fine-grained argillaceous sandstone and metasiltstone, and less than 1 percent is slate. The 100 sandstone beds measured (including metasiltstone and slate at the tops of graded beds) range in thickness from 0.5 feet to 42 feet and have an average thickness of 6.8 feet and a median of 4.0 feet. Distinct beds or units of metasiltstone and slate, not parts of graded units, range in thickness from a few inches to 20 feet.

Slate and argillaceous fine-grained sandstone, like the dark interbeds previously described, constitute units as much as 100 feet thick at a few places near Mount LeConte. Bedding in these pelitic units is generally indistinct, but some are thin bedded; and alternations of dark sandy slate and contrasting lighter colored sandstone are common.

Partial section of Thunderhead sandstone along U.S. Highway 441, across West Fork, Little Pigeon River, from Chimneys Campground, Great Smoky Mountains National Park

Top of section.

Description	*Thickness (feet)*
Sandstone	2. 0
Sandstone; 1 ft argillaceous siltstone at top	6. 5
Sandstone; 0.2 ft siltstone at top	3. 2
Sandstone; scattered granules at base and 2 ft siltstone at top	7. 0
Sandstone, coarse to medium; 8 in siltstone and 1 in slate at top	12. 2
Sandstone; two siltstone partings 2 ft apart near top	6. 1
Sandstone, coarse- to medium-grained; some granule sandstone in fairly well defined beds; siltstone parting at top	27. 3
Sandstone, coarse-granule; thin fine conglomerate at base and thin siltstone parting at top	16. 0
Sandstone, massive; two siltstone partings 2 ft apart near top	34. 4
Siltstone, argillaceous	3. 0
Sandstone	1. 8
Sandstone; abundant slate fragments in upper 3 ft; 1.5 ft argillaceous siltstone with slate fragments at top	11. 5
Siltstone and slate; introduced feldspar veinlets; films of biotite in fractures and along bedding	. 7
Sandstone, massive; contains ill-defined layers and lenses of granule sandstone and a little fine conglomerate; poorly exposed interval at base is probably siltstone. (Altitude sign of 3,000 ft on highway opposite this bed)	35. 0
Sandstone, massive	10. 0
Siltstone, argillaceous	2. 0
Sandstone; coarse grained below, medium grained above; overlying siltstone infolded	20. 0
Siltstone and slate, argillaceous; rather sharply separated from adjacent beds	1. 5
Sandstone, medium- and coarse-grained, well-bedded	1. 4
Standstone; two beds each overlain by a few inches of siltstone and slate	6. 0
Sandstone; three beds with interbeds of argillaceous siltstone	5. 0
Sandstone, massive	6. 5
Sandstone, coarse-granule; finer at top and overlain by 1.2 ft argillaceous siltstone	11. 2
Sandstone; 2 in siltstone at top	1. 0
Siltstone and slate, argillaceous	1. 0
Standstone; many thin darker layers 1–3 mm thick in upper 6 in; just below this are small slate fragments	4. 2
Siltstone and slate, argillaceous; strong slaty and fracture cleavage	16. 0
Concealed	36. 0
Metasiltstone, argillaceous	5. 0
Siltstone, argillaceous; grains and granules of feldspar and blue quartz as large as 2 mm; somewhat coarser and less argillaceous at top	9. 6
Standstone, fine-grained; grades to 0.5 ft argillaceous siltstone at top	5. 0
Siltstone; interbedded argillaceous and fine-grained sandstone in layers 2 ft thick	8. 0
Sandstone; three graded beds 2.7, 3.7, and 3.6 ft thick, including 2 to 5 in siltstone at top of each	10. 0
Slate, sandy	2. 0
Sandstone, coarse; 0.5 ft fine conglomerate at base	12. 5
Sandstone; 1.3 ft siltstone at top	5. 3
Concealed	40. 0
Metasiltstone, mostly argillaceous, or sandy metashale; poorly bedded, with beds less than 1 ft thick of fine-grained feldspathic sandstone	17. 0
Sandstone, massive	8. 0
Sandstone; four beds similar to those below, each about 2 ft thick	8. 0
Sandstone; two beds 2.4 and 4.4 ft thick, each with 1 to 3 in. slaty siltstone at top	6. 9
Siltstone, slaty	. 9
Sandstone, coarse; contains scattered granules; 6–10 in fine conglomerate at base	9. 0
Sandstone, coarse; contains scattered granules	8. 0
Concealed	68. 0
Sandstone, massive	15. 0
Sandstone, coarse; two distinct beds, about 1 ft thick, of fine conglomerate with 8 mm pebbles; abundant feldspar	9. 2
Siltstone, argillaceous; three or four beds 1–2 ft thick of feldspathic sandstone	22. 0
Sandstone; a few slate fragments in lower 2.5 ft	10. 0
Sandstone, coarse, 0.3 ft siltstone at top	4. 3
Sandstone; 0.3 ft siltstone and slate at top	3. 5
Sandstone, granule; grades upward to siltstone and slate	1. 6
Sandstone, graded; 0.5 ft siltstone and slate at top	7. 5
Sandstone; four graded beds, 2.0, 0.5, 1.6, and 1.4 ft thick, each with an inch or two of argillaceous siltstone and a fraction of an inch of slate at top	5. 5
Sandstone; contains granules locally; shows 3 or 4 changes in color and grain size, becoming finer and darker upwards; 2.3 ft siltstone at top contains slate layer	19. 3
Sandstone; contains a few granules; slate fragments in upper 1.5 ft; 1 ft argillaceous siltstone at top	5. 6
Sandstone, granule, massive; graded with poorly defined lenses of fine conglomerate at base; slate slabs as much as 1.3 ft long; 1.1 ft siltstone at top	10. 1
Sandstone, granule; contains scattered pebbles as large as 6 mm; some crossbedding near bottom	11. 5
Sandstone, crossbedded; contains a few slate fragments; scattered pebbles as large as 7 mm	2. 7
Quartz-feldspar conglomerate, fine; pebbles 6–12 mm of rounded blue quartz and subangular white feldspar; unusually well sorted	4. 0
Sandstone, granule; grades downward to fine-grained conglomerate	14. 5
Sandstone, graded; 0.4 ft siltstone and slate at top	2. 6

Slate; 1-in. gritty layer at base	1.0
Graywacke; grades upward into siltstone and slate	.6
Sandstone; 2-in. siltstone and slate at top	1.6
Sandstone, granule; grades upward to coarse sandstone; 0.7 ft siltstone and slate at top	7.2
Slate, dark-bluish-gray	.6
Graywacke; slabs and lenses of slate	1.8
Sandstone, graded; 1 ft siltstone and slate at top	6.2
Sandstone, graded; 0.8 ft siltstone and slate at top	7.8
Sandstone, graded; 0.5 ft siltstone at top	3.5
Slate and argillaceous metasiltstone, interbedded; layers of slate 1 in. or less thick	2.6
Sandstone	1.7
Sandstone, argillaceous, fine-grained; 2 in. slate in middle; argillaceous siltstone at top	3.0
Sandstone, granule, graded bed; 1.0–1.3 ft fine conglomerate at base; 2 ft medium-coarse-grained sandstone at top	7.0
Sandstone, coarse; contains lenses of fine conglomerate a few inches thick; 2 ft siltstone and slate at top	8.3
Sandstone, graded; 1.2 ft siltstone and slate at top	4.2
Concealed	50.0
Sandstone, massive; four poorly graded beds each about 10 ft thick, separated by a few inches or less of argillaceous sandstone or siltstone; 4-in. channel at base of one bed	41.0
Sandstone, argillaceous siltstone, and slate, medium- and thin-bedded	3.0
Sandstone; three beds, each 1.3 ft thick, separated by 5-in. beds of argillaceous siltstone and slate; slate fragments as much as 1 ft long in lower sandstone	5.0
Sandstone, massive	6.0
Sandstone; contains a few granules; slate fragments as large as 0.5 ft	1.3
Sandstone, medium- and coarse-grained, indistinctly bedded; upper 2.5 ft is crossbedded	7.5
Siltstone, argillaceous; 1 in. slate top	1.1
Sandstone; contains indistinct layers of granules; thin straight beds of finer grained sandstone	12.0
Sandstone, argillaceous; contains 2 in. slate	.5
Sandstone, massive	9.0
Siltstone and slate, argillaceous	1.5
Sandstone, medium to very coarse grained, well-bedded; prominent scour-and-fill structure near base and top	16.0
Siltstone, argillaceous; slate at top; thickness variable	.5
Sandstone, very coarse; thickness variable (deposited on eroded surface of underlying bed)	1.5
Sandstone, argillaceous; 3 in. dark-gray slate at top but absent in places owing to erosion	1.3
Sandstone, granule; argillaceous standstone a few inches thick in middle	6.5
Siltstone, argillaceous	.5
Sandstone, granule, massive; contains small pebbles	7.0
Sandstone, argillaceous	.5
Sandstone	1.5
Sandstone, coarse, massive; indistinct layers of granules and fine-pebble conglomerate (8–10 mm); 1 ft argillaceous calcareous sandstone at base and 1.5 ft from top	25.0
Sandstone, very massive; lenses of fine conglomerate and pebbly sandstone; bases of lenses sharp, tops gradational to sandstone above; fine conglomerate fills channels a foot or two deep in the underlying siltstone at basal part of bed	42.0
Sandstone; 1–2 ft argillaceous siltstone at top	6.0
Total thickness, including concealed intervals	964.

Base of measured section, end of outcrop.

As the Thunderhead sandstone is traced eastward, it becomes apparent that the 6,000 feet of beds on the north slope of Mount LeConte constitute only the lower part of the formation and that a thick succession of higher beds extends from Mount Guyot to Mount Cammerer and the valley of Big Creek. Some of these higher beds on Woolly Tops, Chapman Lead, and Mount Guyot are stratigraphically equivalent to the Anakeesta formation on Mount LeConte and represent the middle part of the Thunderhead. The highest beds, occupying the drainage basin of Big Creek east of Mount Guyot and southeast of Cosby Knob and Mount Cammerer, constitute the upper part of the Thunderhead sandstone and are probably higher stratigraphically than most of the Anakeesta formation in the report area. (See fig. 24.)

LOWER PART

The previous lithologic description applies mainly to the lower part of the Thunderhead sandstone, exposed in the northwest part of the report area. Stratigraphically equivalent beds continue northeastward as far as the Greenbrier fault on the north slopes of Maddron Bald and Greenbrier Pinnacle. They consist largely of medium to very coarse feldspathic metasandstone in beds ranging in thickness from 1½ to 20 feet, like the rocks farther west. The upper part of the unit on Woolly Tops is finer grained and contains less conglomerate and fewer thinner argillaceous beds than the beds farther west. To the northeast, however, on Greenbrier Pinnacle and the headwaters of Dunn Creek, conglomerate with pebbles as large as three-fourths of an inch becomes more abundant and dark slaty interbeds more numerous.

MIDDLE PART

The middle part of the Thunderhead sandstone succeeds the lower part without stratigraphic break or noticeable change in lithologic character, the boundary being arbitrarily drawn at the horizon of the top of the Thunderhead on Mount LeConte. From Mount Sequoyah northeastward to Mount Guyot and Maddron Bald, it consists of beds similar to those in the lower part but somewhat coarser and thicker bedded. Most of them are medium to very coarse feldspathic sandstone with many small-pebble layers and lenses and sparse thin interbeds of argillaceous metasandstone and slate. In the upper part of the unit, near Copper Gap, coarse sandstone beds, 5–10 feet thick, are interbedded with thinner beds of fine-grained bluish-gray argillaceous metasandstone and black pyritic slate, both like Anakeesta formation to the southwest.

Farther northeast, the rocks of the middle part form rugged slopes in the headwaters of Cosby Creek, and are abruptly cut off by the Greenbrier fault north of Inadu Knob and Cosby Knob. To the southwest they extend through an area of considerable deformation on the north slopes of Mount Chapman and Mount Sequoyah to an area west of Copper Gap where they appear to grade laterally into the Anakeesta formation.

The least disturbed section of the middle unit on the northwest slopes of Mount Guyot and Old Black is about 3,500 feet thick. This figure may be somewhat excessive because of unrecognized duplication by minor folding and reverse faulting, but at least 3,000 feet of Thunderhead sandstone lies between the horizon of the top of the formation on Mount LeConte and its top on Mount Guyot.

UPPER PART

The upper part of the Thunderhead sandstone consists of 3,000 feet of very coarse grained, thick bedded arkosic sandstone, which is interbedded with dark argillaceous rocks and cobble and boulder conglomerate not present in the middle and lower parts. Dark argillaceous rocks are much more abundant in the upper part than elsewhere in the Thunderhead sandstone and form units ranging in thickness from 10 to 200 feet. They consist mostly of dark thin-bedded silty or sandy argillite, commonly interbedded with much lighter colored feldspathic sandstone; this combination gives fresh outcrops a strongly banded appearance. All proportions of sandstone and argillaceous rock occur in these units. Where sandstone is least abundant it is fine grained and forms very even layers about one-fourth of an inch thick at intervals of ½–5 inches. As sandstone increases, locally to as much as 75 percent, it becomes coarser and thicker bedded. These units of interbedded sandstone and argillite appear to persist with little change for long distances in harmony with their fairly regular bedding.

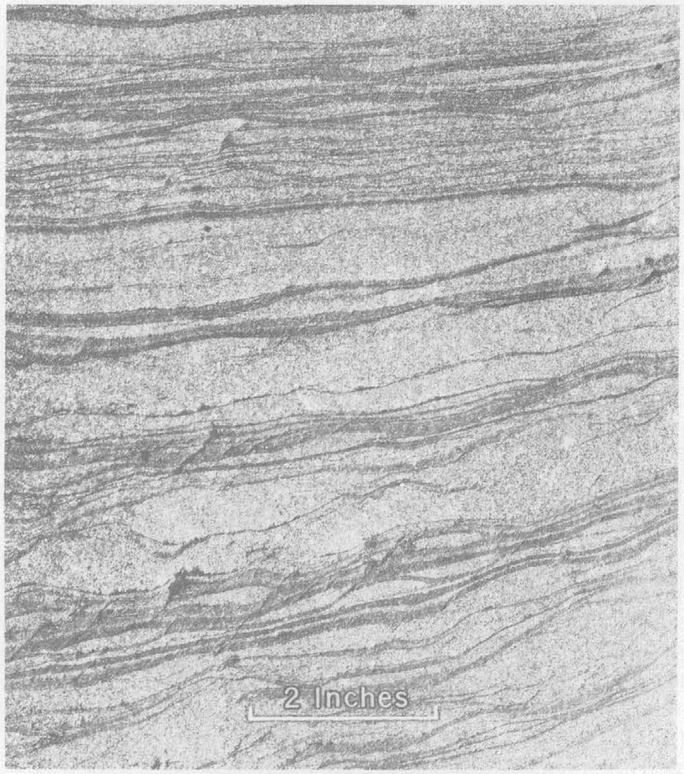
Some argillaceous units 20–400 feet thick consist of thin alternate layers of gray silty argillite and light-gray very fine grained ankeritic sandstone like that in the Rich Butt sandstone. Because of their ankerite content, the sandstone layers weather distinctively brownish or pinkish orange, which is most striking under water. Sandstone layers, mostly ⅛–4 inches thick and either straight or lenticular, are interbedded with argillaceous layers ⅛–1 inch thick that are straight, wavy, or ripple marked conforming to the shape of the sandstone layers. A few fine-grained sandstone beds in these units are 6–12 inches thick, and some paired laminae of very fine ankeritic sandstone and argillite are extremely thin—6–20 laminae per inch. Lenticular-bedded sandstone associated with wavy or ripple-marked argillite is current bedded on a small scale, but the cross laminae are generally visible only where separated by thin films of mud.

Thin-bedded sandstone and argillite show both current bedding and graded bedding, as well as deformation produced by slumping. These features are well exposed on Big Creek where argillite, interbedded with fine-grained ankeritic sandstone, forms a unit about 25 feet thick between very thick beds of coarse feldspathic sandstone. Complex bedding features in these rocks suggest that mud, settling during transportation of the sand by bottom currents, was incorporated into migrating troughs of sand ripples and formed a peculiar pattern of intertonguing dark and light rocks (fig. 20*B*). On the ridged surface left by the currents, more mud settled in quiet water until a smooth surface was again built up, over which succeeding layers of sand were swept. The graded color change from dark to light in the more evenly bedded parts represents a gradual change from rather dark silty mud at the bottom to less silty bluish argillite at the top. The whole sequence indicates relatively quiet muddy water into which fine sand was swept by repeated pulses of bottom currents. These currents were strong enough, locally, to disrupt underlying mud layers, especially where they were underlain by sand and weakened by lack of cohesion to underlying deposits.

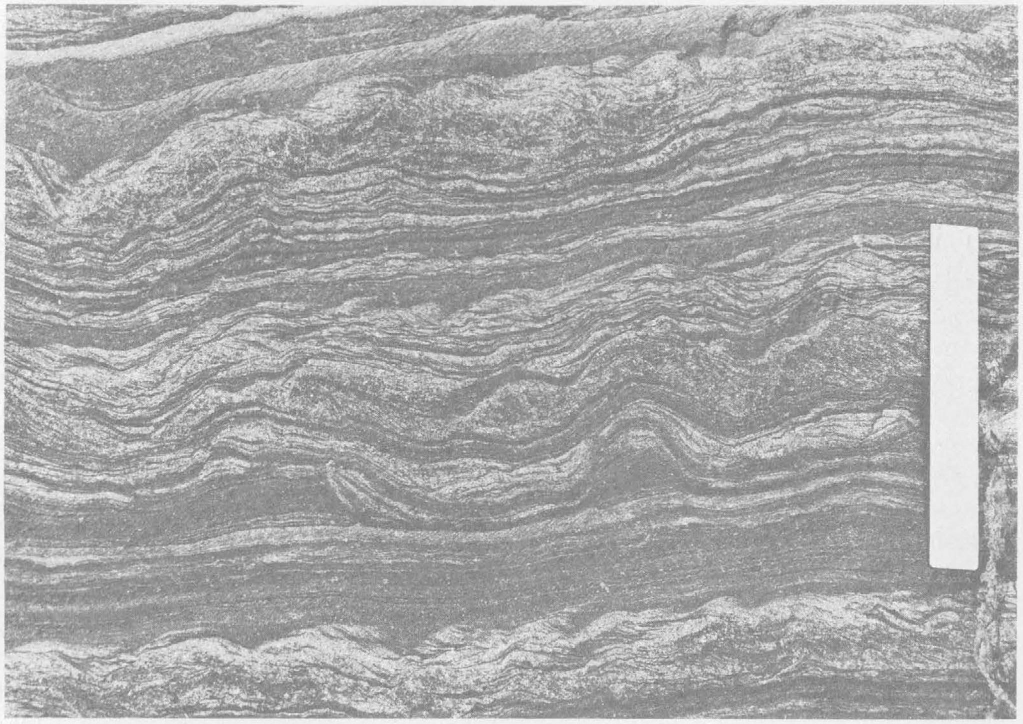
Still other units, 50 or more feet thick, consist of dark-gray carbonaceous argillite or slate interbedded with coarse sandstone and intraformational breccia; they are lithologically identical to parts of the Anakeesta formation and probably represent tongues of that formation in the upper unit of the Thunderhead.

Beds of cobble and boulder conglomerate are widespread in the upper part of the Thunderhead sandstone in the drainage basin of Big Creek from Mount Guyot to below Walnut Bottom. They are especially prominent on the ridge between Big Creek and Gunter Fork and in the tributary that enters Gunter Fork from the west-northwest near the uppermost trail crossing. Smaller but more accessible exposures of conglomerate occur high in a roadcut on the truck trail along Big Creek a mile northeast of the bridge at Walnut Bottom and on the foot trail along Big Creek 0.3 mile west of the end of the truck trail.

Well-rounded pebbles, cobbles, and small boulders, an inch to 15 inches in diameter, are abundant in the conglomerate. Their common large size in most exposures is between 5 and 8 inches; some are as large as 12 inches, and a few boulders are as large as 25–40 inches in diameter. They are embedded in a matrix of very coarse



A. Lenticular bedding in fine-grained ankeritic sandstone and darker argillaceous sandstone, Rich Butt sandstone. East bank of Big Creek one-half mile above bridge at Mount Sterling.



B. Current bedding and slump structure in fine sandstone (lighter) and argillaceous siltstone (darker) in upper part of Thunderhead sandstone. Current flowed from left to right. Ruler is 6 inches long. Big Creek due south of Cosby Knob.

FIGURE 20.—BEDDING IN RICH BUTT SANDSTONE AND UPPER MEMBER OF THUNDERHEAD SANDSTONE

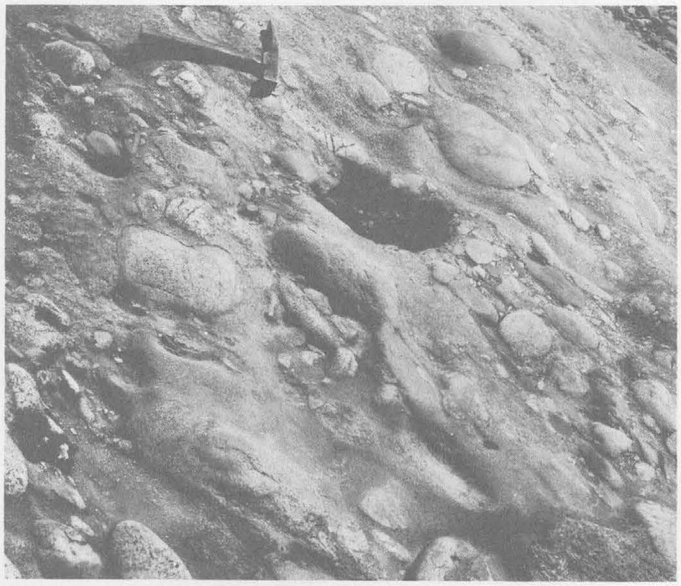
grained pebbly sandstone, highly feldspathic and generally carbonatic. In most places the cobbles are tightly packed with a minimum amount of matrix; in the upper parts and near the edges of some beds, however, the matrix is more abundant and fills spaces between widely separated cobbles and forms cobble-free lenses as much as 5 feet thick. Because of its soluble carbonate content, the matrix has commonly been removed around the larger fragments leaving them in bold relief (fig. 21*A*).

Leucogranite constitutes about two-thirds of the cobbles and boulders in the conglomerate beds that were observed; most of the rest are darker gneissic granite speckled with biotite. Many pebbles are also granite; about 10 percent of the fragments in the average outcrop are pebbles of vitreous quartzite or vein quartz. The leucogranite is fine to coarse-grained (1–10 mm in grain size) and composed of quartz, albite, and microcline, with minor amounts of primary muscovite. The feldspars contain much secondary muscovite and traces of zircon, apatite, and sphene. Large intraformational chips and slabs of argillaceous rocks, abundant in the basal parts of cobble beds at several places, appear to have been torn from nearby beds during transport of the conglomerate.

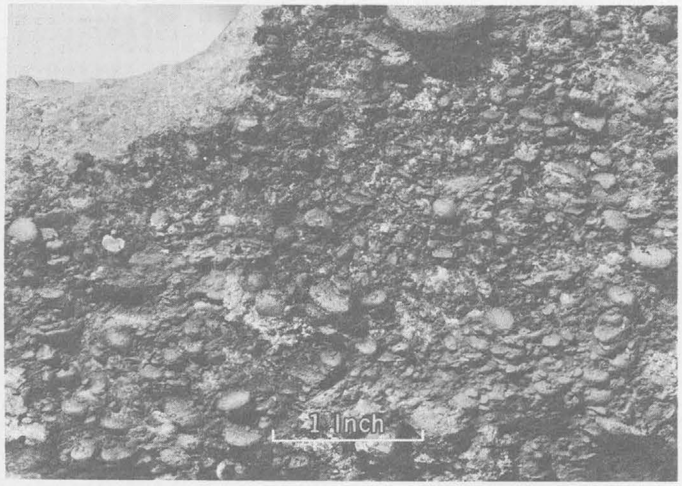
The conglomerate forms layers or lenses ranging in thickness from 1 or 2 feet to as much as 80 feet, but beds more than 30 feet thick are scarce, and the average thickness at 20 places where the full width of conglomerate beds could be measured is 16 feet. The thicker beds are probably fairly extensive, though few of them could be traced for more than short distances. One bed, 80 feet thick, is exposed at intervals for 2,000 feet along the southeast side of the lower part of Gunter Fork. At another place, two conglomerate units separated by a constant interval appear to extend for as much as a mile. A bed 6 feet thick, exposed 0.3 mile west of the truck trail at Walnut Bottom, can be traced 50 feet or so to the edge of Big Creek, where it pinches out in coarse sandstone.

Cobble beds at most places lie between units, 15–30 or more feet thick, of massive or thick-bedded coarse sandstone; locally, however, they lie directly on thin-bedded meta-argillite and fine sandstone. They are known at 6 or 8 horizons through a stratigraphic interval of about 2,000 feet in the Big Creek area. The lowest beds in this interval occur just below the Anakeesta formation at the head of Big Creek between Tricorner Knob and Mount Guyot. Farther east near Cosby Knob, the lowest cobble beds are about 1,000 feet higher in the formation and occur in an interval of about 800 feet. Southwest of the Big Creek area, 0.6 mile due east of Copper Gap, a single 8-foot bed containing abundant granite cobbles as much as 15 inches in diameter and averaging 6 inches is probably lower stratigraphically than any cobble beds farther east.

Aside from the conglomerate and argillaceous rocks described, the upper part of the Thunderhead sandstone consists largely of highly feldspathic metasandstone similar to that elsewhere in the formation. Many exceptionally thick and coarse beds are present, especially in the uppermost part of the formation on Mount Ster-



A. Well-rounded cobbles, mostly of leucogranite, with pebbles of calcareous sandstone and quartzite, embedded in coarse carbonatic sandstone. Bedding dips 15° to right. Upper part of Thunderhead sandstone, Big Creek 0.3 mile beyond the end of the truck trail at Walnut Bottom.



B. Flattened siliceous pisolites in sandy dolomite, Anakeesta formation. Boulevard trail on east side of Myrtle Point, Mount LeConte.

FIGURE 21.—PISOLITES AND CONGLOMERATE, GREAT SMOKY GROUP

ling Ridge. Some of the beds are 30–100 feet thick and their conglomeratic parts contain pebbles of quartz, feldspar, and granite whose common large size is ½–¾ inch. Thick graded beds are common, but they consist almost entirely of coarse- to medium-grained sandstone, argillaceous rocks being thin or absent. Such argillaceous rocks may have been broken up and incorporated in intraformational conglomerate, which is considerably more abundant here than in the Thunderhead farther west.

THICKNESS

The thickness of the Thunderhead sandstone varies greatly because of intertonguing with the overlying Anakeesta formation and underlying Elkmont sandstone. The lower part of the formation on the north slope of Mount Le Conte is 5,000–6,000 feet thick. Farther east, the combined middle and upper parts are at least 6,000 feet thick, but the lower part is cut out at the outcrop surface by the Greenbrier fault. If the lower part is present beneath the middle and upper parts, the Thunderhead has a maximum thickness of about 12,000 feet in the northeastern part of the report area.

STRATIGRAPHIC RELATIONS

The Thunderhead sandstone intertongues extensively with both the underlying and overlying formations, so that it does not occupy a constant stratigraphic position in the Great Smoky group. In general, both its base and top descend southward and westward. (See fig. 24.) Its contacts are generally gradational through at least 100 feet of strata and are commonly so obscured by forest and colluvial cover that they cannot be traced in detail. Nevertheless, their map pattern and the structural data available indicate intertonguing of the three formations on a large scale.

Gradational and intertonguing relations between the Thunderhead sandstone and the Elkmont sandstone along the strike near Greenbrier Pinnacle and on Mount Winnesoka have been described and are shown in plate 1. Similar relations with the overlying Anakeesta formation were observed on Mount LeConte and along the highway to the crest of the range; but, as they occur across the strike rather than along it, they are less easily seen. On the north slope of Mount LeConte, the contact at the top of the Thunderhead sandstone is sharper than elsewhere in the report area and maintains a fairly constant stratigraphic position for several miles along the strike. Southward along the West Fork of the Little Pigeon River and on Mount Mingus, the contact becomes increasingly gradational as dark argillaceous beds appear in the upper part of the Thunderhead. Farther south on Mount Kephart and near Newfound Gap, these beds are divisible into a lower argillaceous part included in the Anakeesta formation and an upper sandy part which forms a tongue of Thunderhead at approximately the same stratigraphic position as the uppermost Thunderhead on the north slope of Mount LeConte. The top of the Thunderhead therefore is about 2,000 feet lower stratigraphically at the crest of the range than on Mount LeConte (plate 1, section *G–G′*). The intertonguing required to accomplish this presumably occurs also along the Thunderhead-Anakeesta boundary farther east, between Balsam Ridge and Eagle Rocks, but exposures in this area are insufficient to show it.

Similar gradational and intertonguing relations between the Thunderhead sandstone and Anakeesta formation occur along most of their mutual boundary, but they can be described better after discussion of the Anakeesta formation itself.

ANAKEESTA FORMATION

DEFINITION

The upper part of the Great Smoky group in the western part of the report area consists of fine-grained dark argillaceous rocks. It is interbedded with metasiltstone and coarse sandstone, named the Anakeesta formation for Anakeesta Ridge, which is about a mile north of Newfound Gap (King and others, 1958, p. 959–960). The formation crops out abundantly on Anakeesta Ridge, The Boulevard, and the crest and southern slopes of Mount LeConte, and it forms the crest of the Great Smoky Mountains as far east as Copper Gap. It lies on the Thunderhead sandstone with conformable and gradational contact and intertongues with the Thunderhead through a large stratigraphic interval.

Parts of the rock mapped as Anakeesta formation are continuous with the Hazel slate of Keith (1895) and with part of the Nantahala slate (Keith, 1907). Although Keith's Hazel slate occupies a stratigraphic position similar to that of the Anakeesta, the name Hazel has prior usage elsewhere and has been abandoned in the Great Smoky Mountains area (King and others, 1958, p. 958). The type Nantahala slate, on the other hand, is a unit in the Murphy belt southwest of the Great Smoky Mountains, where it overlies the Great Smoky conglomerate (Keith, 1907). Hurst (1955, p. 43–45) reports that the base of the Nantahala is sharply defined and possibly unconformable on the underlying Great Smoky group. Keith apparently mistook tongues of Anakeesta in the Thunderhead sandstone for infolds of Nantahala, which is here considered to be a higher stratigraphic unit.

The topography on the formation is characterized by exceptionally narrow and steep-sided ridges with serrate crests and craggy pinnacles, of which the Chimneys near the highway west of Mount LeConte are good examples. Residual soils are notably thin, and considerable areas of the formation have been bared by fire or landslide producing some of the most rugged and spectacular scenery in the park, especially along the Appalachian Trail between Mount Kephart and Eagle Rocks. Typical rocks of the formation can be seen in road cuts along U.S. Highway 441 between Anakeesta Ridge and Newfound Gap. Other good exposures occur at intervals along the trail from Alum Cave Creek to the crest of Mount LeConte, at Cliff Top, and at Myrtle Point.

LITHOLOGY

The Anakeesta formation includes a greater variety of rocks than the formations of the Ocoee series described previously. Among these are small-pebble arkosic conglomerate, graywacke, fine- to coarse-grained feldspathic sandstone, gray chloritoidal slate and argillite, very dark carbonaceous slate and phyllite, and dark carbonate rocks. The most distinctive features of the formation are its dark-gray color and the presence of large bodies of argillaceous or silty pelitic rocks. Iron sulfide occurs in considerable quantities throughout, so that the more recent exposures are heavily stained with rust.

Much of the formation consists of dark-gray indistinctly bedded pyritic and carbonaceous slate or phyllite, dark enough to be loosely called "black slate." It is most abundant in the lower part of the formation, especially along the north side of its outcrop belt, where it forms a unit 100 to 300 feet thick immediately overlying the Thunderhead sandstone. It is also conspicuously interbedded with other rocks of the formation throughout the southern and western parts of the belt (fig. 22*A*).

At many places the black slate grades into, or is interbedded with, silty or finely sandy rocks that are less schistose, for example in the long roadcut just northwest of the highway bridge across the West Fork of the Little Pigeon River a mile northeast of Newfound Gap. Individual beds of fine-grained sandstone and silstone here range in thickness from a fraction of an inch to a foot. The color is distinctly lighter gray in sandier beds but, as individual beds differ little from their neighbors, bedding is not easily recognized. Small porphyroblasts of biotite and garnet are abundant in these rocks, and most contain abundant iron sulfide.

Both black slate and dark metasiltstone are commonly interbeded with fine- to coarse-grained fieldspathic sandstone and fine-grained arkosic conglomerate. These rocks are particularly abundant along the southeast side of the outcrop belt from Mount Mingus to Bradley Fork and are well exposed in roadcuts on U.S. Highway 441 from the vicinity of Newfound Gap to the upper crossing of the West Fork of the Little Pigeon River. Sandstone beds, 1–10 feet thick, are commonly interbedded with the finer rocks and also form units, 50 or more feet thick, with only minor amounts of finer grained interbeds. Most of the sandstone is lithologically similar to corresponding rocks in the Thunderhead sandstone; it is poorly sorted and commonly shows graded bedding. The coarser beds contain dispersed granules and very small pebbles of quartz and feldspar; blue quartz is found throughout the Anakeesta although generally less abundant than in the Thunderhead. Intraformational chips and slabs of dark slate or siltstone are abundant in many sandstone beds (fig. 22*B*).

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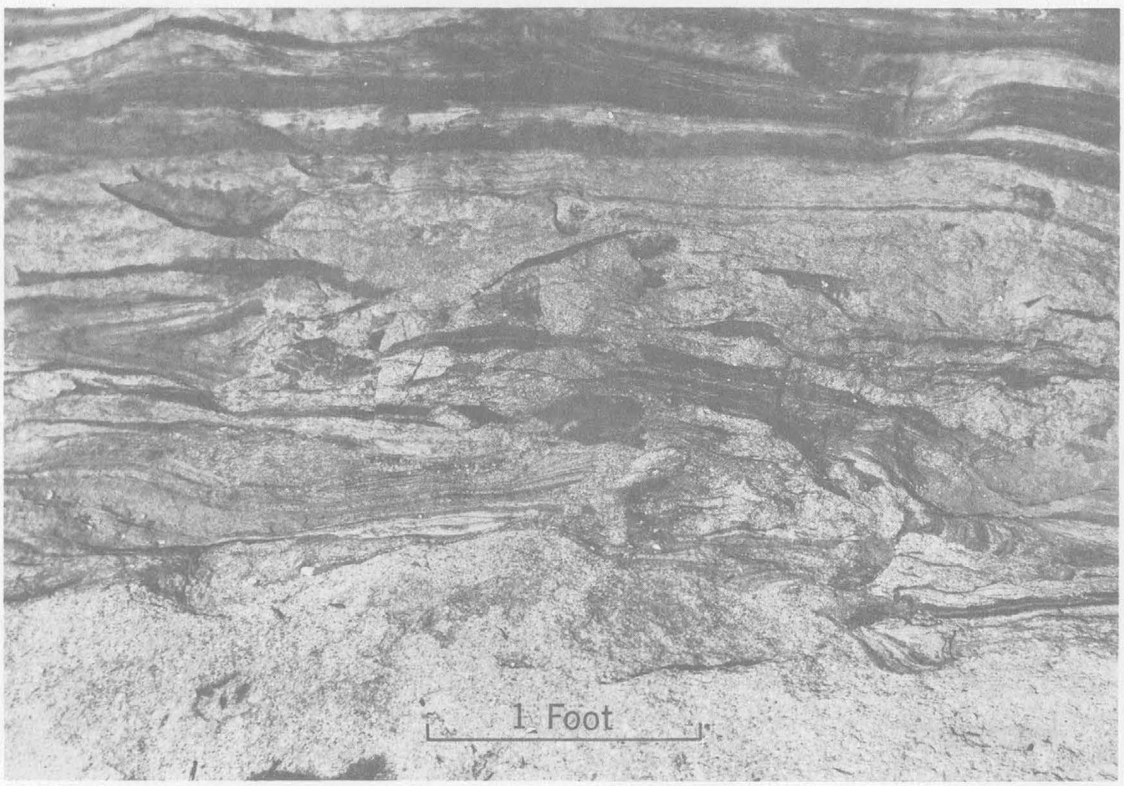
Some coarse sandstone in the Anakeesta is light colored, but much is dark as a result of the admixture of argillaceous and carbonaceous material and sulfides. A common type is schistose graywacke with abundant grains of quartz and feldspar 1–4 mm in size, in a matrix of recrystallized mud, like the graywacke of the Wading Branch formation. It forms beds ranging in thickness from a few inches to 2 or 3 feet interbedded with black slate and coarse sandstone.

Here and there, mainly in the western part of the Anakeesta formation, are carbonate rocks ranging from black fine-grained dolomite to medium-gray sandy dolomite. They form beds, 1–3 feet thick, typically interbedded with black slate and rather coarse sandstone. The beds are widely separated, occurring either singly or in groups of 2 or 3 separated by several feet of other rocks. One dolomite bed is repeated several times by folding in the bed of the West Fork of the Little Pigeon River just below the highway bridge due north of Newfound Gap. In color and texture the carbonate beds so closely resemble the rocks with which they are associated that they would be inconspicuous except for their characteristic solution surfaces. Because they are soluble, they are less well exposed than the other rocks of the formation; nevertheless, they must amount to a very small part of the formation as a whole.

The carbonate rocks contain dolomite, ranging from 40 to 95 percent, and various amounts of quartz, plagioclase, calcite, authigenic chlorite, and carbon dust. The most abundant carbonate rocks contain 10–50 percent of clastic grains, mainly of quartz, with smaller amounts of albite. Some are distinctly lighter colored than purer dolomite and contain less than one-half of 1 percent carbon; others resemble the dark graywacke described previously.



A (upper). Bedding and slaty cleavage in dark chloritoidal slate. View east-northeast at beds dipping 25° SE. Styx Branch, south slope of Mount LeComte, 500 feet northwest of junction with Alum Cave Creek.

B (lower). Intraformational fragments of argillaceous beds in coarse feldspathic sandstone. Dark layers of sandy argillite at top. Alum Cave Creek about 0.2 mile below Styx Branch, south side of Mount LeConte.

FIGURE 22.—INTRAFORMATIONAL BRECCIA AND DARK SLATE, ANASKEETA FORMATION

Unusual pisolitic dolomite was found in a few places on Mount LeConte, where a prominent exposure occurs beside the trail at 6,150 feet altitude just east of Myrtle Point. These dolomite beds are 8–12 inches thick and contain abundant ellipsoidal pisolites, 1–10 mm in diameter, composed of crystalline quartz and calcite (fig. 21*B*). The pisolites are distinctly flattened and have axial ratios close to 1 : 3 : 4; outer shells are smooth and composed of finely granular quartz; the interiors are quartz or calcite and coarser quartz; some show crystal faces (fig. 23). Some of the larger pisolites have eccentric double-walled structure, with the space both inside and outside the quartz wall filled with calcite. Most lie with their shortest dimensions normal to bedding, and crushed and fragmented pisolites are common. Although the pisolites resemble algae such as *Girvanella*, no organic structures are visible in thin sections, and the rocks are too much recrystallized to have preserved them if they were once present. Similar but better preserved structures in Upper Cambrian siliceous oolite near State College, Pa., have been described by Choquette (1955), who belived that they resulted from selective silicification of pisolitic limestone.

The mineral composition of the carbonate rocks is analogous to that of clastic and argillaceous rocks in the formation, with carbonate substituted for the clay fraction. The rocks with the most carbonate are also the darkest, contain the most carbon, and are exactly the same shade of dark gray as the most argillaceous rock—that is, the black slate. The character and distribution of quartz and feldspar in many carbonate rocks are almost the same as those of muddy sandstone or graywacke (figs. 12*B* and 24). This evidence suggests that both the carbonate and the argillaceous components were incorporated into the rocks as mud and were mixed with coarser clastic material by turbulent flow. The origin of this carbonate mud, if such it was, is debatable; in view of its uniformity and the absence of organic structures, it may have been an inorganic precipitate.

CHLORITOID SLATE MEMBER

A body of distinctive light-colored chloritoid-bearing slate and argillite forms a lens 500 feet thick and 3 miles long near the base of the Anakeesta formation on Mount LeConte; it is exposed along the crest of the mountain from Cliff Top to Myrtle Point. Thin even beds and laminae appear on weathered surfaces but are indistinct on fresh surfaces. They consist of darker argillaceous layers alternating with thinner sandier layers. Successive layers are medium gray to medium light gray, according to the content of carbon, which constitutes 1 percent or less of the darkest layers. Similar chloritoid-bearing slate and argillite occur at about the same stratigraphic position on Charlies Bunion and adjacent ridges but do not form units thick or persistent enough to be mapped.

The lighter colored rocks consist largely of sericite and quartz but contain 10–25 percent chlorite and small porphyroblasts of chloritoid accompanied by tiny brilliant plates of ilmenite. The chloritoid porphyroblasts are thin tablets with elliptical or nearly circular outlines, 1–5 mm in diameter and less than a millimeter thick. Their size and abundance differ considerably from bed to bed, and they are notably larger and more abundant in the more argillaceous beds. The tablets occur in all orientations with respect to bedding and cleavage but lie preferentially at high angles to the cleavage.

SANDSTONE MEMBER

The uppermost part of the Anakeesta formation east of Mount LeConte consists of light-colored sandstone and argillaceous rocks, and lacks both the coarser beds and the black slate characteristic of the rest of the formation. This member, probably 1,000–1,500 feet thick, overlies more typical Anakeesta rocks in the northeastern part of the main outcrop area.

The member is characterized by light-greenish-gray fine- and medium-grained sandstone in beds generally 2–4 feet, locally 15 feet, thick. The rock is composed largely of quartz with minor amounts of albite, chlorite, sericite, and ankeritic dolomite; a few beds are light-greenish-gray fine sandy dolomite containing as much as 60 percent ankeritic dolomite together with quartz, chlorite, magnetite, and ilmenite.

In western exposures of the member, sandstone is the principal constituent of units 50–200 feet thick; but it is rhythmically interbedded with chloritoid-bearing argillite and fine-grained sandstone layers an inch or less thick, grading from lighter colored siltier or sandier rock at the base to darker more argillaceous at the top.

Sandstone is most abundant in the lower and more northerly parts of the member, and thin-bedded argillite becomes more prominent in the higher and more southerly parts as in the headwaters of Bradley Fork between Porters Gap and Pecks Corner. Darker argillite beds, both within and at the margins of the member, grade into the more common dark argillaceous siltstone containing garnet instead of chloritoid and make the limits of the member difficult to ascertain.

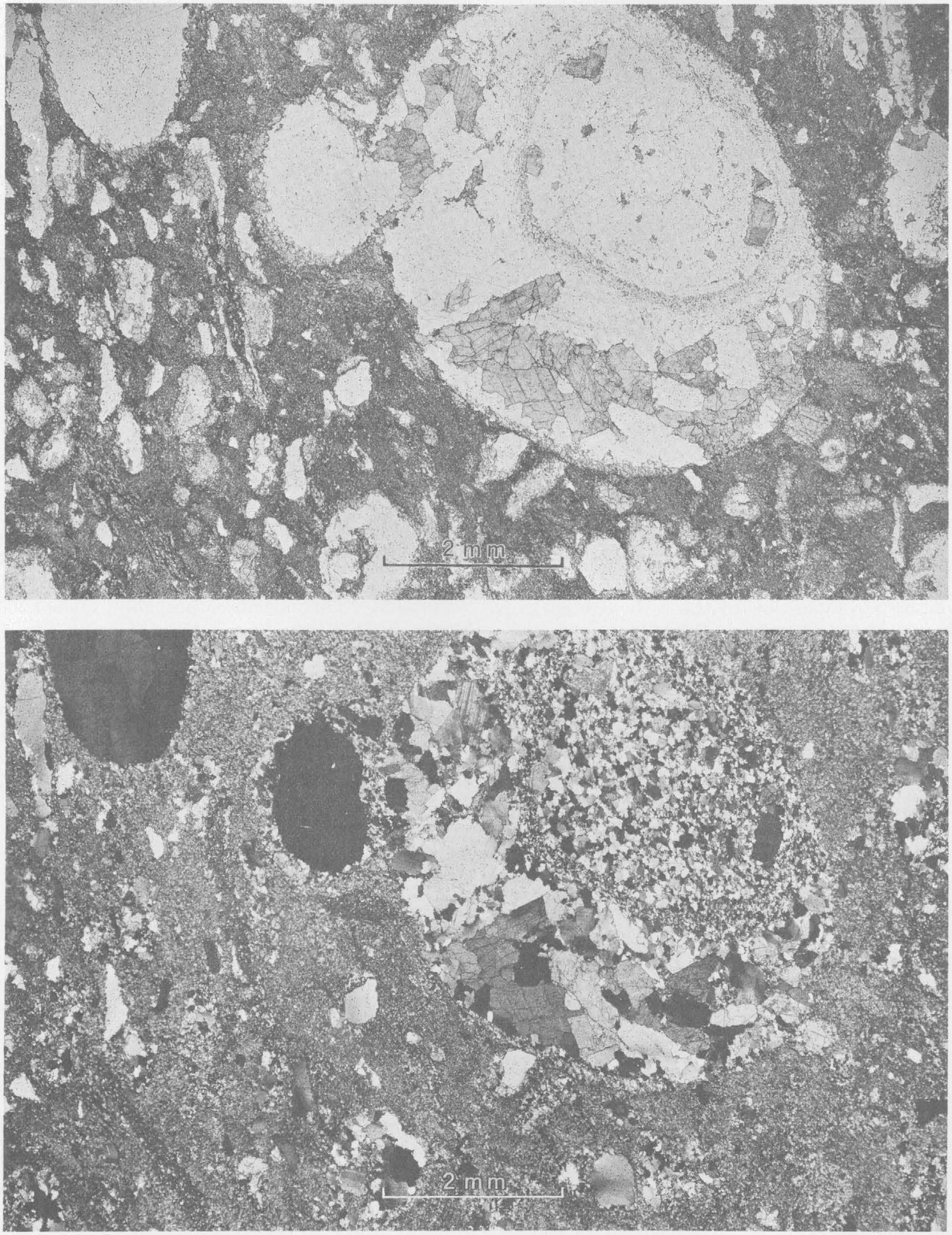


FIGURE 23.—Photomicrographs of siliceous pisolitic dolomite, Anakeesta formation. Large, eccentrically layered pisolite and smaller more uniform pisolites with angular quartz fragments in fine-grained dolomite. The mineral with high relief in the large pisolite is calcite. Fine-grained groundmass is mainly dolomite with carbon dust. *A* (upper) Plane light. *B* (lower), Crossed nicols.

STRATIGRAPHIC RELATIONS

The Anakeesta formation is the uppermost formation of the Great Smoky group in the eastern Great Smoky Mountains, nevertheless it intertongues with the underlying Thunderhead sandstone over most, if not all, of its stratigraphic interval. In general, tongues of the Anakeesta formation thicken southward and southwestward and the higher ones extend farther north and northeast than lower ones; these relations continue into the adjoining area to the west (fig. 24). On Clingman's Dome in the southwest part of the report area, however, this pattern is reversed and Thunderhead sandstone occupies most of the interval occupied by the Anakeesta farther north.

Some tongues of Anakeesta are separated by erosion from the main body of the formation, for example, southeast of Mount Kephart. This tongue can be traced across the Oconaluftee fault and is correlated with a similar unit on the State line a mile and a half northeast of Clingmans Dome. The unit crosses the axis of a major anticline south of Indian Gap, south of which it dips southeastward under several thousand feet of thick-bedded sandstone on and south of Clingmans Dome (structure section *I–I′*). As no large body of dark argillaceous rock is found higher in the section for many miles to the south, much of the Thunderhead sandstone on Clingmans Dome must be stratigraphically equivalent to the lower part of the Anakeesta formation in the vicinity of Newfound Gap.

Rocks of the Anakeesta formation, several hundred feet thick, form an isolated body in a complex syncline west of Bryson City in the southwest corner of the report area. These rocks, although considerably more metamorphosed than those farther north, consist of black carbonaceous phyllite and schist with interbedded feldspathic metasandstone and altered dolomite like the rocks in the main body of the formation. They overlie Thunderhead sandstone with strongly gradational contact. According to structure section *I–I′*, their base is 6,000 feet higher in the Thunderhead sandstone that

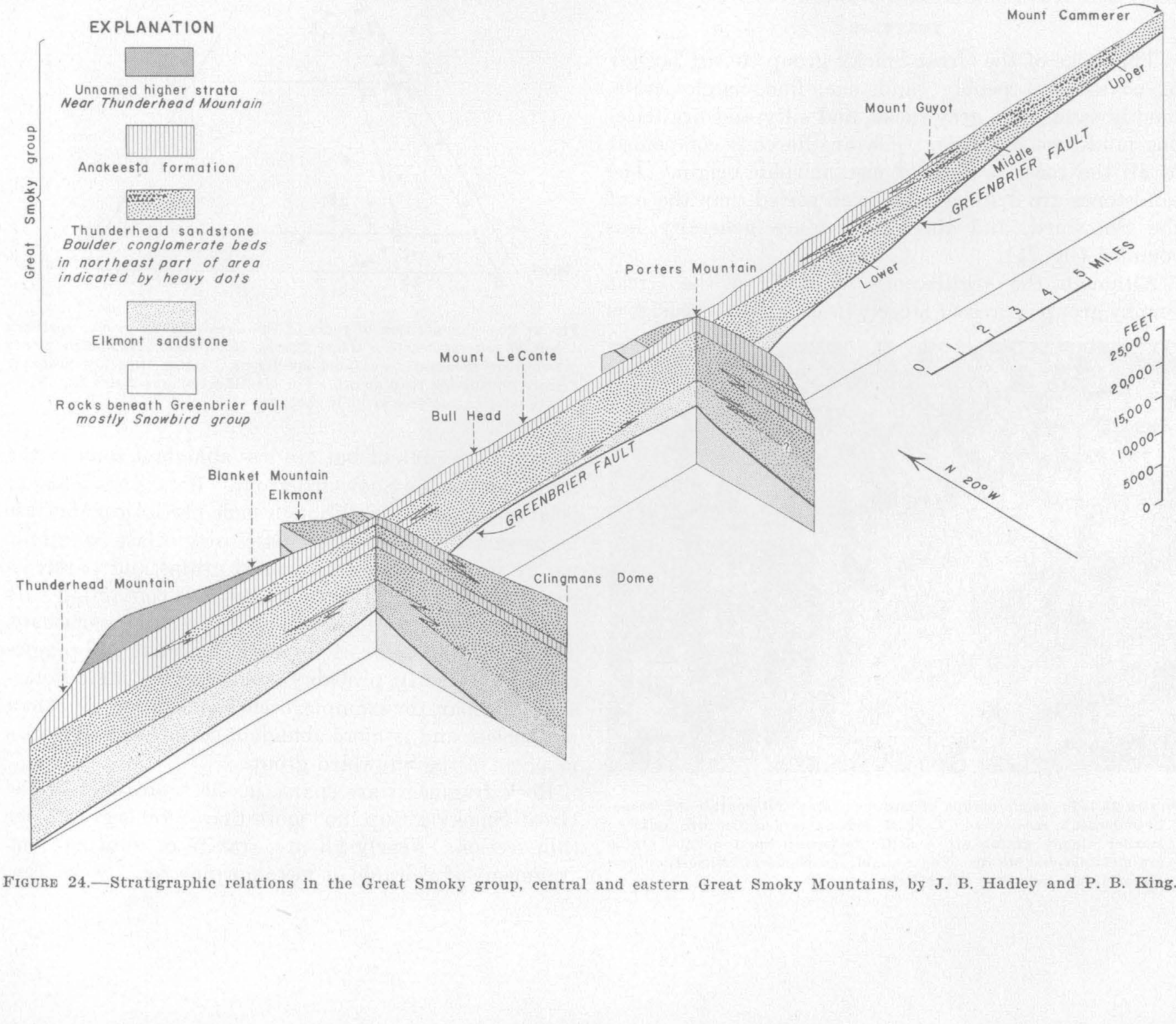


FIGURE 24.—Stratigraphic relations in the Great Smoky group, central and eastern Great Smoky Mountains, by J. B. Hadley and P. B. King.

the tongue of Anakeesta exposed northeast of Clingmans Dome, about 1,000 feet higher than the base of the Anakeesta on the north slope of Mount LeConte, but possibly 2,000 feet lower than the isolated remnant on Mount Guyot.

The syncline west of Bryson City is the north end of a major syncline in which the Murphy marble and other formations younger than the Great Smoky group occur several miles to the southwest (Keith 1907). Evidence obtained during geologic mapping of the Fontana Reservoir area west and southwest of Bryson City (P. P. Fox, written communication, 1947) and the results of our reconnaissance suggest that the Anakeesta formation in this syncline plunges southwestward directly beneath the formations of the Murphy marble belt.

PETROGRAPHY OF THE GREAT SMOKY GROUP

Composition and textures of the rocks of the Great Smoky group differ in several respects from those of the Snowbird group and Rich Butt sandstone, yet there are broad similarities between them.

TEXTURES

The rocks of the Great Smoky group consist largely of coarse and pebbly sandstone, fine conglomerate, muddy sandstone, graywacke, and silty and argillaceous mudstone or shale. The argillaceous component of all the rocks is mica of metamorphic origin. The sandstones are distinctly less well sorted than those of the Snowbird, and their grains are generally less rounded (fig. 25).

Although the argillaceous material in the Great Smoky group is present largely in pelitic interbeds, it is locally mixed with sand and coarser material, forming coarse muddy sandstone or graywacke. These rocks are highly feldspathic and have the angular detrital fragments, dark muddy matrix, and poor sorting characteristic of the classic graywacke, although they are wanting in sand-size rock fragments. They are widely distributed in both the Thunderhead sandstone and the Anakeesta formation but are distinctly minor components of both.

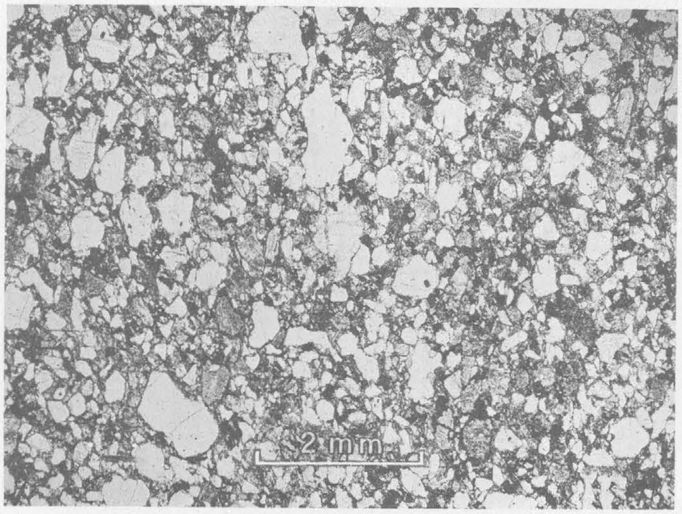


FIGURE 25.—Photomicrograph of medium-grained feldspathic sandstone, Thunderhead sandstone. Largest subangular grains are quartz; smaller cloudy grains are sericitic feldspar; small opaque grains are metamorphic biotite. For mineral and chemical composition, see table 11 (analysis 8). Plane light.

MINERAL COMPOSITION

Both feldspar and quartz are abundant in the sand-sized and coarser fractions, so that the less argillaceous rocks range through subarkose well into the arkose field of figure 26. Both sodic plagioclase and potassium

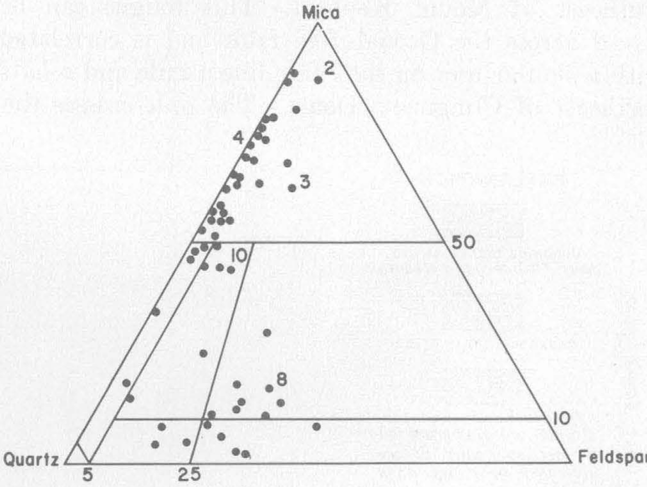


FIGURE 26.—Composition of rocks of the Great Smoky group, northern belt of outcrop, eastern Great Smoky Mountains. Numbered points represent chemically analyzed specimens. Metapelites are probably more feldspathic than shown. For classification see figure 13. Numbers refer to analyses given in table 11.

feldspar are present but are less abundant than in the sandstones of the Snowbird group. Potassium feldspar is largely microcline, although some perthitic orthoclase is present. The characteristic plagioclase is albite, partly in clear lamellar-twinned grains and partly in less twinned and partly altered grains containing tiny inclusions of sericite, potassium feldspar, or carbonate. The relative amounts of potassium feldspar and plagioclase vary greatly, probably because of sorting. Potassium feldspar, for example, occurs in larger grains than plagioclase and is more abundant in the coarser rocks, much as in the Snowbird group.

Rock fragments are sparse in the sandstones of the Great Smoky group, not more than 2 or 3 grains per thin section. Nearly all are granite or quartzite; no fragments of volcanic or metamorphic rocks were seen.

Fragments of dark argillaceous sandstone or slate in the conglomerate are intraformational.

The clay fraction of most of the Great Smoky group is concentrated in beds of sandy or silty metapelite, now containing 40 to 80 percent metamorphic mica. These rocks were at least moderately rich in iron and magnesia as shown by the presence of much biotite and chlorite, which amount to about 20 percent of the total mica in the metapelites of the group and 45 percent of the mica in the more argillaceous sandstones. In general, the proportion of white mica, including both muscovite and paragonite, is highest in the more silty shales, rather than in the most argillaceous rocks as in the Snowbird group.

The dark color of much of the Anakeesta formation is due to the presence of carbon and finely divided iron sulfide. Particles of carbon, a few microns in size, amount to 2.8 percent of one analyzed specimen and probably 5 or 6 percent of the darkest rocks. Iron sulfide, including both pyrite and pyrrhotite, is abundant in fresh slate nearly everywhere but has been leached from long exposed outcrops. About 2.5 percent iron sulfide is present in one analyzed specimen (table 11, analysis 3) and as much as 10 percent was estimated in others.

Most of the feldspathic sandstone, graywacke, and conglomerate of the Great Smoky group contains disseminated carbonate ranging from traces to nearly 10 percent; it is uniformly distributed and rarely conspicuous in the outcrop. Some is calcite but much is dolomite or ankerite. It occurs mainly in the matrix but partly replaces both matrix and larger feldspar grains.

The limited suite of accessory minerals in the Great Smoky group is partly similar to that in the Snowbird group but partly different. (See fig. 16.) Magnetite, apatite, and zircon are abundant in both groups; epidote and sphene, which are most conspicuous in the Snowbird group, are very sparse or wanting in the Great Smoky rocks; whereas tourmaline, scarce in the Snowbird, is common in much of the Great Smoky. The other minor constituents, carbon and iron sulfide, are abundant in parts of the Great Smoky but are syngenetic rather than detrital. Accessory minerals of metamorphic origin are discussed in the section on metamorphism.

Of the detrital heavy minerals, magnetite appears to be the most abundant and widespread, although it is difficult to distinguish from metamorphic magnetite and ilmenite. Amounts present range from a fraction of a percent to several percent. The grains, ranging in size from 0.3 mm downward, are entirely anhedral and commonly appear to be recrystallized aggregates with xenoblastic boundaries. Scarce larger grains are coated with leucoxene as in the basement rocks.

Apatite, the next most abundant heavy mineral, occurs as anhedral roundish grains randomly distributed in two-thirds of the sandstone specimens studied microscopically. It is not as abundant as in the more argillaceous rocks, but chemical analyses indicate that 0.3–0.4 percent apatite is present in most of the rocks of the group.

Zircon is also widespread and appears in a considerable variety of sizes and shapes. Zircon grains are largest and most abundant in the sandstones, where they range in size from 0.02 to 0.25 mm. Most grains are either sharply euhedral or subhedral and rounded: broken fragments are scarce. Some euhedral zircons are still embedded in the quartz or feldspar in which they originally crystallized. Zircon occurs in trace amounts, nevertheless it is by far the most abundant of the resistant nonopaque heavy minerals in sandstones of the Great Smoky group, as shown by studies of saprolite of the Thunderhead sandstone and related formations in the western part of the Great Smoky Mountains (Carroll, Neuman, and Jaffe, 1957, p. 180).

The abundance of detrital tourmaline in the Great Smoky group is of special interest, because it is not found in appreciable quantities in the other rocks of the report area. Like the zircon, tourmaline grains are largest in sandstone where they are 0.1–0.4 mm in diameter. The grains are mostly angular fragments of prisms, although smaller grains are nearly euhedral. They show a typically wide variety of pleochroic colors, including orange brown, muddy greenish brown, brownish green, grayish green, greenish blue, and black. Some grains have thin overgrowths of authigenic tourmaline either colorless or much paler than the host, and small grains of pale probably authigenic tourmaline are fairly abundant in some of the more argillaceous rocks. Tourmaline is less widely and evenly distributed than zircon in the rocks of the Great Smoky group and is generally less abundant, although tourmaline exceeds zircon in some thin sections studied. Similar observations have been made by Carroll, Neuman, and Jaffe (1957, p. 182) on Thunderhead sandstone in the western Great Smoky Mountains.

Iron sulfide has been mentioned as a prominent constituent of the dark metapelite of the Anakeesta formation. It is less abundant in sandstone of the Anakeesta and is absent or very sparse in the Elkmont and Thunderhead sandstones. Pyrite is the most common sulfide, but considerable pyrrhotite is also present in the more metamorphosed rocks. In the argillaceous rocks the sulfides occur as lenticular aggregates, as much as 1 cm long, that are oriented parallel with the cleavage; in the sandier rocks they are xenoblastic intergranular aggregates as much as several millimeters long. Sulfides are locally associated with quartz and carbonate in discontinuous veins. Some of the sulfide in the area may have been introduced, notably that associated with copper deposits in the southwestern part of the mountains; but most of it probably resulted from reorganization of sedimentary sulfide.

Disseminated carbon is more widespread than sulfides in the rocks of the Great Smoky group but is most abundant in the sulfide-bearing rocks. It occurs as minute elongate roundish grains, 1 or 2 microns in diameter. The grains are separate from one another or connected in short irregular chains or ramifying aggregates. The carbon particles may be enclosed in recrystallized grains of quartz, feldspar, or mica, but more commonly they are found along the boundaries of these grains. Carbon grains from the northern part of the area did not reveal geometic outlines under × 700 magnification; but carbon particles from the more highly metamorphosed rocks farther south are hexagonal flakes, as much as 4–6 microns in diameter, suggesting the crystal form of graphite.

Clues to the origin of the carbon in these rocks are its dispersion and extremely fine size, its association with sulfides, and its abundance in the finest grained rocks. The size and distribution of the carbon suggest that it represents very fine material, presumably organic, that settled from sea water steadily while the clastic fraction of the sediments was being deposited at varying rates. This would explain its greater abundance in the slowly accumulating argillaceous and carbonate rocks as compared to the more rapidly deposited sandstones and conglomerates. The association of the carbon with syngenetic sulfides suggests that they were preserved in stagnant basins.

CHEMICAL COMPOSITION

Chemical analyses of 4 pelite samples, 3 sandstone, and 1 graywacke of the Great Smoky group and Rich Butt sandstone are given in table 11. Although the sampling is obviously limited, comparisons between them and similar rocks from the Snowbird group and other areas seem significant.

The sandstones analyzed include only one sample from the Great Smoky group, a medium-grained feldspathic sandstone from the Thunderhead on Highway 441 near Chimneys Campground, and two samples from the Rich Butt sandstone on Big Creek. These sandstones contain significantly less sodium, calcium, and iron than those of the Roaring Fork sandstone, reflecting the large amounts of epidote and plagioclase present in the Roaring Fork. They are more similar to average arkose than to Archean or Franciscan graywackes as cited by Pettijohn (1949, p. 250, 259).

Among the analyzed pelites are typical slate from a relatively thick interbed in the Thunderhead sandstone, representative black slate and chloritoid slate from the Anakeesta formation, and dark-gray sandy slate associated with iron-carbonate beds in the Rich Butt sandstone. The slate from the Thunderhead is notably aluminous, and it is approached in this respect only by the basal schist of the Wading Branch; it is thus exceptionally rich in mica, poor in quartz and feldspar silt, and must have consisted largely of clay minerals. The sandy slate of the Rich Butt, recalculated on a carbonate-free basis, seems much less mature, particularly as it contains more calcium and sodium and less potassium and alumina. In most respects its chemical composition is like that of pelites in the Snowbird group.

The two slates of the Anakeesta formation are notably aluminous, like that in the Thunderhead. The lighter colored chloritoid slate contains unusually large amounts of ferrous iron and about twice as much magnesia as the more carbonaceous slate. A remarkable feature of the carbonaceous slate is the large amount of sodium, which together with the alumina, suggests the presence of paragonite in addition to muscovite. Paragonite could not be positively identified by X-ray diffraction of the powdered rock, however, so part of the sodium is probably in the muscovite. The occurrence of paragonite as a separate phase in low-grade aluminous schists has been noted recently in other parts of the Appalachian region (Rosenfeld, 1956; Arden Albee, oral communication).

Graywacke of the Anakeesta, as compared with that from the Wading Branch formation (table 8, analyses 4, 5), shows the same chemical differences—more alumina, less iron and calcium—that distinguished the pelites of the two formations. When compared with other rocks that have been called graywacke, particularly Archean graywacke from the Canadian shield cited by Pettijohn (1949, p. 250) and Franciscan sandstone from the region north of San Francisco Bay described by Taliaferro (1943, p. 136), the Ocoee examples show both similarities and differences. Graywacke of the Wading Branch resembles the Archean rocks, except that it seems to have been derived from a more granitic and less basic source. As compared with the Franciscan rocks, believed by Taliaferro to have been derived from granodiorite under a cold humid climate, graywacke of the Ocoee is clearly more aluminous and the proportions of alkalies are reversed. This evidence suggests a granitic rather than a granodioritic source.

TABLE 11.—*Chemical analyses and calculated mineral composition in percent, of Rich Butt sandstone and Great Smoky group, northern belt of outcrop, eastern Great Smoky Mountains*

[Analysts: L. D. Trumbull, analyses 2, 3, 4, 8; M. Balazs, analyses 1, 6, 7, 10]

Analysis	1	2	3	4	5	6	7	8	9	10
Laboratory No.	C473	52-1497CD	52-1491CD	52-1500CD		B471	B472	52-1498CD		B468
Field No.	W-519	CT-303	MG-237	CT-328		W-517	W-518	CT-304		CT-488
Chemical analyses										
SiO_2	58.13	46.21	55.80	52.75	53.97	70.62	64.03	75.80	75.98	68.53
Al_2O_3	18.24	29.30	23.24	25.39	24.23	14.93	11.35	10.52	13.29	16.65
Fe_2O_3	1.08	2.55	1.28	1.99	1.73	1.66	.32	.38	.81	1.15
FeO	5.22	2.34	2.58	5.23	3.64	1.80	3.60	2.67	1.27	1.30
MgO	1.99	2.23	1.39	2.61	1.93	.68	1.73	1.02	.63	1.21
CaO	1.78	.15	.52	.20	.39	.09	4.83	.71	.56	.52
Na_2O	1.84	.15	2.41	.90	1.33	2.46	3.54	2.36	3.07	1.87
K_2O	5.01	10.54	4.37	4.28	6.11	5.17	1.93	3.35	2.60	3.69
H_2O-	.04	.12	.14	.11		.05	.01	.02		.23
H_2O+	2.58	4.36	2.73	4.65	3.61	1.41	.64	.73	.98	2.02
TiO_2	.92	1.02	.68	.81	.87	.62	.47	.45	.55	.62
CO_2	2.16	.01	.09	.01	.00	.01	6.96	1.65	.00	.17
P_2O_5	.27	.18	.13	.18	.19	.09	.16	.14	.14	.21
SO_3										.31
S	.15		1.30		.73	.11	.02			.86
MnO	.08	.04	1.07	.10	.32	.04	.25	.06	.05	.03
BaO	.09					.11	.03		.07	.04
C	.12	.52	2.78	.39	.95					.53
Total	99.70	99.72	100.51	99.60	100.00	99.85	99.87	99.86	100.00	99.94
Calculated mineral composition										
Quartz	24.7	5.5	21.1	25.1		36.5	34.3	48.4		43.1
Potassium feldspar	8.5	4.1				13.2	5.8	13.1		1.0
Plagioclase	16.4	1.3	14.3			20.9	33.6	20.0		9.3
Chlorite	10.9		6.9	17.6						1.7
Biotite	1.0	15.8				7.3		4.1		4.2
Muscovite	29.7	69.2	[1] 46.8	[2] 47.2		19.5	8.1	9.0		[3] 35.9
Apatite	.7	.4	.3	.4		.2	.4	.3		.5
Sphene	.6						.7			
Leucoxene		1.0	.7			.2	.8			.3
Magnetite and ilmenite	2.0	1.0		1.5		1.0		1.4		.5
Carbonate	[4] 5.0		.2				[4] 15.9	[5] 3.8		.4
Carbon	.1	.5	2.8	.4						
Pyrite	.3		2.4							2.1
			[6] 5.0	[7] 7.1						[8] 1.1
Total	99.6	99.8	100.5	99.3		99.8	99.6	100.1		100.1
Character of plagioclase	An_5	Ab_{100}	An_{12}			Ab_{100}	An_{11}	Ab_{100}		Ab_{100}

[1] Includes 10.7 percent paragonite.
[2] Includes 11.1 percent paragonite.
[3] Includes 9.4 percent paragonite.
[4] Ankerite: $CaCO_3$, 40 percent; $MgCO_3$, 25 percent; $FeCO_3$, 35 percent.
[5] Ankerite: $CaCO_3$, 25 percent; $MgCO_3$, 30 percent; $FeCO_3$, 45 percent.
[6] Garnet: pyrope, 25 percent; spessartite, 49 percent; almandine, 26 percent.
[7] Chloritoid.
[8] Melanterite.

1. Rich Butt sandstone. Medium-dark-gray finely sandy argillaceous metasiltstone, from the east side of Big Creek, 0.8 mile above bridge at Mount Sterling. Grain size ranges from 0.2 mm (quartz and feldspar) to 0.05 mm (mica). Contains about 25 percent fine sand. Specimen shows indistinct bedding laminae and weak schistosity; micas are poorly oriented. Chlorite is yellowish green with low birefringence and blue extinction colors; calculated as about 2 parts iron chlorite to 1 magnesium chlorite.
2. Thunderhead sandstone. Medium-gray slate from cut on U.S. Highway 441 north of Chimneys Campground. Average grain size is 0.02 mm. Biotite calculated as about 2 parts annite to 1 part phlogopite.
3. Anakeesta formation. Dark-gray pyritic argillite from near Appalachian Trail a quarter of a mile northwest of Eagle Rocks. Grain size ranges from 0.02 mm (quartz) to 0.04 mm (mica); garnet porphyroblasts 0.1–0.3 mm. Composition of plagioclase is assumed. Carbon is present as extremely small grains, 1–4 microns, disseminated throughout the rock.
4. Anakeesta formation. Medium-dark-gray moderately foliated argillite from Styx Branch, 500 ft northwest of its junction with Alum Cave Creek, south of Mount LeConte. Grain size ranges from 0.1 mm (quartz) to 0.03 mm (mica); chloritoid forms subcircular tablets 1–2 mm in diameter. Bedding laminae and rich in quartz and show microscopic offsets on mica foliation surfaces.
5. Average of 1–4, omitting carbonate and uncombined water.
6. Rich Butt sandstone. Medium-gray fine-grained feldspathic sandstone from east side of Big Creek, 0.9 mile above bridge at Mount Sterling. Average grain size is 0.25 mm (quartz). Composition of plagioclase determined from thin section. Well-sorted subangular, inequidimensional quartz grains in finer grained matrix amounting to about 40 percent of rock. One percent limonite is present as pseudomorphs after leached iron carbonate.
7. Rich Butt sandstone. Light-gray fine-grained feldspathic sandstone from trail on east side of Big Creek, 0.8 mile above bridge at Mount Sterling. Thin argillaceous seams amount to less than 5 percent of the rock. Grain size ranges from 0.2 mm (quartz) to 0.02 mm (matrix). Texture similar to sample given in analysis 6.
8. Thunderhead sandstone. Medium-grained feldspathic sandstone from cut on U.S. Highway 441 north of Chimneys Campground. Average grain size 0.5 mm. Feldspars include microcline, microperthite, orthoclase(?), and albite. Carbonate replaces micaceous matrix. Magnetite grains are coated with leucoxene.
9. Average of 6–8, omitting carbonate and uncombined water.
10. Anakeesta formation. Medium-dark-gray argillaceous graywacke from cut on U.S. Highway 441, half a mile due north of Newfound Gap. About 45 percent angular quartz and feldspar grains, 1–2 mm in diameter, in micaceous matrix of recrystallized quartz, feldspar, and mica (0.1 mm in grain size). Weak foliation is considerably sheared and folded. The rock is somewhat weathered and contains minor amounts of limonite and sulfate.

ORIGIN AND MANNER OF DEPOSITION

The rocks of the Great Smoky group record marked changes in source area, direction of transport, and manner of deposition from those which produced the Snowbird group. The source seems to have shifted from a southeastern to a northern area and to have been more granitic. The coarser sediments, at least, were laid down in abrupt pulses of deposition rather than by slow movement across the floor of the sedimentary basin. During the later phases of sedimentation, the carbonaceous and sulfide-rich sediments of the Anakeesta formation settled in what were probably poorly ventilated pockets in the basin.

Changes in the character of the rocks that furnished sediments to the Great Smoky group are indicated by the mineralogic differences between it and the Snowbird group. The paucity of epidote and sphene, both rather abundant in the basement rocks now exposed in the

Great Smoky area, and the presence of tourmaline and abundant zircon in the Great Smoky group suggest that the source area lay farther north or west in the basement complex, in a region where granite should be increasingly abundant according to the known distribution of plutonic rocks in the complex. This is also suggested by the greater proportions of potassium and alumina in the finer grained rocks of the Great Smoky as compared with the Snowbird. Massive leucogranite of a type scarce in the exposed parts of the complex is abundant in shoulders and cobbles of the upper part of the Thunderhead sandstone and is common in smaller fragments throughout the formation.

The sediments were probably transported by rapid and massive movements into a deep basin. The manifold repetition of thick graded beds so characteristic of the sandstones of the group appears to have been produced by turbidity currents, such as those described by Kuenen (1952; Kuenen and Migliorini, 1950) and other researchers in recent years. That such currents are capable of moving large quantities of coarse sediment on the ocean floor seems highly probable and the thickness and coarseness of the sandstone beds in the Great Smoky seem to be within the limits permissible (Kuenen, 1952). Although exceptionally large turbidity currents set in motion by earthquake shocks may have traveled at great velocities over hundreds of miles on very gentle slopes (Heezen and Ewing, 1952), the currents responsible for the deposition of the Thunderhead were probably much less extensive and may have been caused by continuous sliding of sediments on an unstable slope. Initial velocities may have been high as indicated by the coarseness of the beds, but they soon decreased as the main part of the suspended load dropped out. The currents that deposited the sandstone beds of the report area seem to have had little eroding power, for sediment-filled channels are shallow and not abundant. This was, rather, an area of dominant deposition under stable conditions with little evidence of later disruption by sliding. In some places, currents perhaps representing the final stages of turbidity currents carrying little sediment produced a minor amount of current bedding, laminar bedding, and scour-and-fill structures.

Only minor quantities of mud settled with the coarser deposits of the advancing turbidity flows; considerably more was deposited by the tails of the flows, thus producing the terminal fine muddy sandstone and slate layers of many graded beds. The fact that many other beds, however, lack such layers suggests that the finer grained sediments were carried farther into the basin and formed the more extensive argillaceous rocks now found in the southern part of the area. Increasing metamorphism in that direction has unfortunately destroyed minor bedding features that might support this hypothesis.

During the middle and later part of Great Smoky sedimentation, the dark carbonaceous and sulfide-rich sediments of the Anakeesta formation were laid down, and the presence of carbon and sulfides and the intertonguing relations with the Thunderhead suggest that they were deposited in local poorly ventilated pockets in the larger sedimentary basin. The exceptionally coarse conglomerates of the uppermost Thunderhead were apparently deposited at least locally along the margins of these depressions.

Flow markings, channeling, and other evidence of the direction of transport of turbidity flows were not generally found in the Great Smoky group, largely because bedding surfaces are seldom well exposed. Some evidence, however, of the direction of source areas is provided by the distribution of coarser and finer grained rocks in the Thunderhead sandstone and Anakeesta formation. The grain size of the coarsest sandstone and conglomerate of the Thunderhead increases irregularly but perceptibly northward and eastward throughout the report area. Although very coarse feldspathic sandstone and fine quartz-feldspar conglomerate are abundant throughout the area, pebble, cobble, and boulder beds are limited to the northern and northeastern parts. Conversely, argillaceous rocks become more abundant southward so that argillaceous sandstone, siltstone, and slate, which constitute about one-fifth of the measured section of Thunderhead sandstone near Chimneys Campground and probably less than that farther east, constitute one-third to one-half of the formation in the southern part of the report area. Sandstone tongues in the Anakeesta also pinch out southward and southwestward in the central and eastern parts of the area and indicate movement of coarser material in those directions. None of these features indicate closely the direction of transport, for individual beds cannot be traced and their textural changes studied in detail. From the many irregularities in the distribution of coarser and finer rocks of the Great Smoky group, it can be concluded only that the direction of transport was generally southwestward.

WALDEN CREEK GROUP

WILHITE FORMATION

The Walden Creek group of formations, comprising a considerable part of the Ocoee series in the foothills north and west of the present report area, is represented by a belt of rocks, 1,000–1,500 feet wide, extending from near Cosby eastward to Hartford. The rocks are continuous with the upper part of the Wilhite formation in the adjacent area to the west (Hamilton, 1961) but are limited to a narrow slice between two major low-angle faults. The rocks are markedly less resistant to erosion than either the coarse sandstone and conglomerate of the Cochran formation to the north or the Pigeon siltstone to the south and underlie a lowland that skirts the south slope of Green Mountain and is followed by the Pigeon River for 1½ miles between Hartford and Bluffton.

The Wilhite formation is best exposed on the south side of the river one-fourth mile east of Bluffton and along Tennessee Route 32, about 1½ miles southeast of Cosby. The dominant rock at both places is dark-gray fissile slate. Near Bluffton the slate is interbedded with thin beds of gritty sandstone, calcareous and rusty weathering, and with thicker layers and lenses of dark-gray limestone that are in part conspicuously sandy. Farther west in the bed of Cosby Creek at the south side of the belt, it contains dark silty beds and many thin laminae of calcareous sandstone, as well as thin limestone lenses. If the bordering faults dip 35° S., the slice is 600–900 feet thick; but the rocks are much folded and sheared, and this figure has little relation to the actual thickness of beds involved.

The Wilhite belt is bounded by coarse-feldspathic sandstone and arkosic conglomerate on the south slopes of Green Mountain and Stone Mountain, well exposed in cliffy outcrops on the northeast side of Cosby Creek southeast of Cosby and in the gorge of the Pigeon River north of Bluffton. Although these rocks were not mapped, they are lithologically like the Cochran or Unicoi formation in the lower part of the Chilhowee group, and were so shown by Arthur Keith (written communication) and by Rodgers (1953, pl. 10).

YOUNGER INTRUSIVE ROCKS

Intrusive rocks younger than the late Precambrian Ocoee series are scarce in the Great Smoky Mountains region. Within the area of this report they consist of dikes and sheetlike bodies of metadiorite, granite pegmatite, trondhjemite, and ultramafic rocks, all probably related to early or middle Paleozoic orogeny.

METADIORITE DIKES AND SILLS

Dikes and sills of variously altered diorite and diabase were exposed at several places in the report area from its west edge nearly to the northeast corner. Ten occurrences were found, three as float only and most of the others in exposures less than 100 feet wide. As the bodies are small and generally covered, others may have been overlooked; but the absence of fragments of these easily recognizable rock types in most stream beds suggests that they are not abundant in the area. Similar rocks occur in the area of the Fontana and Hazel Creek copper deposits (Espenshade, 1943; B. C. Moneymaker, oral communication).

The largest and most abundant intrusive bodies are on the north slope of Clingmans Dome, where three sills or lenses are exposed in the headwater branches of the Little River on the strike of a belt of similar rocks on Hazel Creek, 17 miles to the southwest. The largest of these bodies, 350 feet thick, can be traced 2 miles eastward across the State line ridge, where it forms conspicuous red saprolite beside the Clingmans Dome road, 1,000 feet southwest of its junction with the trail on Fork Ridge. The upper contact of the sill, seen in two stream exposures, dips about 35° SE. parallel to bedding in the adjacent rocks, although in strike the sill appears to follow regional cleavage rather than bedding (pl. 1). The wallrock relations at the lower contact and those of the other bodies were not seen.

Much of the rock in these bodies is hornblende metadiorite, which is medium to coarse grained and in some places porphyritic. The smaller bodies and the margins of the thicker ones are generally finer grained (1–3 mm) and ophitic. Much of the central part of the 350-foot sill on Clingmans Dome is conspicuously spotted with subhedral to euhedral plagioclase phenocrysts, 5–10 mm long, which locally are so abundant that the rock is coarse-grained anorthosite. In most places the feldspar outlines are blurred by penetration of amphibole, which forms crystals or dark aggregates, 3–5 mm across.

These rocks consist of approximately equal amounts of plagioclase and hornblende with minor amounts of chlorite and magnetite and traces of apatite, biotite, muscovite, clinozoisite, and sphene. Some of the finer grained rocks also contain 3–5 percent quartz, which is generally absent in the coarser and more feldspathic rocks. The plagioclase is generally subhedral and strongly zoned. The cores range from calcic labradorite to calcic andesine, and the margins are commonly sodic oligoclase. Where the original igneous texture is best preserved in the finer grained rocks, euhedral feldspar crystals are bordered by micrographic intergrowths of quartz and sodic oligoclase of the same composition as the crystal margins (fig. 27*A*). Subophitic texture, evident in outcrops and in thin sections, is masked by abundant subidioblastic hornblende which has everywhere replaced the original mafic minerals and deeply penetrated the plagioclase. In several specimens, dark areas within the hornblende are caused by minute specks of sphene and iron oxides. They show angular outlines between euhedral feldspars and apparently are ghosts of titaniferous pyroxene from which the sphene and iron oxides were derived (fig. 30*B*). No pyroxene was found, however, and amphibolitization appears to be complete.

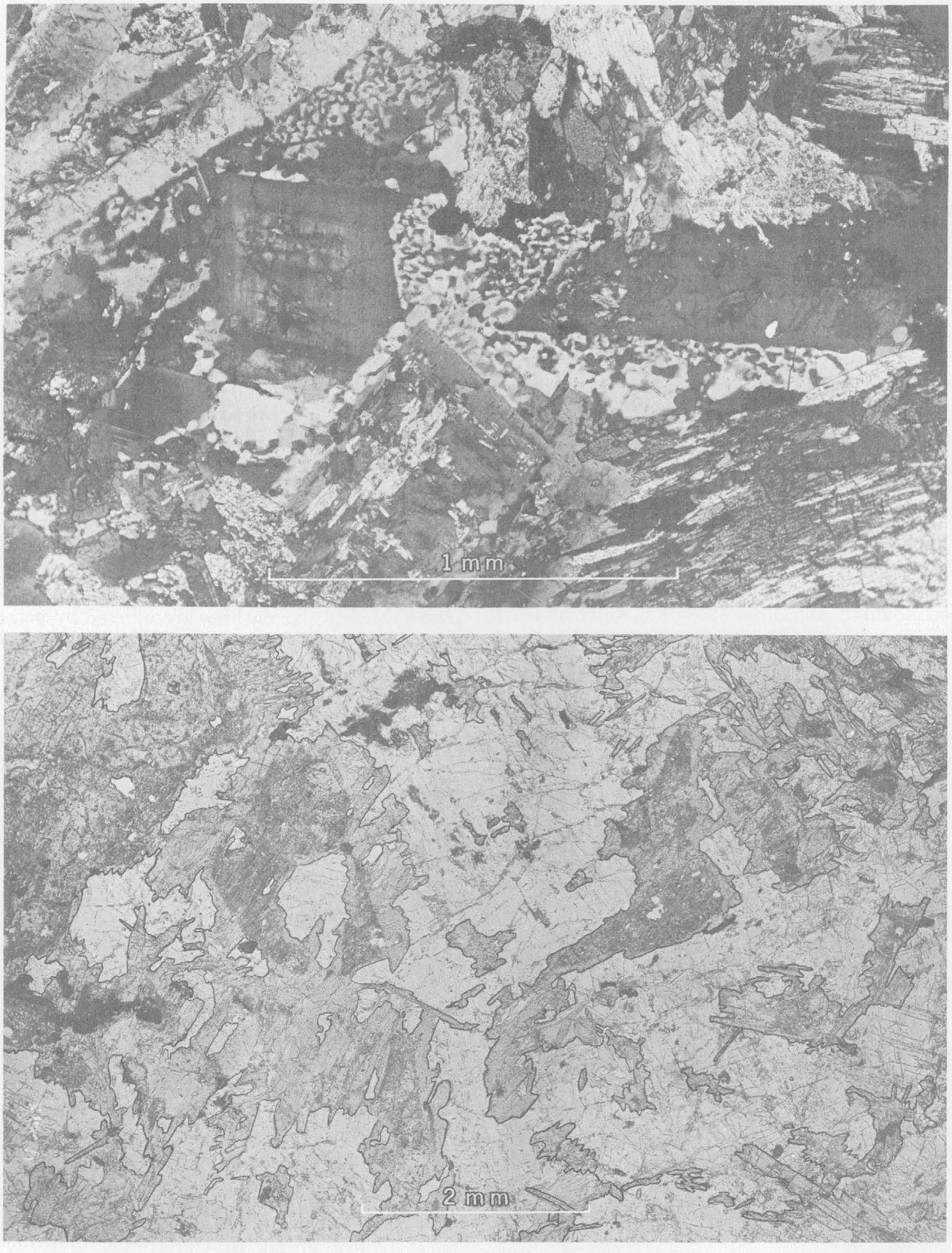


FIGURE 27.—Photomicrographs of metadiorite, north slope of Clingmans Dome. *A* (upper), Finer grained metadiorite showing micrographic quartz and oligoclase interstitial to zoned plagioclase, all penetrated by hornblende. The opaque areas are magnetite. Crossed nicols. *B* (lower), Coarser grained metadiorite showing plagioclase penetrated by amphibole, which contains ghosts of former pyroxene (darker areas) originally bounded by plagioclase.

Both the original igneous texture and that resulting from amphibolitization are variably masked by deformation and metamorphism. Even in the less altered rocks, calcic plagioclase is broken and irregularly veined by sodic plagioclase, and hornblende is partly replaced by chlorite.

A few smaller bodies on the north slope of Clingmans Dome show further alteration to light-gray or medium-greenish-gray fine-grained schist composed of granoblastic andesine and chlorite with smaller amounts of hornblende, ankerite, quartz, biotite, muscovite, sphene, and magnetite. Traces of coarse subhedral plagioclase are preserved, but all other igneous texture is gone. Hornblende, distinctly darker and presumably containing more iron than the amphibole of the metadiorite, occurs in slender idioblastic or poikiloblastic prisms, as much as 1 cm long, penetrating the plagioclase-chlorite fabric. The proportion of the mafic constituents is about the same as in less altered rock. Plagioclase, however, is less abundant, its place apparently taken by ankerite, which forms conspicuous anhedral or subhedral porphyroblasts. About 5 percent quartz is present as granoblastic grains scattered through the rock. The borders of some anhedral plagioclase grains are more calcic than the interiors and are believed to indicate reheating after lower grade metamorphism.

All the remaining bodies occur farther north and east and have been more thoroughly altered by regional metamorphism of somewhat lower grade than that on Clingmans Dome. One of them, exposed on the southeast bank of Big Creek 0.65 mile above the bridge at Mount Sterling village, is a dike 130 feet thick striking east and dipping 60° S. in sandstone of the Rich Butt formation. Others are narrower, 30–50 feet wide. Two exposures 2,000 feet apart along the strike on the northwestern slope of Greenbrier Pinnacle are probably parts of a single sill parallel to the southeastward-dipping schistosity of rocks near the Greenbrier fault. Two more are known only from float fragments near the Greenbrier fault. (See pl. 1.) A fifth is a dike, 35 feet thick, in Thunderhead sandstone; it is poorly exposed in the bed of Roaring Fork on the upper slope of Mount LeConte and is emplaced parallel to the southeastward-dipping cleavage of fine-grained argillaceous metasandstone. Foliation is variably developed in these bodies, but it is everywhere more conspicuous near the borders and is parallel to the walls where the walls can be seen.

The northern bodies consist of various proportions of plagioclase, epidote or clinozoisite, chlorite, and amphibole, with minor amounts of quartz, biotite, sphene, magnetite, and calcite. Plagioclase, clinozoisite, and epidote are entirely granoblastic; they have generally crystallized independently, but in the more massive rocks they are arranged in rectangular aggregates suggestive of plagioclase euhedra. Most of the amphibole is hornblende, some of it actinolitic, in granoblastic grains, granular aggregates, or larger anhedral poikiloblasts. Commonly the latter are noticeable megascopically as dark green spots, 3–6 mm across, in a medium-greenish-gray background of fine-grained feldspar and chlorite. Chlorite, mainly penninite, is an abundant product of the alteration of hornblende especially in the marginal parts of the bodies. Plagioclase is albite or sodic oligoclase with an average composition of An_9. Small amount of biotite, especially in the margins of the bodies, probably result from introduction of potassium from the country rock, and much of the quartz, too, has probably been introduced. Sphene is abundant in this rock, and it nearly always appears in fine granular pseudomorphs of tabular crystals believed to have been ilmenite.

Chemical analyses of the intrusive rocks (table 12) indicate that rocks of both basaltic and dioritic composition are present. Two of the rocks (table 12, analyses 2, 3) are similar to average tholeiitic basalt and dolerite (analyses 4, 5), although they contain more normative plagioclase and less femic constituents. The rocks with modal quartz are dioritic (analysis 1) and contain normative andesine rather than labradorite, but they lack the potassium found in normal diorites (analysis 5). The presence of euhedral plagioclase with strongly sodic outer zones and the interstitial eutectic quartz and oligoclase in these rocks suggests that they crystallized from basaltic magma locally enriched in sodium and silica.

These mafic rocks represent intrusions of basaltic magma during the earlier stages of Paleozoic orogeny, after initial folding of the Ocoee series but considerably before the peak of regional deformation and metamorphism, during which the intrusive bodies in the northeastern part of the area were altered to chloritic greenstone. The mafic rocks near Clingmans Dome were amphibolitized independently and probably earlier, for they did not pass through a greenschist phase that would have destroyed their igneous textures.

TRONDHJEMITE DIKES

Dikes of biotite trondhjemite are common in the Carolina gneiss east and southeast of Dellwood in and just outside the present map area. In road cuts along the Pigeon River 4½ miles northeast of Dellwood a trondhjemite dike cuts mica gneiss of the Great Smoky group. Few dikes were observed in the Soco-Cherokee belt; but similar bodies are mentioned by Cameron (1951, p. 12) as occurring in the granite and adjacent rocks in the vicinity of Bryson City.

TABLE 12.—*Chemical composition and norms, in percent, of metadiorite and metadiabase dikes and sills, Great Smoky Mountains, Tenn. and N.C.*

Analysis	1	2	3	4	5
Lab. No	E2150	E2151			
Field No	CD-157	CD-172			
Chemical Composition					
SiO_2	55.45	50.29	50.9	50.83	51.86
Al_2O_3	15.28	18.90	15.2	14.07	16.40
Fe_2O_3	.97	.78	1.6	2.88	2.73
FeO	7.34	6.14	8.4	9.06	6.97
MgO	5.58	7.69	7.5	6.34	6.12
CaO	8.07	9.58	10.8	10.42	8.40
Na_2O	4.06	2.83	2.4	2.23	3.36
K_2O	.16	.09	.2	.82	1.33
H_2O+	1.23	2.41	.85	.91	.80
H_2O-	.12	.17			
TiO_2	1.38	.83	1.7	2.03	1.50
P_2O_5	.12	.08	.20	.23	.35
MnO	.14	.12		.18	.18
CO_2	.00	.02			
S			.10		
Cu			.46		
Total	99.90	99.93	100.31	100.00	100.00
Trace elements, midpoints of ranges determined by semiquantitative spectrographic Analysis [J. C. Hamilton, analyst]					
Ba	0.003	0.003			
Co	.003	.003			
Cr	.015	.015			
Cu	.0015	.003			
Ga	.0015	.0007			
Ni	.007	.007			
Sc	.003	.003			
Sr	.03	.03			
V	.015	.007			
Y	.003	.003			
Zr	.007	.007			
Norms					
Quartz	4.74	0.0	2.16	3.5	0.3
Orthoclase	1.11	0.56	1.11	5.0	7.8
Albite	34.06	24.10	20.44	18.9	28.3
Anorthite	23.07	38.36	30.02	25.9	25.8
$CaSiO_3$	6.73	3.83	9.51	10.3	5.6
$MgSiO_3$	13.9	17.00	18.8	15.8	15.3
$FeSiO_3$	10.56	8.19	11.35	11.2	8.5
Mg_2SiO_4		1.54			
Fe_2SiO_4		.82			
Magnetite	1.39	1.16	2.32	4.2	3.9
Ilmenite	2.74	1.52	3.19	3.8	2.9
Apatite	.34	.20	.34	.5	.8
Total	98.64	97.28	99.24	99.10	99.20
Normative plagioclase	57.13 An_{40}	62.46 An_{61}	50.46 An_{60}	44.8 An_{58}	54.1 An_{48}

1. Hornblende metadiorite, medium-grained, north slope of Clingmans Dome, eastern Great Smoky Mountains. Modal composition (in percent): hornblende, 50; plagioclase, 40; quartz, 5; magnetite, 3; sphene, 1; apatite, etc., 1. D. F. Powers, analyst.
2. Hornblende metadiabase, medium-grained, north slope of Clingmans Dome, eastern Great Smoky Mountains. Modal composition (in percent): hornblende, 47; plagioclase, 44; chlorite, 6.5; clinozoisite, 1.5; sphene, 1. D. F. Powers, analyst.
3. Hornblende metadiabase from dike southwest of Adams mine on Sugar Fork of Hazel Creek, southwestern Great Smoky Mountains (B. C. Moneymaker, written communication). TVA Materials Testing Laboratory analyst.
4. Average tholeiitic basalt and dolerite (Nockolds, 1954, p. 1021).
5. Average diorite (Nockolds, 1954, p. 1019).

The trondhjemite dikes in the eastern part of the report area range in width from 2 inches to 10 feet, although most are 2–3 feet wide. The rocks are light to medium gray and mostly even grained, the grains ranging in diameter from 2 mm in the coarsest to 1 mm in the finest. The larger dikes have the coarsest texture except for a fine-grained contact zone, a few millimeters thick, rich in quartz and free of mafic minerals. Irregular patches of coarser texture with indistinct outlines occur locally in the dikes, and more sharply defined dikelets of still coarser rock traverse them, apparently along fractures nearly contemporaneous with their emplacement.

The composition of the trondhjemite dikes, shown in table 13, is fairly uniform throughout the range of specimens collected. Calcic oligoclase is the dominant constituent and forms the largest grains, which are twinned on the Carlsbad law and generally well zoned. The grains are anhedral to subhedral, with irregular margins containing many inclusions of quartz and biotite. The quartz is somewhat finer grained and commonly crushed; with biotite it forms a weak flow structure in some of the dikes. Potassium feldspar generally amounts to less than 5 percent of the rocks, is predominantly interstitial, and only rarely occurs in larger grains. Biotite and magnetite are the only ferromagnesian minerals present in most dikes. Biotite, either reddish brown or olive green in different dikes, is mostly in disseminated flakes less than 1 mm across, but it locally appears in small clusters. One dike cutting hornblende gneiss near Purchase Knob contains xenocrysts of green hornblende that are rounded and embayed, and surrounded by green biotite.

The trondhjemite dikes follow the strike of the country rocks but dip steeply and cut across them in vertical dimension. Locally they form small phacoliths in folds of the Carolina gneiss. The only effect of contact with the Carolina gneiss was minor and local silicification of the wallrocks, but mica schist and mica gneiss of the Ocoee series were locally feldspathized and kyanite altered to muscovite in thin contact selvages.

Although the dikes sharply cut layering and foliation in the gneisses, they are themselves weakly foliated parallel to slip cleavage or secondary foliation in the wallrock, and cataclastic textures are evident in thin section.

TABLE 13.—*Modal composition in percent, of trondhjemite dikes*

	1	2	3	4
Quartz	32	25	30	25
Oligoclase	59	65	65	50
Muscovite	Tr.			
Biotite	6	5	3	15
Potassium feldspar	3	5	1	10
Apatite	Tr.		Tr.	
Epidote	Tr.	Tr.	Tr.	Tr.
Sphene	Tr.		Tr.	Tr.
Orthite	Tr.		Tr.	Tr.
Magnetite		Tr.		Tr.
Hornblende				Tr.
Zircon				Tr.
Total	100	100	99+	100

1. Ten-foot dike in biotite gneiss, west side of North Eaglenest Mountain, Dellwood quadrangle.
2. Three-inch dike in biotite gneiss, south side Eaglenest Mountain.
3. Two-foot dike in epidote biotite gneiss, 3 miles east of Dellwood quadrangle.
4. Two-foot dike in biotite-hornblende gneiss, southeast slope of Purchase Knob, Dellwood quadrangle.

PEGMATITE

Many small bodies of granite pegmatite are distributed along the southern and southeast margins of the area in both the basement complex and the Ocoee series. They are probably Paleozoic (p. B107) and are closely related to the trondhjemite dikes in composition, areal distribution, and relations to the enclosing rocks. They differ from older granite pegmatites of the basement complex in their more sodic composition, white rather than pink feldspar, and comparative lack of deformation. Pegmatites are scarce within the map area but become more abundant east and southeast of Dellwood and in the vicinity of Bryson City, where they attain their greatest size and have been extensively worked for feldspar.

Pegmatites in the Dellwood area are small, few, and little exposed. They are at most only a few feet wide and occur predominantly in the more micaceous rocks of the Carolina gneiss; on Setzer Mountain west of Maggie and in the Plott Balsams, they also occur in mica schist and mica gneiss of the Ocoee series. The smaller bodies visible in single outcrops are lenticular and follow the dominant foliation in the rock. In the more micaceous rocks they have irregular shapes that cut across wallrock structures.

No important pegmatite bodies were seen in the Soco-Cherokee belt, but a few 1–12 feet thick and several tens of feet long were found in the Ocoee series on Mount Noble northwest of Cherokee village and at the east edge of the gneiss northeast of Ravensford. Many small pegmatite bodies, ranging in width from a few inches to 4 feet, are present in mica schist of the Ocoee series near the dam on the Oconaluftee River at Ela.

The pegmatite in these areas consists principally of quartz, white oligoclase, and white to cream-colored perthite in subequal amounts. It contains muscovite in flat or prismatic books, 2–4 inches across, and traces of ragged anhedral biotite. All the bodies are too small or too poorly exposed to reveal internal structure.

The pegmatites of the Bryson City district have been fully described by Cameron (1951). They are abundant both in the granite complex and the surrounding metasedimentary rocks but are concentrated along the northwest margin of the complex. The largest body is nearly 500 feet long and 40–200 feet wide; others appear to be less than 200 feet long and less than 50 feet thick. They are grossly lenticular although the larger ones are very irregular in detail. Most of them are elongate northward and dip steeply westward; some have been explored to sufficient depth to indicate that their major dimensions pitch steeply southwest.

Cameron (1951, p. 24) points out that fractures controlled the emplacement of many pegmatite bodies and bedding and foliation in the metasedimentary rocks controlled the emplacement of others. Some of the larger bodies along the northwest margin of the granite complex appear to be controlled by faults and fractures related to asymmetric flexures plunging moderately to steeply southwest in a marginal belt of augen gneiss.

Internal features of the pegmatite bodies include successive zones, or shells, of different structure and composition; replacement of pre-existing pegmatite with or without obvious structural control; and fracture filling in previously consolidated pegmatite. The sequence of zones inward from the walls is that usually found in zoned pegmatites, although only five simple mineral assemblages are generally present: plagioclase-quartz with minor to subordinate perthite; plagioclase-quartz-perthite; perthite-quartz and quartz-perthite with an anomalous subdivision consisting of perthite-plagioclase-quartz; and quartz. Muscovite is abundant in only a few pegmatites and commercial mica production has been small. The most abundant accessory minerals are biotite, magnetite, and garnet. Tourmaline, allanite, and beryl occur in a few pegmatites, and a little pyrite, fluorite, and galena occur along fractures in some of them.

ULTRAMAFIC ROCKS OF UNCERTAIN AGE

Metamorphosed ultramafic rocks occur at many places in the basement complex. Most of them are bodies a few feet to a few tens of feet wide, but a larger body, 1,000 feet across, crops out near the crest of Hurricane Mountain near the east edge of the report area and another lies northwest of the Redmond mine at Shelton Laurel. The larger bodies are all poorly exposed, and little is known about their shapes or contact relations. The rocks in them are generally dark and rusty weathering. Some are composed of actinolite or tremolite, garnet, quartz, and magnetite; others are pale to dark green, weakly schistose, and composed largely of chlorite and actinolite. One specimen contains iron-rich olivine, apparently of metamorphic origin, and small amounts of apatite and magnetite.

Smaller bodies of ultramafic rock are widely distributed in the basement complex. Most are dull yellowish- or brownish-green rocks composed of fibrous actinolite and chlorite in various proportions. The chloritic varieties locally contain abundant biotite. Such a body, nearly 150 feet wide, is prominently exposed beside the truck trail on Bradley Fork, 2,200 feet beyond the gate at the north end of the campground at Smokemont; it lies between feldspathic sandstone of the Thunderhead sandstone and biotite augen gneiss of the Ravensford body. Against the sandstone it is bordered by a thin selvage of biotite schist, and against the gneiss, by dark hornblendic rock with pale-brown garnet—both probably products of post-Ocoee metamorphism.

Similar, but smaller bodies of ultramafic rock, a few feet to a few yards wide, occur near the basement-Ocoee contact on Piney Mountain and south of Shelton Laurel. Most of them contain hornblende in addition to actinolite, with subordinate amounts of chlorite and traces of biotite, apatite, and sphene. In the Dellwood quadrangle, such rocks are represented only by float fragments but appear to occur particularly along the east margin of the Carolina gneiss south of Maggie and near the base of the Ocoee series along the west side of Buck and Setzer Mountains.

Because of their high magnesia content and the absence of feldspar, most of the smaller bodies appear to represent altered peridotite similar to that found in the Carolina gneiss in adjoining parts of the Blue Ridge province to the east and south (Pratt and Lewis, 1905; Keith, 1907, p. 3; Hadley, 1949). They were not found in the Ocoee series, but they commonly occur at or near its contact with the basement complex, suggesting that they are younger than the Ocoee series and were emplaced in early Paleozoic time.

STRUCTURAL GEOLOGY

The rocks of the eastern part of the Great Smoky Mountains have a great variety of folds, faults, cleavages, and joints that have resulted from deformation beginning in Precambrian time and continuing intermittently throughout most of the Paleozoic. Precambrian deformation affected only the rocks of the basement complex, and structural features of this age have been so obscured by later deformation and metamorphism that little is known about them. Both deformation and metamorphism in the Ocoee series appear to have reached their greatest intensity in Devonian time, when an early stage of folding was followed by extensive low-angle thrust faulting and then by intense folding accompanied by the principal regional metamorphism. These events were succeeded in the late Paleozoic by renewed low-angle faulting by which folded and recrystallized Ocoee rocks were pushed northwestward over the Paleozoic rocks of the Tennessee Valley but were otherwise not greatly affected.

The welter of structural features thus produced includes larger folds and faults which can be mapped, as well as a host of minor folds, various cleavages, foliations, lineations, and joints that can not be adequately shown on maps but have wide, commonly overlapping, distribution. The major elements that make up the structural framework of the eastern part of the Great Smoky Mountains consist of (1) westward-trending folds and high-angle reverse faults in the rocks of the foothill belt, (2) a group of low-angle thrust faults, represented by the Greenbrier fault, on which basement and Ocoee rocks have been brought northward over other Ocoee rocks, and (3) another series of folds and faults, younger than the overthrusting and trending northeast (pls. 1 and 3). In the following discussion they are considered mainly according to geographic location from north to south. Structural aspects of cleavage, foliation, and lineation are included with the description of the major structural units; their petrological aspects are considered in the section on metamorphism. Other minor features, such as joints and cleavage relations, are discussed separately.

FOLDS AND FAULTS OF THE FOOTHILL BELT

COPELAND CREEK AND CARTERTOWN ANTICLINES

In the northwestern part of the map area the Roaring Fork sandstone and Pigeon siltstone appear in a complex anticlinal belt, 5 miles wide, that is bounded on the south by the Greenbrier fault. A well-defined northern flank extends along the northern boundary of the map; an equally well defined southern flank occupies much of the area east of Gatlinburg; and a less well defined crestal region trends slightly south of east from the vicinity of Cartertown to the north slope of Greenbrier Pinnacle. The crestal region contains several subordinate anticlines trending east-northeastward, separated by high-angle reverse faults, and dying out successively en echelon (pl. 3). Two of these subordinate anticlines, the Cartertown anticline to the northwest and the Copeland Creek anticline to the southeast, are more clearly defined than the others and are separated by the Gatlinburg fault.

The structural details of the Cartertown and Copeland Creek anticlines are much alike. The north limbs of both folds are largely in the Pigeon siltstone, whose beds dip generally 20° northward to vertical. Locally overturned beds dip as low as 60° S. Minor folds in the northern limb of the Copeland Creek anticline produce local reversals in attitude so that gentle southeast dips appear at several places, but many of these folds are so small that the accompanying reversed dips are suppressed on the map in favor of more representative attitudes. The north limb of the Cartertown anticline has no reversals of dip (except for overturned beds), but gently plunging minor folds are revealed by large variations in the inclination of northward-dipping beds. The south limb of the Copeland Creek anticline is largely in the Roaring Fork sandstone, whose beds have much gentler dips, ranging from 15° to 30° SE., and few minor folds of mappable size. The southeast limb of the Cartertown anticline, on the other hand, is largely in Pigeon siltstone in a belt only one-half mile wide just north of Dudley Creek, and the beds on this limb are considerably more folded.

The major folds plunge consistently east-northeastward as shown by many bedding attitudes in the crestal region. Such attitudes in the Copeland Creek anticline range generally from 10° to 20° E.; those in the Cartertown anticline are steeper, ranging from 22° to 45° E.

Minor folds of outcrop size (roughly 5 ft or less in wavelength) occur in the thinner bedded rocks of both the Pigeon siltstone and the Roaring Fork sandstone. They are open folds with apical angles more than 90°, always asymmetrical with northward-dipping limbs much steeper than southward-dipping ones. Rather well defined axial surfaces are inclined 30°–60° S. and axes plunge gently 5°–20° E. In the vicinity of the Gatlinburg fault, minor folds occur in moderately thick sandstone beds of the Roaring Fork; these folds are tighter, with apical angles less than 90°, and show more erratic and steeper plunges, a few plunging westward.

Regional slaty cleavage is variable in the finer grained rocks of the Copeland Creek and Cartertown anticlines. It is most pronounced in slate and phyllite but occurs also in most of the metasiltstone and in the finer grained and more argillaceous sandstone. It is not visible in most sandstone beds either in the Roaring Fork sandstone or Pigeon siltstone. Slaty cleavage increases in intensity southward; but along the crest and north limb of the Copeland Creek anticline east of the Little Pigeon River it is inconspicuous even in the finer grained rocks.

The regional cleavage strikes northeastward and dips southeastward throughout the two major folds, its average attitude in the Cartertown anticline being N. 50° E., 57° SE. and in the Copeland Creek anticline N. 40° E., 42° SE. (fig. 28*A* and *B*). It thus strikes nearly parallel to beds on the south limbs of these folds but is highly oblique to beds on the north limbs. Many outcrops show that the cleavage lies within the apical angle of minor folds, and intersections of bedding and cleavage plunge consistently east-northeastward parallel to the plunge of the major folds.

CHESTNUT MOUNTAIN ANTICLINE

The steeply dipping beds of the north limb of the Copeland Creek anticline can be traced eastward nearly to the Sevier-Cocke County line, beyond which they are abruptly succeeded by beds dipping moderately southeastward. These beds form the south limb of a faulted anticline whose crest lies in the area of Chestnut Mountain and its northeast continuation known locally as Gulf Mountain. Fine exposures of folded Roaring Fork sandstone in the crestal region can be seen where the Pigeon River cuts through Gulf Mountain a mile southeast of Hartford, Tenn. The south limb of the Chestnut Mountain anticline forms a belt, 1–2 miles wide, extending eastward across Buckeye Lead, Gabes Mountain, Round Mountain, and Turkey Knob. Beds of the Roaring Fork sandstone and Pigeon siltstone dip generally 25°–40° SSE. throughout the belt; very few minor folds and no reversed dips are present. The north limb, largely cut off by the Gatlinburg fault system, consists of steeply dipping beds striking east-northeastward and commonly overturned toward the north. The crestal region near Hartford is marked by open folds plunging 20° WSW. opposite to the plunge of the Copeland Creek and Cartertown anticlines.

Slaty cleavage strikes uniformly east-northeast and dips 30°–50° SSE. Both cleavage and bedding are visible in many outcrops, especially in the Pigeon siltstone, where cleavage is either somewhat steeper than bedding, or nearly parallel to it. In the crestal part of the anticline, slaty cleavage dips 50°–75° SSE. and is considerably steeper than it is farther south.

SNAG MOUNTAIN FAULT

The boundary between the Copeland Creek anticline and the Chestnut Mountain anticline is the Snag Mountain fault on which the uppermost part of the Roaring Fork sandstone is brought northward over Pigeon siltstone at least 2,000 feet higher in the sequence. The fault is not well enough exposed to determine its dip; nevertheless, stratigraphic and structural relations on either side indicate that it is a reverse fault dipping moderately southeastward. As stratigraphically lower rocks appear on the southeast side of the fault, the fault must dip more steeply than the faulted beds, which in this area dip 10°–25° SE. On the other hand, the fault has cut through a major anticline so as to bring gently dipping beds from the south limb over steeply dipping beds on the north limb. The fault is therefore less steep than the axial plane of the fold affected, which, if similar to the Copeland Creek anticline, dips between 50° and 60° SSE. Thus the Snag Mountain fault is probably a reverse fault, dipping perhaps 35° SE. It follows that the Chestnut Mountain anticline may be a displaced part of an eastward continuation of the Copeland Creek anticline, the rest of which is concealed beneath the Greenbrier fault.

GATLINBURG FAULT ZONE

The Cartertown and Copeland Creek anticlines are separated by a zone of steep reverse faults that extends throughout the foothill belt in the eastern part of the Great Smoky Mountains. Some of the faults are ex-

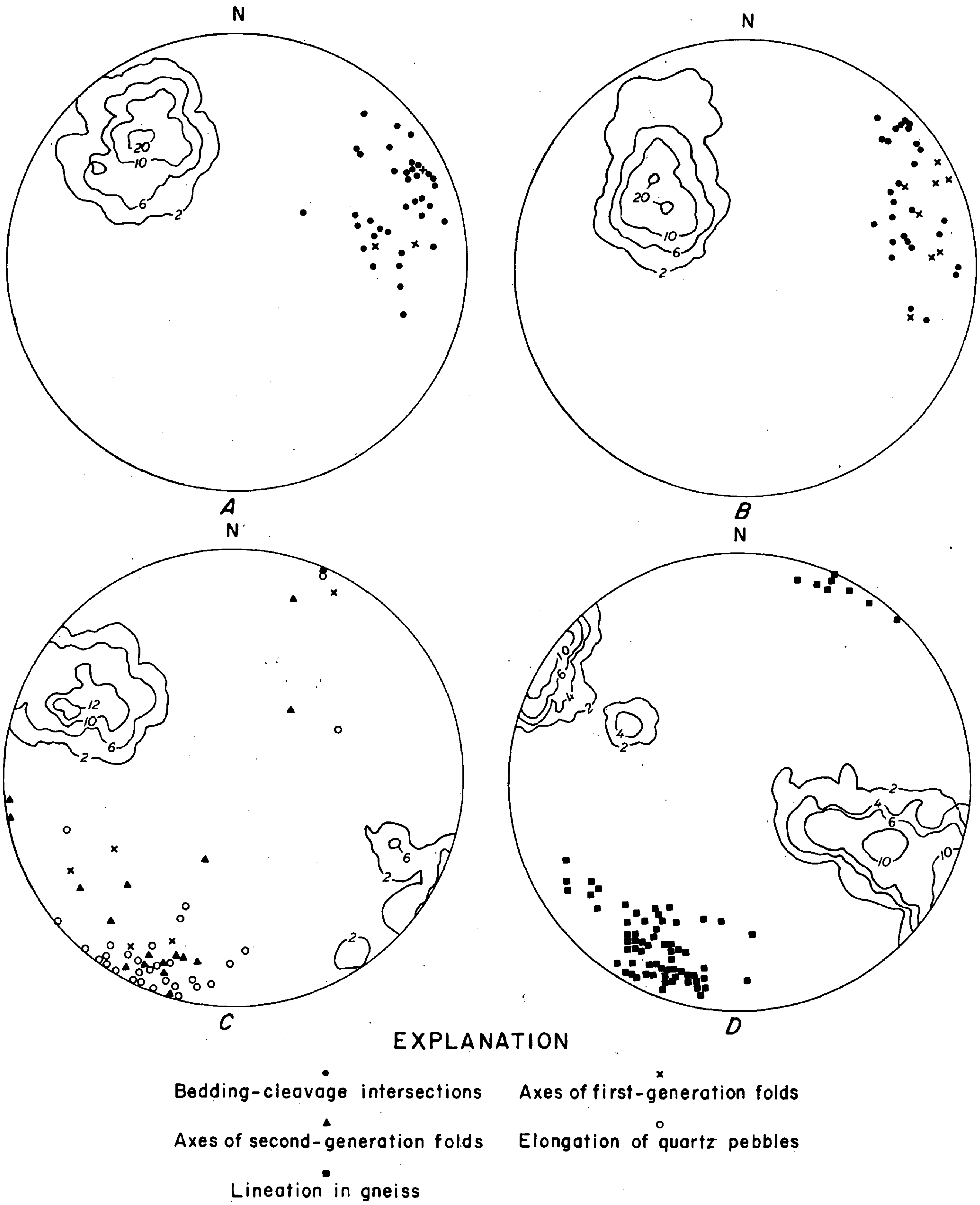


FIGURE 28.—Equal-area stereographic projection on lower hemisphere of schistosity, fold axes, and lineation in the Cartertown, Copeland Creek, and Ravensford anticlines, eastern Great Smoky Mountains.

posed in the town of Gatlinburg, where they have been named the Gatlinburg fault system by King (1963). Throughout the present report area the Gatlinburg fault system is represented by a zone of faults, in part, marked by topographic expression but defined mainly by the larger structural features that are displaced along it. The zone finds topographic expression in the troughlike strike valley of Dudley Creek and farther east in the valley of Webb Creek. Through most of its course the zone is either poorly exposed or covered by alluvium; and topographic expression, though marked in some places, is absent in others.

Faults of the Gatlinburg zone are exposed chiefly in highway cuts along Tennessee State Route 73 between Gatlinburg and the west part of the Webb Creek valley. In these exposures the Roaring Fork sandstone and Pigeon siltstone are unusually broken, sheared, and marked by slickensided surfaces trending northeastward to east-northeastward and dipping 50°–80° SE. Striations on these surfaces plunge 20°–80° SE. The rocks on opposite sides of the zone are so similar that no fault can be identified as the principal one, and the amounts of displacement on individual faults are not evident. The exact location or width of the fault zone is not evident, and the line drawn on the map shows only its approximate position.

A better impression of the magnitude of the Gatlinburg fault is gained from the larger structural features that are displaced by it. It separates the Cartertown and Copeland Creek anticlines, offsets the trace of the Snag Mountain fault by more than a mile, and brings a thick section of Roaring Fork sandstone against Pigeon siltstone for 7 miles west of Hartford.

The top of the Roaring Fork sandstone on the crest of the Copeland Creek anticline is about 5 miles east of its position on the crest of the Cartertown anticline, and part of this difference has resulted from vertical movement on the Gatlinburg fault zone. As the top of the formation, however, is stratigraphically lower in the Cartertown anticline than in the Copeland Creek anticline (p. B34), the apparent displacement is exaggerated; to allow for this, the offset of comparable beds on opposite sides of the fault is estimated at 3 miles. If the trace of the displaced beds in the fault zone plunges 20° E., approximately parallel to the plunge of the nearby folds, the vertical component of displacement on the fault is about 1 mile. Stratigraphic displacement on the fault where it is crossed by section *G–G′* estimated at 6,000 feet, which agrees with the postulated fault movement.

Along the valley of Webb Creek, the Gatlinburg fault zone consists of two fault strands one-half mile apart, both of which cut the Snag Mountain fault. If one assumes dips of 35° SE. for the Snag Mountain fault and 60° SSE. for the strands of the Gatlinburg fault, the offset on the southern strand would have a vertical component of displacement of about 4,000 feet. Farther east at least 4,000 feet of Roaring Fork sandstone and an unknown thickness of Pigeon siltstone are missing at the Gatlinburg fault zone. As these beds have been cut by movements on both the Snag Mountain and Gatlinburg faults, no estimate of movement on the Gatlinburg fault is possible.

Although only vertical components of the fault movement have been considered so far, southeastward-plunging striations on fault surfaces in the Gatlinburg fault zone show a pronounced strike-slip component by which the uplifted southern block has moved west relative to the northern block. The attitudes of striations suggest that the strike-slip component is less than half the dip-slip component, but observations were too few and the attitudes too divergent to make this more than an approximation. The strike-slip component was probably not large or it would have more fully counteracted the displacements produced by the vertical component.

MINOR FAULTS

The rocks of the Copeland Creek and Cartertown anticlines are broken by many smaller faults related to the Gatlinburg fault system. Many interbedded sandstone and siltstone units in the Roaring Fork sandstone are offset along steep southward-dipping reverse faults of a few hundred feet displacement. Nine such faults, traceable for 1½–4 miles, are shown in the south limb of the Copeland Creek anticline and others are undoubtedly present. Most clearly seen in the field is the fault a mile north of Greenbrier Cove, on which a sequence of interbedded sandstone, siltstone, and phyllite is offset 800 feet and the stratigraphic displacement is about 300 feet. A similar sequence of thick sandstone units on the lower part of Roaring Fork just southeast of Gatlinburg is offset on a fault with stratigraphic displacement of about 130 feet. Displacements on other

Explanation of Figure 28

A. Cartertown anticline, contours on 85 poles to slaty cleavage, in percent.
B. Copeland Creek anticline, contours on 152 poles to slaty cleavage, in percent.
C. Thunderhead sandstone on northwest side of Ravensford anticline; contours on 71 poles to schistosity, in percent. In this and figure 28*D* note the partial girdles formed by schistosity and foliation about the axes of second generation folds.
D. Gneiss of the Ravensford body, Ravensford anticline; contours on 103 poles to foliation, in percent.

faults cannot be as confidently estimated. In 1 or 2 exceptional places the fault surfaces themselves were seen; otherwise exposures reveal only that the faults are moderately steep.

A particularly instructive exposure is a cut 200 feet long on the Park Service road between Emerts Cove and Greenbrier Cove about 1.8 mile southeast of the park boundary. At least six small faults are exposed in this cut (fig. 29); most dip from 20° to 40° S., although

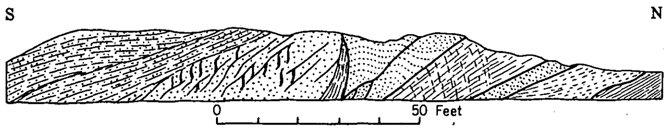


FIGURE 29.—Minor faults in Roaring Fork sandstone, road cut on Little Pigeon River, 1.75 miles south of park boundary. S-joints, mostly filled with quartz, are bent or slightly displaced on minor faults with slickensided surfaces.

one curves steeply upward to vertical attitude. Bedding in these rocks is more folded that usual in the vicinity, and several of the faults are nearly parallel to slaty cleavage in the more argillaceous rocks. The faults themselves are marked by thin zones of highly sheared rock but not much gouge; the associated shear joints in sandstone are slickensided. From this and similar exposures elsewhere, it appears that minor faults were guided by bedding, slaty cleavage, and associated joints.

Another instructive exposure is in a large cut on the north side of Highway 73 about a mile east of the town of Gatlinburg. Here a fault which offsets Roaring Fork sandstone by several hundred feet, was exposed during highway construction in 1950 when the section shown in figure 30 could be seen. The footwall consists of sandstone dipping 25° SE. underlain by about 5 feet of light-green slate and an unknown thickness of darker green moderately well bedded metasiltstone in the upper part of the Roaring Fork sandstone. Slaty cleavage in these beds strikes northeastward and dips 40°–75° SE. The fault, striking about N. 35° E., is a sharp contact between gently dipping sandstone in the footwall and steeply dipping argillaceous sandstone upturned in the hanging wall. It follows bedding in the overriding rocks, but rises in the overridden rocks, thus bending the overriding argillaceous sandstone into near vertical position and rotating its normally southward-dipping cleavage to northwestward-dipping attitudes.

Several other minor faults of the Gatlinburg system trend north-northeastward rather than parallel to the east-northeastward trend of the Gatlinburg fault zone. They are probably closely related to larger reverse faults trending north-northeastward in the vicinity of Gatlinburg and west of it in the central Great Smoky Mountains area (King, 1963), and they are interpreted as dip-slip faults striking at right angles to the northwestward movement of the system as a whole.

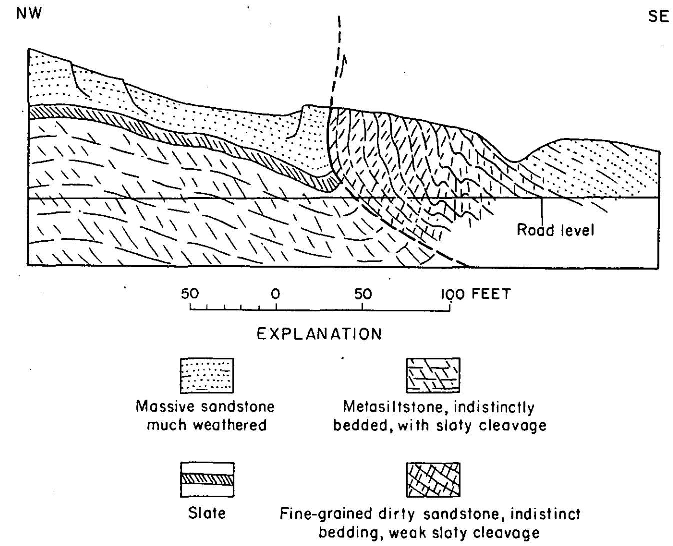


FIGURE 30.—Thrust fault in Roaring Fork sandstone cuts sharply across massive sandstone and rotates cleavage. Large roadcut on Tennessee Highway 73, a mile east of Gatlinburg.

AGE

No faults of the Gatlinburg system cut rocks younger than the Ocoee series, therefore no direct evidence of their age is available. The faults are younger than the regional metamorphism of the Ocoee rocks, for the regional cleavage is distorted near them and sheared rock and slickensided surfaces are not recrystallized. Faults of the system displace the Greenbrier fault west of Gatlinburg according to King. Thus the Gatlinburg fault system is postmetamorphic, late in the tectonic history of the region, and may belong to a late Paleozoic episode of deformation.

DUNN CREEK FAULT

The Wilhite formation between Cosby and Hartford is separated from the Pigeon siltstone by a southeastward-dipping fault continuous with one mapped by Hamilton (1961, p. A–40) to the west and called by him the Dunn Creek fault. A similar fault at this place is also shown by Rodgers (1953, pl. 10).

Exposures close to the fault can be seen on Tennessee Route 32, 2,200 feet northwest of its intersection with Route 73 southeast of Cosby, and on the upper slopes of the bluffs overlooking the Pigeon River east of Bluffton. Although the fault is concealed in most places, it marks a sharp contact from dark-gray slate of the Wilhite to greenish sandstone and siltstone of the Pigeon. In the exposure on Tennessee Route 32, the Pigeon is much fractured and cut by seams of gouge, and the fault apparently dips moderately southward.

On the ridge east of Bluffton, prominent sandstone beds in the Pigeon dip 20°–30° SE. and overlie folded dark-gray slate of the Wilhite dipping 25°–65° SE. Shear surfaces in the sandstone dip about 35° SE., and the underlying fault as traced down the west end of the ridge dips between 20° and 25° SE. Just west of Hartford, the fault, together with bedding and cleavage in the adjacent rocks, bends sharply southward as though in a southwestward-plunging fold. The fault must steepen downward as shown in sections *A–A′* and *B–B′* (pl. 1), for it is not brought up south of the Gatlinburg fault.

GREAT SMOKY FAULT

The northern boundary of the Wilhite belt is also a fault, mainly because it is strongly discordant to bedding in the Cochran formation on the south slope of Green Mountain and in the gorge of the Pigeon River between Green Mountain and Stone Mountain. This fault is largely covered by coarse surficial deposits shed from Green Mountain and is not exposed within the area studied. Parallelism of the mapped boundaries of the Wilhite belt, however, suggests that the bounding surfaces are also approximately parallel and that the northern fault also has a low south dip. Rocks near the fault are exposed on the north bank of Caney Creek, 100–400 feet east of its junction with Cosby Creek at the southwest corner of Green Mountain, where a broad smooth ledge of sandstone of the Cochran formation, much sheared and silicified, slopes 15°–25° S. beneath the alluvium of the valley floor. The soft slate of the Wilhite formation, exposed 300 feet to the south on Route 32 and on the road along Caney Creek, becomes increasingly sheared and brecciated northward, and the southward-sloping ledge of Cochran may represent a fault surface from which the overriding Wilhite has been stripped. Nearby spurs on the south side of Green Mountain, whose average slope is between 18° and 20° S., may also be close to the original fault surface.

The fault is probably the same as a southward-dipping low-angle fault described by Hamilton (1961, p. A-43) in the adjacent Jones Cove quadrangle, which brings other rocks of the Walden Creek group over the Cochran formation and is correlated with the Great Smoky fault of the central and western Great Smoky Mountains.

GREENBRIER FAULT

The folded and faulted rocks of the foothill belt are cut off on the south by a folded low-angle thrust fault on which rocks of the Great Smoky group are brought northward over the Snowbird group. This fault extends along the north front of the range in the eastern, central, and western parts of the mountains and is especially well revealed on the north slope of Greenbrier Pinnacle where it was first recognized and named. To the east, the fault curves sharply south around the Cataloochee anticlinorium in the eastern part of the report area. On the southeast side of this structure it cuts below the Great Smoky group through rocks of the Snowbird group into the basement complex, which thus appears in the overriding block. The Greenbrier fault appears again bounding the Straight Fork window in the central part of the report area.

For most of its length, the Greenbrier fault is one of the most easily traceable contacts in the area. From Greenbrier Pinnacle eastward, it is marked by the abrupt lithologic contrast between fine-grained rocks of the upper parts of the Snowbird group and Rich Butt sandstone and the much coarser sandstone and conglomerate of the Thunderhead sandstone. At many places from Greenbrier Pinnacle to the headwaters of Cosby Creek and again on Mount Sterling Ridge, this contrast is reinforced by marked divergence between the trend of the fault and the attitudes of bedding in the adjacent rocks.

The fault is less easily traced where finer grained sandstone of the Elkmont sandstone overlies similar rocks of the Roaring Fork. The relation is more deceptive, because in this area beds above and below the fault are nearly parallel for several miles. Similar deceptive relations exist in the vicinity of Big Creek southeast of Cammerer Ridge, where thicker and coarser beds of the Rich Butt sandstone resemble those of the Thunderhead sandstone, and there is little structural discordance on opposite sides of the fault.

The Greenbrier fault can be located within less than 100 feet at many places on steep ridges and ravines crossed by it, and the dip of the fault measured at such places ranges generally from 25° to 35° S. On Mount Winnesoka, the fault dips 25° SSE. in a vertical distance of 700 feet; at the west end of Greenbrier Pinnacle it dips 25° SSE. through a vertical distance of 1,700 feet. In both places the fault dips more steeply than the overlying beds so that lower units in the Elkmont sandstone are cut off updip. Steeper dips were noted along the fault as far east as Cosby Creek, but in these places exposures of the fault are worse, and their vertical range is less. On Mount Cammerer the fault flattens to 15° locally, and in the northernmost exposure, just northeast of the fire tower, it appears to be sharply downfolded or downfaulted to the north. The fault steepens to 30° again where it begins its southeastward course a little southeast of Mount Cammerer and increases to 45° SW. near Big Creek. On Mount Sterling Ridge and Indian Ridge, the fault probably dips 45°–55° WNW.

On the crest and southeast side of the Cataloochee anticlinorium, the Greenbrier fault is not well exposed although it can be traced without much difficulty. The overlying rocks of the Great Smoky group contain much mica schist which is similar to metapelitic rocks in the underlying Roaring Fork sandstone and reduces the lithologic and topographic contrast across the fault. Northeast of North Carolina Route 284 between Dellwood and Mount Sterling, displacement along the fault has brought rocks of the basement complex and the Wading Branch formation against very different rocks of the Longarm quartzite, but exposures reveal only a general dip southeastward.

At the north end of the Straight Fork window, the Snowbird group and basement rocks are nearly surrounded by Thunderhead sandstone; the contact between them dips outward, is discordant to structures within the window, and is interpreted as the Greenbrier fault exposed in a large anticline comparable to the Cataloochee anticlinorium. Because coarse-grained feldspathic metasandstone and quartz-feldspar conglomerate of the Thunderhead sandstone has been brought against finer grained biotitic metasandstone and dark feldspathic micaceous schist of the Roaring Fork sandstone, the contact can be recognized fairly easily in good exposures despite regional metamorphism of both units. In some places, however, as on Hyatt Ridge and on Straight Fork near Roses Gap, darker finer grained rocks of the Thunderhead are distinguished with difficulty from the adjacent Roaring Fork sandstone.

On the southeast side of the window from Big Cove almost to Cherokee, interbedded feldspathic sandstone and conglomerate with minor amounts of muscovitic schist, have been brought against dominantly light-colored gneissic feldspathic quartzite of the Longarm. The rocks on both sides are strongly sheared and recrystallized, and little structural discordance exists between them; nevertheless, where exposures are good the fault can be located closely.

Farther southwest the Greenbrier fault becomes increasingly difficult to recognize because of deformation and recrystallization of all the rocks involved. Along the west side of the south part of the Straight Fork window and in the Ela and Bryson domes, rocks of the Great Smoky group lie directly on the basement complex. No intervening rocks of the Snowbird group could be mapped, although, rocks at several places immediately above the basement complex resemble parts of the Roaring Fork sandstone or Longarm quartzite. Consideration of the larger structural relations indicate that the Greenbrier fault separates basement rocks from the overlying metasedimentary rocks on the northwest side of the Straight Fork window. Evidence for the existence of the fault around the Ela and Bryson domes is inconclusive.

The Greenbrier fault has been traced for nearly 90 miles from the northeast to the southwest limits of the Great Smoky Mountains and extends an unknown distance beyond them. In the eastern part of the mountains, it is exposed for 17 miles across this trend, from Mount Winnesoka to the southeast side of the Straight Fork window near Cherokee, or 20 miles if the distance is measured in cross section and folding is taken into account. Because of this folding the original attitude of the fault is not known, but its present trend N. 70° E. along the mountain front is probably approximately the regional trend before folding. As older rocks appear in the southeastern part of the overriding mass, the fault descended in that direction, and the overriding rocks moved northwestward relative to the overridden rocks.

The fault brings younger rocks (Great Smoky group) over older (Snowbird group) throughout much of its extent, the amount of displacement therefore could be considerably less than the width of its outcrop belt. Nevertheless, the displacement accounts for the great difference in thickness of the Snowbird group on opposite sides of the fault near Cove Creek Gap and therefore is considerable. The restoration of the Snowbird group before folding and faulting, suggested in figure 10, indicates that a belt of Snowbird, at least 15 miles wide, is concealed beneath the Greenbrier fault southeast of the gap, and the fault therefore must have moved this distance. The estimate is based, however, on the questionable assumptions that the rate of northwestward thickening of the Snowbird is approximately known and that no important erosion of the group occurred before faulting.

Although the Greenbrier fault formed early in the tectonic history of the region, it was preceded by folding in both the underlying and overlying rocks. This is most evident along the mountain front (pl. 3) where the Copeland Creek anticline is cut off by the Greenbrier fault and the related, though somewhat older Snag Mountain fault. Folds in the overriding Thunderhead sandstone are cut off along the fault between Greenbrier Pinnacle and Cosby Creek, and probably also on the north of Mount Sterling Ridge. Most of these older folds trend nearly due east.

A consideration of the stratigraphic relations of the Greenbrier fault also yields clues to the disposition of the sedimentary rocks before and during the early low-angle faulting. As the fault is traced westward from its easternmost exposure southeast of Harmon Den Mountain, the stratigraphic position of rocks immediately above the fault rises sharply from the upper part of the basement complex in the Cove Creek Gap quadrangle through thin Snowbird rocks into the Great Smoky group; the fault reaches its highest level in the vicinity of Big Creek, southwest of Waterville, N.C. From there westward to the Little Pigeon River, it descends again through at least 10,000 feet of Thunderhead and Elkmont strata. These relations suggest that the fault sliced through a broad eastward-trending syncline of Great Smoky rocks, cutting higher strata in the trough and much lower ones on the limbs.

A similar conclusion is reached with regard to the beds immediately below the fault. Beneath the Greenbrier fault at its eastern limit is the Wading Branch formation, but westward the fault cuts progressively higher units including the Longarm quartzite, Roaring Fork sandstone, and Rich Butt sandstone. The highest beds of the overridden rocks are now along Big Creek where the highest overriding rocks have come to rest. From there westward, the fault cuts down again in the sequence so that it lies on upper Roaring Fork at the west edge of the map area. At this place the prefault syncline was less deep, and the upturned Snowbird rocks along the mountain front seem to represent principally the south limbs of the Copeland Creek and Chestnut Mountain anticlines.

FAULT SLICES BENEATH GREENBRIER FAULT

In two places on the north slopes of Greenbrier Pinnacle and Maddron Bald, rocks of the Rich Butt sandstone below the Greenbrier fault are separated from the underlying rocks by low-angle faults similar to the Greenbrier fault. In the eastern area, southward-dipping medium-grained and argillaceous metasandstone and dark-gray slate of the Rich Butt are sharply separated from overriding sandstone and arkosic conglomerate of the Thunderhead. The underlying Pigeon siltstone is little exposed and not much is known about the intervening contact. Because the Pigeon is unusually thin here, it is assumed that the upper beds have been cut off by a low-angle fault that dips less steeply than the underlying beds and has brought part of the Rich Butt sandstone up from beneath the Greenbrier fault.

In the western area, very similar rocks of the Rich Butt lie between Thunderhead sandstone above the Roaring Fork sandstone below. Here the Rich Butt is more folded, and marked structural discordance appears at both contacts. Bedrock exposures are few between the two areas, but evidence from float indicates that Pigeon siltstone intervenes and the fault slice is locally overlapped by the Greenbrier fault. Displacement on the lower fault need not be great, for autochthonous Rich Butt a few miles to the east probably extends beneath the Greenbrier fault and could serve as a source for the fault slices.

ALUM CAVE SYNCLINE

South of the Greenbrier fault, the rocks of the Thunderhead sandstone and the Anakeesta formation occur in a complex syncline, 6–7 miles across, which includes the northern part of the eastern Great Smoky Mountains for more than 20 miles northeast of Newfound Gap. Although dominantly synclinal, this structural feature is much complicated by many subordinate folds and strike faults ranging from those visible only in outcrops to some traceable for several miles. One fault, the Mingus fault, forms the north boundary of a large anticline of Thunderhead sandstone around which the principal synclinal trough divides toward the southwest. A similar but unnamed fault forms the south boundary of a subordinate syncline, north of the principal axis, in which the Anakeesta formation appears between Tricorner Knob and Mount Guyot. Besides these, lesser folds and faults are present, as indicated on plate 3. Minor folds in the western part of the syncline and throughout its northern flank plunge gently eastward, so that the stratigraphically highest rocks occur at its extreme east end. In the central and southeastern parts of the syncline, however, the rocks have been uplifted and thrust northward in a belt, 4 miles wide, extending around the north end of the Ravensford anticline, so that the plunge reverses to the southwest and the main trough eventually disappears south of Mount Guyot.

The Thunderhead and Elkmont sandstones throughout the northern limb of the syncline dip south-southeastward with a fairly consistent attitude varied somewhat by broad folds plunging gently eastward. Thick sandstone and conglomerate beds of the Thunderhead dip generally 20°–35° SSE., or 15°–20° E. on the crests of broad minor anticlines. Farther east, dips on the crests of these folds reach 30°–45° E. A few folds strong enough to be marked by northward-dipping beds near the main synclinal axis on Mount LeConte, in the vicinity of Mount Chapman, and north of Mount Guyot are indicated by fold axes (pl. 3). As in the rocks north of the Greenbrier fault, interbeds of metasiltstone and slate are locally drag folded on a small scale.

Cleavage, conspicuous only in slaty interbeds, strikes N. 40°–70° E. and dips 30°–50° SE. throughout this limb. Unusually low dips of 20°–30° occur between unusually thick and gently dipping sandstone beds. Other deviations from the regional attitude were noted on the crests of eastward-plunging folds, where the cleavage of thin slaty interbeds follows the northward trend of adjacent sandstone beds, although not so far as to produce northward-dipping cleavage anywhere in the north limb of the syncline.

A large anticline of Thunderhead sandstone on Mount Mingus rises in the major synclinal trough, thus shifting its principal axis to the south in the area northeast of Indian Gap. The south limb of the anticline consists of thick-bedded sandstone and conglomerate dipping south-southeastward; the northern limb, of vertical or steeply dipping overturned beds; the anticline as a whole plunges moderately east-northeastward parallel to minor folds in both Thunderhead and Anakeesta strata.

The south limb of the Alum Cave synclinorium west of Richland Mountain consists of near-vertical beds of the lower part of the Anakeesta and the upper part of the Thunderhead sandstone striking east-northeastward. The lower tongue of the Anakeesta formation makes a conspicuous outcrop belt on this limb. Individual beds are either vertical or are overturned northward to dips ranging from 60° to 80° S., although a few beds dip steeply northward. Graded sandstone beds at many places in the Thunderhead and cleavage-bedding relations in the Anakeesta formation indicate that the tops of these beds are to the north. Subordinate folds on this limb are few, but some are found along the highway northeast of Newfound Gap, where gently dipping sandstone and metasiltstone beds sheared from the south limb of a minor anticline are caught between minor reverse faults. In nearby roadcuts, just below the upper highway tunnel, a steeply dipping sandstone bed shows drag folds overturned northward. At Newfound Gap, interbedding argillaceous metasandstone and minor phyllite at the base of the main body of the Anakeesta formation are overturned to dips of 50°–55° S., unusually low for this limb.

Rocks in the trough of the Alum Cave syncline are much more intricately folded than those on the north limb, especially because of the presence in the western part of the syncline of easily folded pelites of the Anakeesta formation. Minor folds are conspicuous in the slate and metasiltstone of the Anakeesta immediately overlying much less folded Thunderhead sandstone in the vicinity of the Chimneys. In the main trough of the syncline, folds are so abundant that no principal axis can be identified. Many are small enough to be exposed in individual outcrops, 10–20 feet across. Their shapes and attitudes are varied, ranging from asymmetrical open folds to tightly closed folds strongly overturned toward the northwest as seen at Alum Cave. Most folds plunge 5°–35° ENE., although many plunge east-southeastward or west-southwestward. Minor folds in the vicinity of the Mingus fault and the minor faults northeast of Newfound Gap are unusually closely spaced with the limbs sheared out and the crests undulating. This evidence indicates that the folding and faulting are closely related.

Slaty cleavage, seen in nearly all the fine-grained rocks of the Anakeesta formation, strikes northeastward and dips southeastward fairly consistently in this part of the syncline; a stereographic plot shows a cleavage pattern similar to that in the Copeland Creek anticline (fig. 28*B*). Cleavage is generally subparallel to the axial planes of minor folds of the bedding, and bedding-cleavage intersections are parallel to fold axes.

The structure of the south limb and trough of the Alum Cave syncline east of Richland Mountain and Porters Gap differs from that farther west in that the plunge of both major and minor folds is reversed, and this is accompanied by a new type of minor folds in which regional cleavage is also folded. Westward plunge of the major syncline is shown by the outcrop of the base of the Anakeesta formation near Copper Gap and Eagle Rocks. The abrupt eastward disappearance of the Anakeesta here has resulted mainly from erosion of a southwestward-plunging syncline, but partly also from intertonguing with the upper part of the Thunderhead sandstone to the east. Unfortunately, structural complexity combined with heavy cover made it impossible to map these relations in detail. Minor folds in the Anakeesta formation plunge 5°–35° SW. west of Eagle Rocks and Pecks Corner. Most of these folds deform not only bedding but also slaty cleavage; they are therefore younger than folds in which undeformed slaty cleavage is parallel to axial planes. The extent and significance of these two types of folds will be dealt with later; they exist together in the same rocks, generally have rather different attitudes, and greatly confuse attempts to deduce large-scale relations from small-scale structural features.

For about 4 miles east from Copper Gap, the trough of the Alum Cave syncline can be traced in the Thunderhead sandstone, whose beds are not so complexly folded as those of the Anakeesta formation farther west. Here, and as far as the north slope of

Mount Chapman, axes of subordinate folds are nearly horizontal or plunge gently westward, and the north limbs of anticlines are generally steep or overturned toward the north. The folding culminates in a zone of steep reverse faults north of Mount Chapman, in which at least 1,000 feet of southward-dipping Thunderhead strata are brought up against the lower part of the Anakeesta formation, preserved in a tight syncline in the gap between Tricorner Knob and Mount Guyot.

East of Hughes Ridge, the structural features and extent of the south limb of the Alum Cave syncline are obscured by the younger folding. Bedding is visible in the Thunderhead sandstone, but its attitude becomes more and more erratic on the upper part of Straight Fork, on Shawano Ridge, and Cataloochee Mountain. Regional cleavage, relied upon as a guide to structural relations farther north and west, here appears in diverse attitudes and is much transected or replaced by slip cleavage. In places, however, steeply dipping beds trending east-northeastward can be identified by graded bedding or cleavage-bedding relations as belonging to the south limb of the major syncline, but many deviations occur in which both bedding and slaty cleavage lie at large angles to this trend. Such deviations are more abundant near the north end of the Ravensford anticline and are related in part to the rise of this anticline.

MINGUS FAULT

The anticline of Thunderhead sandstone on Mount Mingus, northwest of Newfound Gap, is cut off by a steep reverse fault in its steep northern limb, comparable to the faults farther east just described. Although steeply dipping beds along both sides of the fault are so nearly parallel that they could be interpreted as an uninterrupted sequence, faulting is indicated on Anakeesta Ridge where gently dipping beds on the south limb of the anticline abut against overturned beds north of the fault. The fault apparently continues with increasing displacement for at least 6 miles southwest, beyond the area of the present report (King, 1963).

OCONALUFTEE FAULT

The west end of the Alum Cave syncline terminates abruptly against the transcurrent Oconaluftee fault. Like the Gatlinburg fault zone, the Oconaluftee fault is followed by segments of streams and occupies prominent gaps in the intervening ridges. It is named from its location in the straight upper part of the Oconaluftee River southeast of Newfound Gap and is well marked topographically from there to the west edge of the report area and for several miles in the central part of the mountains (King, 1963). Large structural features are offset by the fault. Thus the lower tongue of the Anakeesta formation southeast of Newfound Gap is displaced half a mile, and farther northwestward the Mingus fault and adjacent outcrop belt of the Anakeesta formation are displaced at the boundary of the report area 1 mile. At both places, rocks southwest of the fault are displaced northwestward relative to corresponding rocks on the northeast side, indicating a large right-lateral strike-slip movement.

Because of its straight course across ridges and valleys, the fault must be steep. Rocks nearest the fault, at Indian Gap and along the highway south of Newfound Gap, are unusually fractured, sheared, and disrupted. Minor fault surfaces occur in various attitudes; some of the more prominent strike northeastward, dip southeastward and have southward-plunging striations. At other places, bedding, striking northwestward and dipping steeply northeastward at variance with the regional trend, appears to have been dragged toward the position of the fault. These zones of dragged, broken, and sheared rock, like those along the Gatlinburg fault, apparently account for its topographic expression. Disturbed cleavage and preservation of slickensides indicate that movement occurred after the regional metamorphism; but whether all or most of the movement on the fault occurred at this time is uncertain.

STRUCTURAL FEATURES SOUTHWEST OF OCONALUFTEE FAULT

The Alum Cave syncline cannot be recognized southwest of the Oconaluftee fault, where stratigraphic relations are more obscure and new structural elements appear. Thunderhead sandstone and the lower tongue of the Anakeesta formation on Clingmans Dome and Mount Collins dip southward in apparently unbroken sequence. Graded beds and minor erosion channels, seen at the east end of Forney Ridge parking area on Clingmans Dome (fig. 18*A*) and at other places in the sequence, show that the rocks are right side up.

Between Mount Collins and Indian Gap, the lower tongue of the Anakeesta formation is folded in an anticline joining southward-dipping to overturned beds in the displaced southeast limb of the Alum Cave syncline. The outcrop pattern and minor folds in roadside exposures south of Indian Gap show that this anticline plunges gently westward. It should thus be overlain by the main body of the Anakeesta formation, but rocks of Anakeesta aspect occur only in a small area just south of Indian Gap, where they are folded and seem to be underlain by Thunderhead sandstone a short distance to the northwest. They probably represent a tiny remnant of the trough of the Alum Cave syncline raised by movement on the Oconaluftee fault.

On the south limb of the anticline, the lower tongue of the Anakeesta formation is cut off abruptly by a southward-dipping reverse fault, which may be the fault and 6-inch gouge zone exposed along the road on the first spur north of Fork Ridge. Although little is known about the extent and displacement of this fault, it seems reasonable to correlate the two principal units of Anakeesta north and south of it. Northwest of the State line, the fault may lie in the vicinity of the metadiorite sills low on the north slope of Clingmans Dome. For some distance north of these sills, thick-bedded sandstone and feldspathic conglomerate of the Thunderhead are interbedded with dark metapelitic rocks which probably represent tongues of Anakeesta higher in the sequence than the tongue to the south, rather than lower as would be implied in the absence of the postulated fault.

CATALOOCHEE ANTICLINORIUM

The eastern part of the Alum Cave syncline is bounded on the southeast by a large compound anticline or anticlinorium, 5–6 miles wide and 15 miles long, outlined by the trace of the Greenbrier fault. Like the Alum Cave syncline, this structural feature is composed of several large folds sliced lengthwise by steep strike faults. The Snowbird group is largely involved, but basement rocks, also much folded and faulted, occur in the northeastern part of the anticlinorium and in a fault slice extending into its core. In broad view, the Cataloochee anticlinorium is divided by this slice and the associated faults into two approximately equal parts.

NORTHWESTERN PART

The northwestern half of the anticlinorium is largely the northwest limb of a large anticline which includes the whole of the Snowbird group. A body of basement rocks on Harmon Den Mountain forms the core of the anticline, whose axis plunges southwestward and is cut off by the Cold Springs fault near the Pigeon River.

Beds in the Snowbird group throughout this part of the anticlinorium dip generally rather steeply west-northwestward, though they are locally overturned toward the northwest. Many open minor folds are expressed by variations in northwest dips, although locally the beds dip southeastward, as in the Wading Branch formation near the Pigeon River. Normally southeastward-dipping beds can usually be distinguished from overturned beds by their lower dip, bedding-cleavage relations, or current bedding where the rocks are not too sheared.

Toward the southwest, Longarm quartzite has been brought up on a steep strike fault of moderate displacement. The fault crosses North Carolina Route 284 a mile northwest of Cataloochee Creek, where overturned beds of the lower Longarm are in contact with normally southeastward-dipping beds, high in the formation, and also farther southwest where southeastward-dipping Longarm quartzite is adjacent to folded beds of the Roaring Fork sandstone. How far this fault extends to the northeast is conjectural, for it cannot be located in the Longarm quartzite or Wading Branch formation on the southeast slope of Longarm Mountain, but a prominent fault dipping 45° SE. on the north side of the Pigeon River, just west of the highway tunnel, might be the same fault.

SOUTHEASTERN PART

The principal structural feature in the southeastern half of the anticlinorium is one limb of a large anticline in which the Longarm quartzite dips generally southeastward. It is thus complementary to the northwestward-dipping rocks in the northwestern half but probably is not part of the same fold. Open folds, several hundred feet across, are plainly visible along the Pigeon River northwest of Hurricane Mountain. (See pl. 3 and structure section *A–A′*.) Bedding on their crests dips 5°–10° SW., and this southwestward plunge is confirmed by the presence of folded rocks of the Wading Branch formation beneath the Longarm quartzite south of Harmon Den Mountain.

COLD SPRINGS FAULT AND ASSOCIATED FAULT SLICE

The slice of basement rocks in the middle of the Cataloochee anticlinorium is the most puzzling structural feature in the eastern Great Smoky Mountains. It consists of much-sheared dark gneiss of the basement complex well exposed near Cold Springs Creek, on the Pigeon River northeast of Wading Branch Ridge, and on North Carolina Route 284 a little northwest of Cataloochee Creek. It is 500–700 feet wide throughout most of its extent, tapers slightly southwestward, and pinches out shortly beyond Route 284 on Noland Mountain.

The slice is bounded by parallel faults dipping 45°–50° SE. in the vicinity of Cold Springs Creek; these faults steepen to 60° or 65° where they cross the Pigeon River and are vertical at Route 284. The northwestern fault, called the Cold Springs fault, is clearly a reverse fault, rising from the basement rocks in the core of the Harmon Den anticline, through the overlying Wading Branch formation into the lower part of the Longarm quartzite. To the southwest, on the strike of the slice, the low-dipping Greenbrier fault is offset 2 miles by a similar reverse fault whose southeast side also has risen relative to the northwest side, and the two faults are considered to be continuous.

The fault on the southeast or upper side of the basement slice, although parallel to the other, must have a very different character, for younger rocks appear everywhere on its hanging wall. These rocks consist of the Wading Branch formation and Longarm quartzite, cut off sharply by the fault along the Pigeon River and Cold Springs Creek. Farther southwest the fault is presumed to be cut off by the Cold Springs fault where the slice pinches out on Noland Mountain. Despite the presence of younger rocks in the hanging wall, the fault probably did not originate as a normal or gravity fault with its present attitude; it is more likely a relic of earlier thrusting, presumably older than the Greenbrier fault, which is not affected by it.

Whatever the history of the fault on the upper side of the slice, both faults and the basement rocks between them show marked effects of a deformation younger than the upper fault. Rocks along both faults are much sheared, and the upper fault is firmly welded. Well-developed cataclastic foliation within the basement rocks is everywhere subparallel to the contacts and is accompanied in the interior parts of the slice by a strong lineation consisting of elongate porphyroclasts and intersecting shear surfaces that plunge 10°–30° SW., somewhat more steeply at the northeast. This lineation is probably normal to the direction of deforming movements rather than parallel and suggests that they were directed both upward and westward away from the nearby basement area.

CLEAVAGE

The rocks of the Snowbird group in the Cataloochee anticlinorium have a cleavage or schistosity, relatively weak in the northwestern part but very strong in the rocks northwest of the Cold Springs fault and northwest of the Greenbrier fault at the southeast edge of the anticlinorium. Metasiltstone and more argillaceous and finer grained sandstone and well-foliated nearly everywhere. In coarse-grained quartzite and arkose of the Longarm, the foliation is in places weak, as along the Pigeon River below Walters Dam, or strong with much cataclasis, as in the vicinity of Canadian Top and Noland Mountain and on North Carolina Route 284 northwest of Cove Creek Gap, where small quartz pebbles are flattened to wafers and even coarse sandstone is highly fissile. At most places, only one cleavage or schistosity transects bedding with low-plunging intersections parallel to the axes of minor bedding folds, in much the same fashion as in the folded rocks of the foothill belt farther west. By far the greater part of this cleavage strikes northeastward and dips variably southeastward. It is not folded, and variations in attitude seem to have resulted mainly from differences in competence and relations to local folds, faults, or other inhomogeneities in the rocks affected.

Along the southeast slope of Mount Sterling Ridge, however, most cleavage dips northwestward. Its appearance is like that farther southeastward, except that it is generally weaker, even in distinctly argillaceous rocks. It is reinforced where nearly parallel to bedding but cuts across folded bedding as well and is not noticeably folded. In a few places, northwestward-dipping and southeastward-dipping cleavage occur in the same outcrop, where they appear to represent competing cleavage directions rather than a single cleavage arched with the folding of the anticlinorium.

Large folds and faults like those in the Cataloochee anticlinorium appear in the basement and basal Snowbird rocks above the Greenbrier fault to the east. Major folds plunge gently or moderately southwest and are cut by strike faults. Near Shelton Laurel, the basement rocks beneath a relatively tight syncline in the Snowbird and Great Smoky groups have yielded largely by shearing and faulting, and incidentally provided the locus for a small lead-zinc deposit at the Redmond mine. Cataclastic foliation parallel to these faults is widespread in the basement complex here, but diminishes markedly northwestward, where it is confined mainly to the neighborhood of major faults and shear zones.

RAVENSFORD ANTICLINE

Southwest of the Cataloochee anticlinorium, rocks beneath the Greenbrier fault appear also in a great upfold, 15 miles long and as much as 3½ miles wide, called the Ravensford anticline. Comparable to the Cataloochee anticlinorium in size and trend, the Ravensford anticline involves large subsidiary fault slices below the Greenbrier fault, as well as more intense folding and metamorphism. Rocks of the Snowbird group in three subordinate window areas are overlain or completely surrounded by overthrust masses of basement and Great Smoky rocks; indeed, the Greenbrier fault at the southwest end of the anticline probably encloses both basement and Snowbird rocks in a still larger window. The northwestern part of the anticline is cut by a reverse fault dipping steeply northwestward and is also modified by a zone of intense and relatively late shearing trending east-northeastward in the vicinity of Enloe Ridge.

Rocks of the Snowbird group in the window area east of Hyatt Bald consist of coarse feldspathic quartzite, arkose, and finer grained sandstone, and pelitic rocks of the Longarm quartzite and Roaring Fork sandstone similar in every way to those in the adjacent Cataloochee anticlinorium. They are strongly folded on northeastward-trending axes parallel to that of the Ravensford anticline as a whole. Minor folds are open in the northeastern part, where fold axes and cleavage-bedding intersections plunge northeastward at relatively low angles. In the southwestern part of the window, near Straight Fork, these features plunge southwestward and the folds are considerably tighter. Cleavage or foliation occurs in the coarsest rocks and is vertical or dips steeply southeastward along the southeast margin of the window. In much of the northwestern part, especially near thrust slices, it dips at moderate angles northwestward and is considerably folded.

The northern part of the Ravensford anticline contains an overthrust mass of basement rock consisting largely of coarse augen gneiss and related granitic gneiss that encloses a thin fault slice of Longarm quartzite. These rocks and their structural relations are well exposed on both sides of Straight Fork, especially northwest of the ranger station, where the valley cuts through them to a depth of 1,500 feet. They overlie the main body of Snowbird rocks in the window area just described and are in turn overlain by Thunderhead sandstone above the Greenbrier fault.

An intercalated body of Snowbird rocks, 4 miles long and 200 to 500 feet thick, appears in the lower part of the basement mass, 300–400 feet above its base at the northeastern end but nearly 1,000 feet higher at the southwest end. Both upper and lower contacts are probably faults, but subsequent deformation has been such that little could be learned of their relations, and the faults cannot be recognized beyond the limits of the Snowbird rocks. The Snowbird consists largely of feldspathic quartzite of the Longarm, which is much foliated and recrystallized and toward the south, much sheared. In the northeastern part of the slice, quartzite is overlain for about a mile by coarse-grained feldspathic quartz-mica schist with quartzose or feldspathic layers, resembling parts of the Wading Branch formation. Both are well exposed in cliffy outcrops on the northeast side of Straight Fork, 400–500 feet above the stream. Here, about 100 feet of very coarse-grained feldspathic quartzite dipping 5°–10° E. has recognizable current bedding, although tops of beds could not be determined. The overlying schist, 100 feet thick, continues for 1,500 feet along the banks of Straight Fork, apparently in a much folded mass.

The lower slice of basement rocks overlies folded Longarm quartzite and Roaring Fork sandstone with a sharply discordant contact that can be traced closely from its highest point, near Beech Gap, southwest to its lowest point in the Straight Fork valley northeast of Big Cove. Along the northern three-fourths of its course, the contact dips northwestward with gentle to very steep attitudes reflecting pronounced folding. On the east side of Straight Fork valley, the contact dips eastward for a short distance on the southeast limb of a minor anticline. In the southern part of its course, where the contact descends the east side of Hyatt Ridge, it dips southward, at least in part, although its attitude cannot be closely determined here.

The Snowbird appears also farther north on Straight Fork and the adjacent slopes of Hyatt Ridge and is overlain in the vicinity of Hyatt Bald by augen gneiss similar to that in the fault slices to the east. These rocks have been uplifted on a fault which offsets the Greenbrier fault about a mile on Shawano Ridge and brings to view the upper slice of basement rock with part of its original cover of Wading Branch formation. Although the fault is little exposed, its straight course for several miles southeastward across Hyatt Ridge and into the valley of Raven Fork shows that it is steep. It is the only large fault in the area on which rocks are upthrown to the northwest.

The Wading Branch formation along the northwestern side of the uplifted block is much folded and sheared along with the adjacent gneiss, so that the relations between them are obscure even in good exposures on Raven Fork. Here and in intermittent outcrops on the south slope of Highland Ridge, layering and foliation in the metasedimentary rocks and the adjacent gneiss dip steeply northwestward; minor folds are tightly compressed and their pattern indicates relative movement upward from the northwest. Several folds contain cores of gneiss so sheared as to resemble closely foliated feldspathic sandstone in the folded metasediments. A smaller lens of Wading Branch formation, sandwiched between gneiss along Raven Fork east of Enloe Ridge, is interpreted as part of the sedimentary cover of the gneiss immediately to the east, although separated from it by faults.

The central and southern parts of the Ravensford anticline are occupied almost entirely by gneiss of the basement complex apparently continuous with the overthrust slices. Whereas the total thickness of the slices to the north is probably only 2,000 or 3,000 feet, the gneiss farther southwest must be much thicker, although greatly folded and sheared. Its contact on the southeast with adjacent Snowbird and Great Smoky rocks is almost vertical and maintains a straight course across entrenched meander spurs along the lower course of Raven Fork south of Big Cove. At the northwest, however, the contact between the gneiss and the

Thunderhead sandstone above the Greenbrier fault is less regular, reflecting generally lower dips and folds in which the gneiss plunges southwestward beneath the Thunderhead. Gneiss has been brought up in the largest of these folds 2 miles northwest of the Ravensford anticline.

At the southeast side of the Ravensford anticline, Snowbird rocks appear in a flanking anticline, which, though analogous to the uplifted block on Hyatt Bald, was raised by folding rather than by faulting, as indicated by a tight syncline of Thunderhead sandstone that separates it from the main part of the anticline southeast of Big Cove. The boundary between these Snowbird rocks and the central mass of gneiss probably represents the base of the overthrust mass, here pushed into vertical position by the same compressive forces that produced the adjacent anticline and syncline. Figure 31 is a schematic section of these features showing the manner in which they were probably produced.

The extent to which the basement slices were deformed during the development of the Ravensford anticline is indicated not only by their folded and welded contacts but also by their internal structure. Strong foliation dips at low angles in the thinner northern slices and in their marginal parts is likely to be subparallel to the bounding fault contacts. This is evident at most places along the base of the lower gneiss, whose foliation commonly dips as little as 20°. In many places the foliation is folded on a small scale, analogous to the larger folds of the slices themselves. In these places a steeper second foliation intersects the first with prominent lineations, parallel to the axes of the minor folds. Lineations and fold axes are uniformly parallel to the plunge of the larger folds (pl. 3) and were probably formed at the same time.

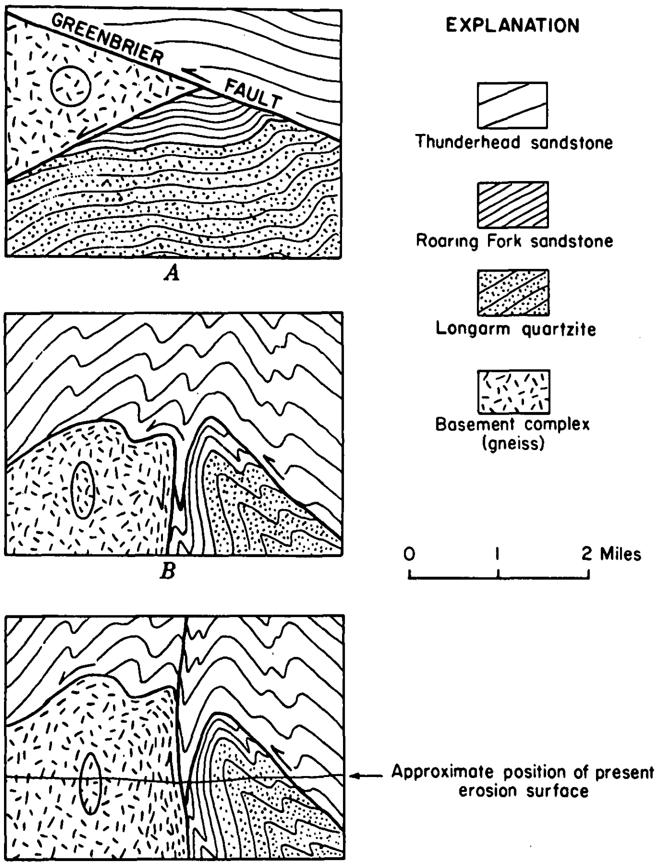


FIGURE 31.—Structural development of east side of Ravensford anticline at Big Cove. *A*, After low-angle faulting but before folding. *B*, After folding of Ravensford anticline. *C*, After later high-angle faulting.

The interplay of folded and transecting foliations becomes more pronounced in the large central body of gneiss; both low- and high-angle foliation is present, and several foliation directions occur in many outcrops. In other places all foliation is obscured, and only a pronounced lineation remains. These foliations and lineations in the gneiss of the Ravensford body are shown in figure 28*D*. They are, however, not equally distributed in the gneiss body. Northwestward-dipping foliation is dominant in most of the gneiss and suggests structural affinity with the northwestward-dipping slices farther north. Northeast of Big Cove, foliation dips at lower angles and is accompanied by northeastward-plunging lineations, whereas southwest of Big Cove, the foliation is steeper and lineations plunge uniformly southwestward in conformity with the folded northwest boundary of the gneiss. Foliation in the gneiss steepens both southwestward and toward the vertical southeastern boundary of the gneiss where vertical or steep southeastward-dipping foliation is common. As the foliation steepens it becomes stronger and lineation disappears, as though folding or rolling within the gneiss was subordinate to planar shearing in this part of the body. This intensification of shearing appears to be inherent also in the narrowing and tightening of the whole anticline southwest of Ravensford.

A zone of strong shearing cuts the northwest flank of the Ravensford anticline between Becks Bald and Enloe Ridge, where coarse-grained augen gneiss and infolded and infaulted Wading Branch formation have been intensely sheared and contain thick intercalations of mylonite. The mylonite forms bodies, 5–15 feet wide, that alternate with strongly sheared augen gneiss in a belt 500–1,000 feet wide. This belt trends east-northeastward across Hughes Ridge and Raven Fork and is best exposed on the steep slopes west of that stream just south of Enloe Ridge. Mylonite layers dip steeply southeastward, cutting sharply across the north-northeastward trend of the adjacent gneiss. East of Raven Fork, the mylonite belt is lost under a heavy surficial cover, but it probably dies out in the gneiss near the south end of the Longarm slice or in the belt of metasedimentary rocks west of it.

The mylonite resulted from movements that raised the northern part of the central gneiss body relative to the rocks north of it. The Greenbrier fault has also been displaced by steep reverse faults which are parallel to the mylonite zone and form the northwest boundary of the gneiss from Enloe Ridge to a point northwest of Becks Bald. The fact that the mylonite cuts across older structural features and is not greatly recrystallized indicates that it formed relatively late in the deformation of the region. Although it is tempting to relate the mylonite to the Oconaluftee fault, no evidence was found in the rocks between it and the east end of this fault to support such a view.

STRUCTURE AROUND RAVENSFORD ANTICLINE

Rocks of the Great Smoky group for several miles around the Ravensford anticline consist of monotonously thick-bedded metasandstone and schist in which major structural features are indistinct because of insufficient exposures, lack of marker beds, lack of bedding in much of the sandstone, and complexity of structure in the finer grained rocks. Observed bedding attitudes indicate that eastward-trending folds like those in the northern part of the report area are crossed by folds trending north-northeastward, parallel to the Ravensford anticline, which gradually become dominant southeastward. The latter folds are evident southeast and west of the anticline in variably dipping beds striking north-northeastward. They are least evident north and northeast of the anticline, where the anticline disappears in the rocks of the Great Smoky group. To the southwest, several major anticlines and intervening synclines, 1 to 2 miles apart, appear to be related to the Ela and Bryson domes.

Two features east of the Ravensford anticline suggest the presence there of another major fold or fault, but they do not definitely show what the structure is. The first is a small isolated area of dark augen gneiss of Ravensford aspect just south of the Blue Ridge Parkway, 2 miles east of Ravensford. The gneiss body is mantled by thick cover so that its shape and contact relations were not clearly seen, but it lies in rocks of the Great Smoky group dipping 25°–30° E. near the trough of a major syncline. Its presence in this anomalous structural position was first interpreted as evidence that both this and the larger gneiss unit of the Ravensford body to the west were intrusive in the Great Smoky group. As the view that the latter is part of the basement complex is more in accordance with regional structural relations, the smaller body is perhaps faulted or squeezed into the overlying rocks during the folding of the Ravensford anticline.

The second anomalous feature is a lens of light-colored current-bedded feldspathic quartzite of Longarm aspect intercalated in the Thunderhead sandstone northeast of the gneiss body. This lens, 200–300 feet thick and a mile long occurs on the upper part of the west slope of the ridge between Raven Fork and Bunches Creek east of the Greenbrier fault. Because rocks of the Great Smoky and Snowbird groups are not known to intertongue elsewhere in the area, the beds in question are either anomalous interbeds in the Great Smoky or, alternatively, a slice of Longarm quartzite faulted into the Great Smoky sequence, as shown on plate 1.

DELLWOOD QUADRANGLE AND CHEROKEE-SOCO BELT

The Dellwood quadrangle is dominated by anticlinal uplifts of basement rocks and intervening synclines of the Ocoee series (pls. 2 and 3). In the northern part of the quadrangle is the Cataloochee Divide syncline of schist and sandstone of the Thunderhead sandstone. To the southeast successive folds are the Fie Creek anticline, Buck Mountain syncline, Campbell Creek anticline, Walker Bald syncline, and Plott Balsam syncline. The Ocoee series is closely folded on a small scale reflecting the shapes and attitudes of the larger folds. The basement rocks, on the other hand, possess a detailed structure that is more complex and less explicit. Some minor features, notably foliations and small folds, are common to both groups of rocks; but little could be learned of the overall structure of the basement.

CATALOOCHEE DIVIDE SYNCLINE

The syncline of Ocoee rocks, separating the basement uplifts in the Dellwood quadrangle from the Cataloochee anticlinorium, is narrowest and its structure simplest along the Cataloochee Divide in the Dellwood quadrangle. To the southwest it merges with a broader mass of highly folded rocks, and to the northeast it bends sharply eastward and occupies a transverse position between basement uplifts to the north and south. Structural details within the syncline are obscure because of the absence of stratigraphic marker beds in the Great Smoky group. Beds in the Thunderhead sandstone and underlying Snowbird group in the northwest part of the syncline dip fairly regularly 30°–45° SE. and are not much folded. In the southeastern part of the syncline, the beds are steeper, more folded, and overturned northwestward.

BUCK MOUNTAIN, PLOTT BALSAM, AND WALKER BALD SYNCLINES

Similar but narrower synclines of Ocoee rocks occur along Buck Mountain and Setzer Mountain, and on Hard Ridge and North Eaglenest Mountain. The Buck Mountain syncline consists of sandstone and schist of the Great Smoky and Snowbird groups, much folded and metamorphosed. Bedding is not commonly measurable but appears to be generally steep and tightly folded with fold axes plunging at low angles parallel to the larger structural features. Folded cleavage is prevalent and conforms in pattern to the bedding. The straight course of the contacts and the constant width of the Ocoee rocks across the valley of Jonathans Creek indicate that the limbs of the larger fold are steep and nearly parallel to a depth of 1,500 feet. Farther southwestward, the fold is less deep and the marginal dips lower (pl. 1, section *E–E′*). Small deviations in the trend of the contact at the south end of Buck Mountain reflect minor folds in the adjacent Ocoee series.

A narrow sliver of basement rocks, 200 feet wide and a mile long, appears amid the Snowbird rocks on the west slope of Buck Mountain, half a mile north of the highway, and on the northwest slope of Setzer Mountain to the south (fig. 32). It apparently represents a tightly squeezed anticline bounded by steep reverse faults.

The similar Plott Balsam syncline in the southeast part of the Dellwood quadrangle continues along the Plott Balsams at least 15 miles southwest beyond the mapped area. In the Dellwood quadrangle, the southeast limb of the syncline is steep and the basement-Ocoee contact straight. The northwest limb is complicated by faults, displacement along which has brought up basement rocks, and by minor folds, which have caused digitations in the outcrop pattern just south of the highway near Dellwood.

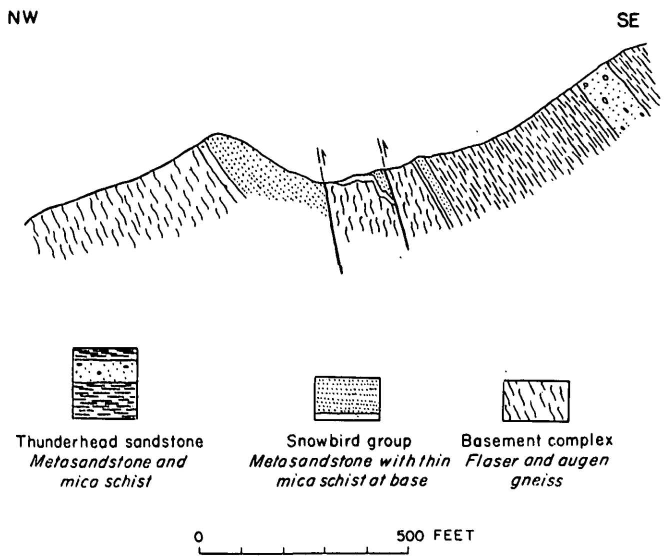


FIGURE 32.—Section of sliver of basement rock in the Ocoee series, northwest slope of Buck Mountain, half a mile north of Jonathans Creek, Dellwood quadrangle.

The Walker Bald syncline, between the Buck Mountain and Plott Balsam synclines, extends northeastward from Johnson Gap to Leatherwood Top and has brought down a broad irregular body of Ocoee rocks comprising most of Middle Top and Walker Bald. As shown in section *D–D′*, the fold is asymmetrical with its deepest part near the southeast side of the Ocoee outcrop. It seems to die out southward near the edge of the quadrangle and cannot be recognized in the basement rocks northeast of Middle Top.

FIE CREEK ANTICLINE

A belt of basement rocks half a mile wide extends between the Buck Mountain and Cataloochee Divide synclines from the headwaters of Hemphill Creek down the valley of Fie Creek into that of Jonathans Creek west of Maggie. Farther southwest it merges with the Soco-Cherokee belt and continues for a total distance of more than 20 miles. Throughout the length of this belt, the basement rocks are flanked by rocks of the Snowbird and Great Smoky groups, although its south side was not mapped in detail southwest of Soco Gap. The trend and structure of the belt change from the Fie Creek valley, where it trends north-northeastward and is a comparatively straight tight anticline, to the lower part of Soco Creek valley, where it trends nearly eastward and is complicated by large subordinate folds trending north-northeastward.

In the Dellwood quadrangle, the Fie Creek anticline, like the adjacent Buck Mountain syncline, is nearly isoclinal with straight parallel limbs dipping steeply southeastward. Foliation in the basement rocks dips uniformly and steeply southeastward without revealing an axial region. In the upper part of Hemphill Creek valley, the structural elements become more complex; a small subsidiary anticline projects northward into the Cataloochee Divide syncline, and the southeast limb is obscurely marked by a detached belt of Snowbird rocks southwest of Purchase Knob.

The northwest limb of the Fie Creek anticline southwest of the Dellwood quadrangle loses its simplicity and becomes progressively more folded. Just west of the quadrangle boundary, the basal Ocoee contact strikes S. 80° W. for 2,000 feet and dips 25° N.; a little farther west on the lower end of Wolf Ridge it appears in a tight syncline and anticline strongly overturned to the northwest as shown in plate 1, section *E–E′*. Similar relations, although on a smaller scale, occur along the contact as far west as Lickstone

Ridge, beyond which northeastward-plunging folds become larger and asymmetrical rather than overturned (section $G–G'$). Southeastward-dipping beds of the Snowbird group in these folds are relatively uncrumpled and dip as low as 15°–30°; northwestward-dipping beds are steep, and some are vertical. Northwest of Wrights Creek, minor folds in the Snowbird group become more intense as the south end of the Ravensford anticline is approached.

CAMPBELL CREEK ANTICLINE

The nearly enclosed area of basement rocks in the valley of Campbell Creek and northeast of Maggie is a compound anticline, with a medial downfold of the Ocoee series trending northeastward through Maggie

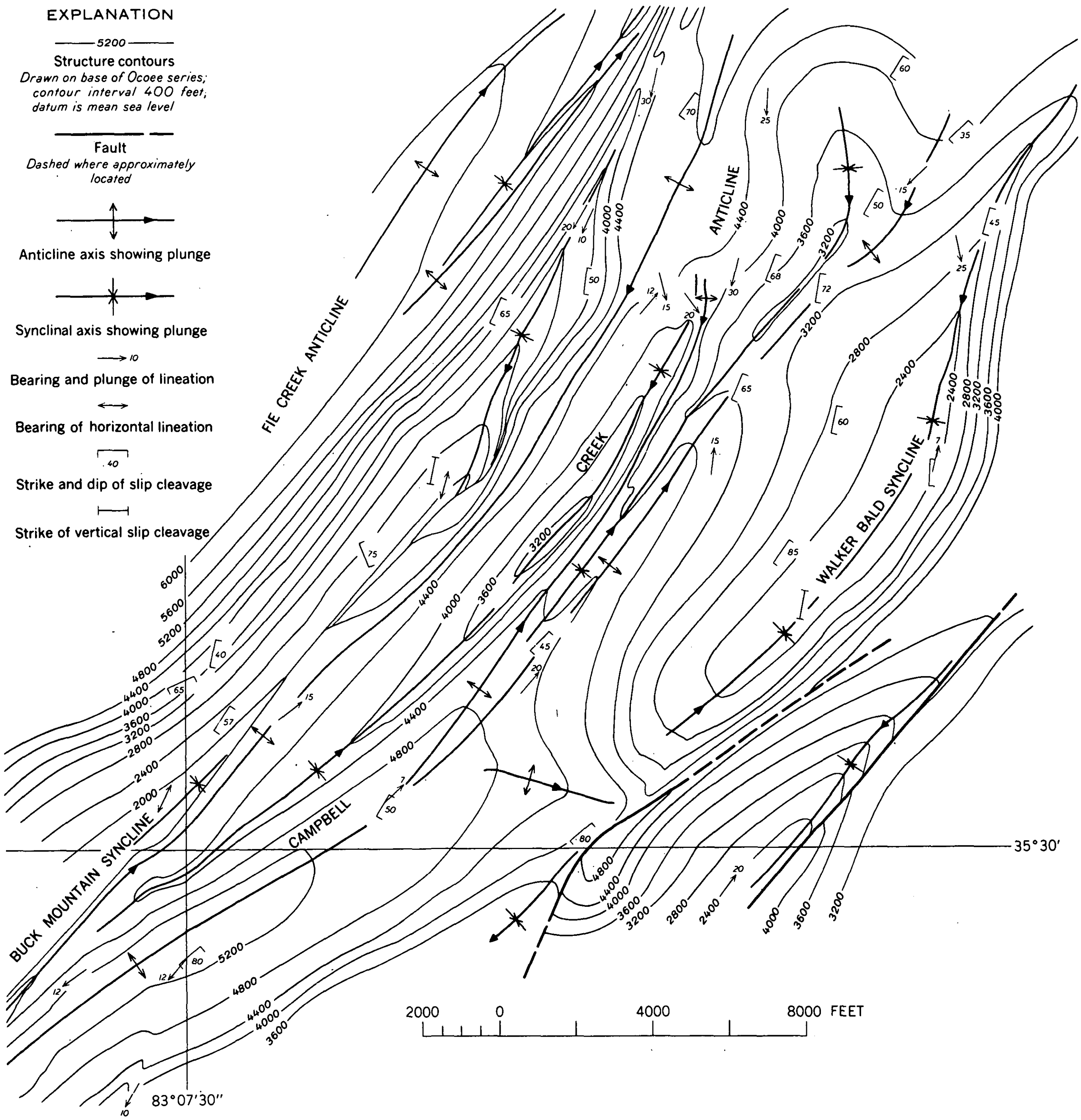


Figure 33.—Structure-contour map of the base of the Ocoee series near Maggie, N.C., showing relationship of major structural features to slip cleavage and lineation in the Ocoee series and basement complex.

(fig. 33). The two anticlinal parts of the feature are en echelon so that the southern part along Campbell Creek becomes less distinct toward the northeast around Middle Top, whereas the northern part, prominent northwest of Walker Bald, dies out southwestward on the slopes of Setzer Mountain. Farther southwestward, the Buck Mountain syncline apparently merges with the Plott Balsam syncline, and the Campbell Creek anticline disappears. Anticlinal structure in the basement rocks is reflected by the outcrop pattern of the Carolina gneiss and overlying plutonic gneiss bodies and by foliation which dips away from the anticlinal axis. Foliation in both parts of the anticline shows crenulations whose gently plunging axes are parallel to the trend of the anticline and to folds in the surrounding Ocoee series.

BASEMENT ROCKS NORTHEAST OF WALKER BALD SYNCLINE

Larger structural features in the basement rocks in the central and eastern parts of the Dellwood quadrangle are obscure, owing to the heterogeneity of the rocks, their structural complexity, and the lack of stratigraphic control. Well-defined folds and faults of post-Ocoee age generally cannot be traced in the basement rocks. Traces of older folds can be seen locally, but little structural continuity could be found.

Larger structural features are revealed in some places by attitudes of the more distinctly layered parts of the Carolina gneiss and by the distribution and attitude of foliation in the more massive rocks. Thus, the southern slope of Purchase Knob consists of layered gneiss in clearly defined broad folds plunging northward about 40° and cut off sharply at the west and north by augen gneiss. Another area, northeast of Dellwood, shows a crude dome in which layered gneiss on Goat Rock Ridge, Utah Mountain, and Trit Knob dips away from a poorly defined center east of Jonathans Creek and about a mile north of Utah Mountain. The good exposures in this vicinity show that many layers in the gneiss are isoclinally folded and that the dome has been impressed upon complexly folded and foliated rocks late in their history. As the area lies between the Plott Balsam and Walker Bald synclines, the doming may be related to the formation of these two folds. Another area of complexly folded Carolina gneiss is on the south side of Hemphill Creek, where minor folds in both layers and foliation plunge southward under similarly folded Ocoee rocks and are probably a product of post-Ocoee rather than pre-Ocoee folding.

The area of basement rocks from Hemphill Creek to Suttontown and Cove Creek has been uplifted as indicated by the abrupt termination of the Ocoee series at the north end of the Walker Bald and Buck Mountain synclines and by overturned bedding in the Thunderhead sandstone east of Suttontown. The northwest margin of this uplift is marked by a narrow remnant, or "keel," of basal Snowbird that is apparently a continuation of the Buck Mountain syncline, all but pinched out by rising basement rocks to the east. The uplift is abruptly terminated on the northeast where the basement-Ocoee contact swings directly across its structural trend for 2 miles. Vertical movements seem to have combined with northward thrusting in this part of the basement, for foliation and overturned bedding in the adjacent Thunderhead sandstone dip southward beneath the older rocks. Movements in the northern and northwestern parts of the uplift are also recorded in zones of recrystallized cataclasite in the plutonic gneiss, extending from the north end of the "keel" northeastward to the Left Fork of Cove Creek east of Suttontown. These shear zones, however, cut across the eastward-trending foliation of the gneiss at the north margin of the uplift and thus are younger than the original doming.

ELA AND BRYSON DOMES

Southwest of the Ravensford anticline near Ela and Bryson City, granitic gneiss forms two domes flanked by rocks of the Great Smoky group. Although variously interpreted by previous writers (Cameron, 1951; Stose and Stose, 1944, 1949), the bodies are probably basement rocks in mantled gneiss domes analogous to the series of en echelon folds east of Cherokee. This is certainly true of the Ela body, which contains many rocks characteristic of the basement complex farther east. In the more granitic Bryson body, however, intense post-Ocoee deformation and metamorphism, and emplacement of undoubtedly younger granitic rocks have combined to obscure the origin of the body and its relation to the adjacent metasedimentary rocks.

The gneiss body near Ela has been mapped as an elongate dome, 5½ miles long and 1½ miles wide. The contact with surrounding metasedimentary rocks is sharp where exposed, although much of it is concealed by surficial deposits. Folded beds in the mantle and foliation in both gneiss and mantle rocks along the boundary dip outward from the gneiss 65°–80° along the sides, 15°–35° near the ends. Foliation in the interior of the gneiss has diverse gentle and steep attitudes, together with minor folds and lineation similar to the Ravensford body.

The outline and structure of the Bryson body as shown by Cameron (1951, pl. 1) resemble those of the Ela body. Contacts between gneiss and mantle rocks are generally sharp and, locally at least, subparallel to foliation in the marginal parts of the gneiss and to isoclinally folded beds in the adjacent metasedimentary

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rocks. Uncommonly low dips occur at the north end of the body, where bedding in the Thunderhead sandstone and foliation in the adjacent gneiss dips 15°–25° NNE.

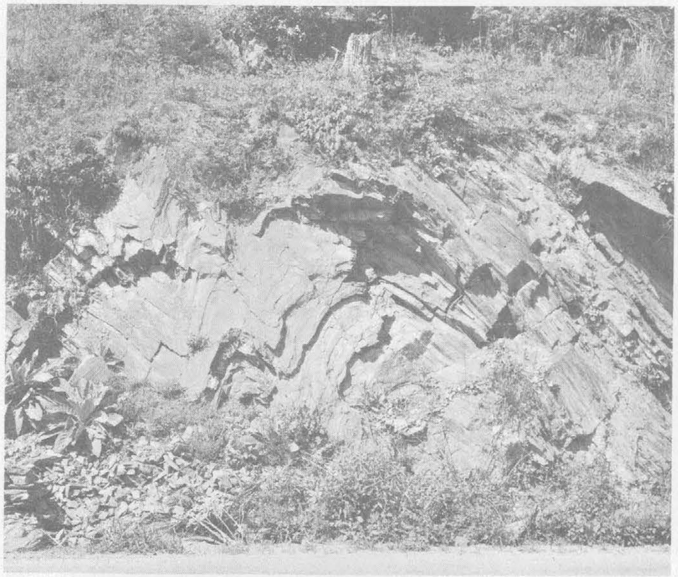
These gneiss bodies may be parts of the Greenbrier thrust sheet analogous to the en echelon folds of basement rocks east of Cherokee, they may lie below the Greenbrier fault like the basement rocks in the Ravensford anticline, or they may intrude or otherwise have displaced the surrounding rocks. The evidence is inconclusive, and the boundaries on plate 1 are intended to be noncommittal.

The best evidence that the gneiss domes are detached parts of the basement above the Greenbrier fault is the fact that the gneiss in them is more like that in the Soco-Cherokee belt than that beneath the fault as represented by the Ravensford body. Unfortunately, however, where the two gneiss bodies come together southwest of Cherokee no definite contact and no satisfactory evidence of their relations was found. Moreover, recognizable conglomerate of the Great Smoky group occurs at many places within a few hundred feet of the gneiss, and the border relations resemble those around the Ravensford anticline, where the Thunderhead sandstone lies directly on basement rocks, rather than those in the overriding block east of Cherokee, where a well-recognized sequence of Snowbird rocks at least 1,000 feet thick overlies the basement.

Whatever its former relation to the surrounding rocks, the Bryson body is now far above the base of the Ocoee series. Well-bedded Thunderhead sandstone along the railroad and highway between the east side of the Bryson dome and the south end of the Ela dome appears to be a continuous sequence overturned toward the west. If so, the rocks at the east side of the Bryson dome must be several thousand feet higher stratigraphically than those at the west side of the Ela dome. Also, a belt of Thunderhead sandstone less than 1,500 feet wide separates the west side of the Bryson dome from the Anakeesta formation thousands of feet above the base of the Great Smoky group. The strata of Thunderhead and Elkmont sandstones missing on both sides of the Bryson dome may have been eliminated by the Greenbrier fault, by later faulting, by diapiric displacement, or by a combination of these movements.

SECOND-GENERATION FOLDS AND ASSOCIATED MINOR STRUCTURAL FEATURES

As mentioned in the description of the Alum Cave syncline, a system of minor folds and associated features younger than the folds and regional cleavage found farther north appears on the southern flank of the Great Smoky Mountains. These second-generation folds are the most prominent structural features in the Great Smoky group in the southeastern part of the report area. They consist largely of minor folds of outcrop size accompanied by crinkled and folded schistosity transected by slip cleavage. The folds are generally open rather than isoclinal, asymmetrical with southward-dipping axial planes like the first-generation folds, although many have vertical or northward-dipping axial planes. Schistosity in the pelitic interbeds characteristically follows bedding around the crests and troughs rather than remaining subparallel to axial surfaces (fig. 34*A*). In the more argillaceous



A. Second generation folds in metasandstone and schist, showing absence of axial-plane foliation and parting along folded schistosity. U.S. Highway 19 near Wilmot, N.C.

B. Quartz-feldspar conglomerate of the Thunderhead sandstone showing severely flattened quartz pebbles and relatively undeformed microcline. Becks Bald, three-quarters of a mile southeast of the summit.

FIGURE 34.—FOLDS AND FLATTENED QUARTZ PEBBLES IN GREAT SMOKY GROUP

rocks, folded schistosity is more prominent than bedding and is accompanied by planar slip cleavage approximately parallel to the axial surfaces of the cleavage folds. Slip cleavage is used here in the sense of a transposition cleavage (Knopf, E. B., 1931, p. 16–18) for foliation surfaces produced by rotation of previously alined micas into new positions along closely spaced zones of shear. It grades toward, but rarely becomes, a type of fracture cleavage in which closely spaced shear fractures are marked by little or no rotation or mineral orientation, depending partly on the amount of mica present and partly on the amount of recrystallization accompanying shearing. The second-generation folds are primarily shear folds, in which the slip cleavage marks the plane of shear and governs the attitude of the fold. Because the shear surfaces are easily deflected by variations in the rocks affected and because the folds were imposed on rocks with previously existing folds and cleavage, their pattern is considerably more complex than that of the first-generation folds exposed in the northern part of the area.

North of the Alum Cave syncline, second-generation features consist largely of slip cleavage and minor folds in the thicker slate and phyllite beds in the Roaring Fork sandstone and Pigeon siltstone. Slip cleavage in the phyllite just north of the Greenbrier fault in the northwestern part of the report area strikes east-northeastward and dips generally steeply southward. The older slaty cleavage, which dips southward less steeply than the slip cleavage, is consistently displaced upward on the south, thus reflecting the northward thrusting movements of asymmetrical first-generation folds and small faults in this part of the area. Similar slip cleavage appears sporadically in the thicker slaty interbeds of the Thunderhead sandstone and in the Anakeesta formation on the north limb of the Alum Cave syncline, but few folds accompany it.

Second-generation folds and attendant slip cleavage are generally dominant over older features in the southeastern half of the report area (pl. 3). They are most abundant near the Ravensford and Cataloochee anticlines and the Ela and Bryson domes, where both slip cleavage and fold axes trend north-northeastward along the trend of the master folds. Remnants of the older east-northeastward-trending folds and cleavage exist in places, but nearly all minor folds on the northwest flank of the Ravensford anticline trend north-northeastward and are second-generation folds. The attitudes of slip cleavage and associated fold axes are more varied southeast of the anticline; nevertheless, north-northeastward trends and steep eastward dips predominate.

As slip cleavage increases southward in the pelitic rocks, interbedded sandstone and conglomerate become foliated in various degrees. Foliation is visible in most sandstone but is most distinct in the coarser rocks, in which quartz granules and pebbles are greatly flattened (fig. 34*B*). Flattened pebbles first become conspicuous a few miles southeast of the center of the Alum Cave syncline, where the longest dimension of flattened ellipsoidal pebbles is commonly 2 or 3 times the shortest. Farther southeastward near Becks Bald, Smokemont, and Newton Bald, long dimensions 5 or 10 times the shortest are common, and even greater flattening occurs locally southeast of the Ravensford anticline and in the Cataloochee syncline (fig. 35). In many places pebbles are also elongated so that their longest axes are several times longer than their intermediate axes. This elongation is most prominent where second-generation folds are abundant and the direction of elongation is universally parallel to the axes of such folds (fig. 28*C*).

In many outcrops in the vicinity of the Ravensford anticline, the foliation of metasandstone is subparallel to slip cleavage in interbedded schist (fig. 36), although in some places they diverge considerably and in a few the foliation of metasandstone is itself folded. Figures 28*C* and 28*D* show that this pattern of foliation and lineation is repeated in the Ravensford body of gneiss in the core of the anticline; thus most of the foliation and pebble lineation in sandstone of the Ocoee series in this part of the area resulted from the later deformation rather than the earlier, and these movements were dominant in deformation of the basement rocks as well.

Farther southeast, as exemplified by conditions in the Dellwood quadrangle, the pattern of minor folds, foliation, and lineation in the Ocoee series is more complex. Small isoclinal first-generation folds, rarely seen, generally plunge eastward- to east-northeastward. Most minor folds in the area are second-generation folds, the anticlines asymmetrical in cross section with steeper limbs on the northwest. They trend northeastward to north-northeastward, with axes inclined at low angles either northeastward or southwestward in concordance with the master folds of the Ocoee rocks. Mica schist is generally crinkled; the crinkles are 3 to 15 mm in wavelength, and are larger than similar features farther northwest. In many places the microfolds are isoclinal and the resulting slip cleavage is scarcely distinguishable from the older schistosity. Toward the southeastern part of the quadrangle on Hard Ridge, the cleavage folds become larger still, and slip cleavage is weak or absent. This evidence suggests that deformation proceeded by flexure and slip along schistosity planes rather than by shearing across them. Foliation in well-recrystallized sandstone and

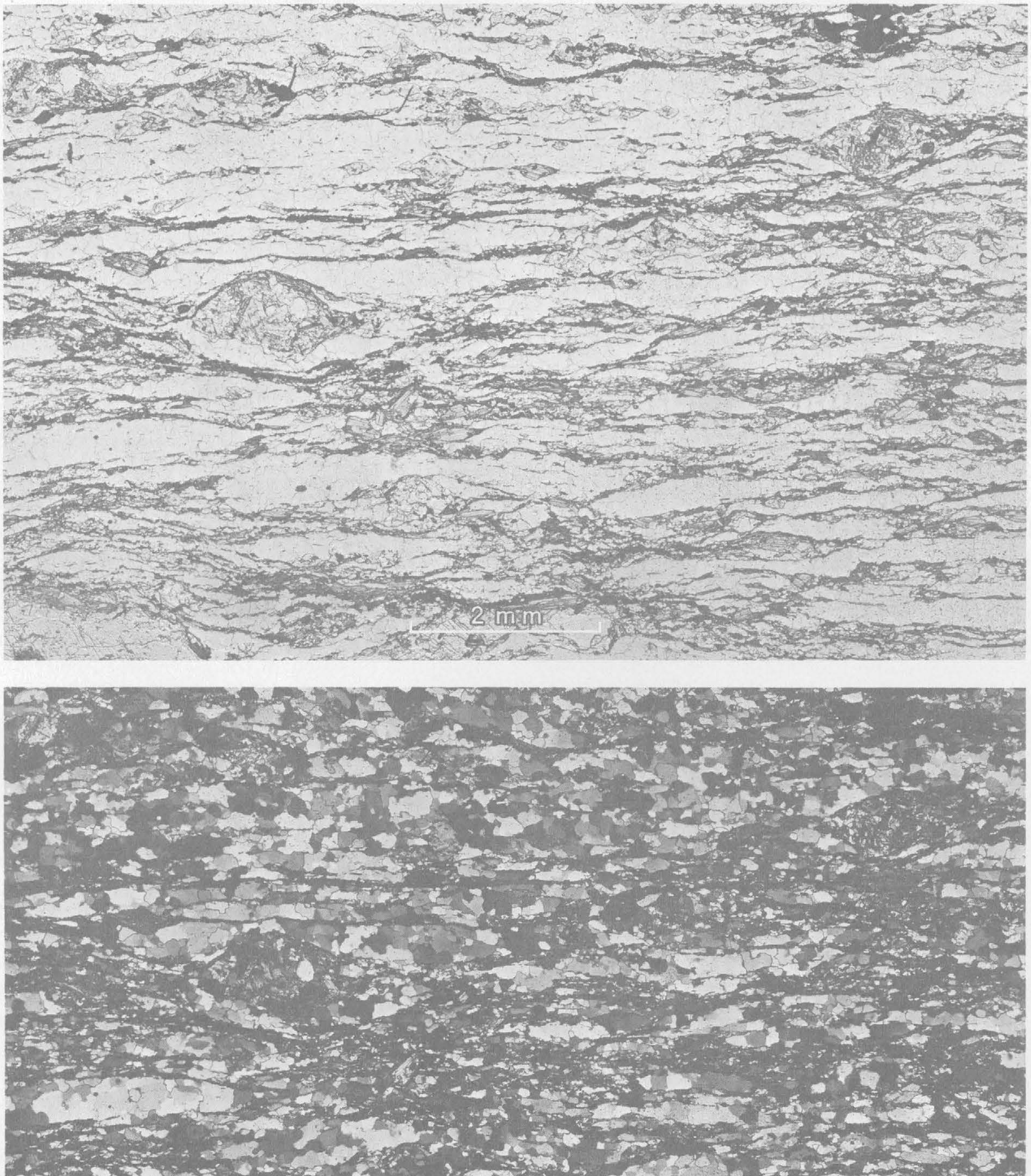


FIGURE 35.—Photomicrographs showing foliation and flattened quartz pebbles in Thunderhead sandstone. Microcline forms small augen. *A* (upper), Plane light. *B* (lower), Crossed nicols, showing granulation of quartz pebbles. Dellwood quadrangle, 2 miles southwest of Cove Creek Gap.

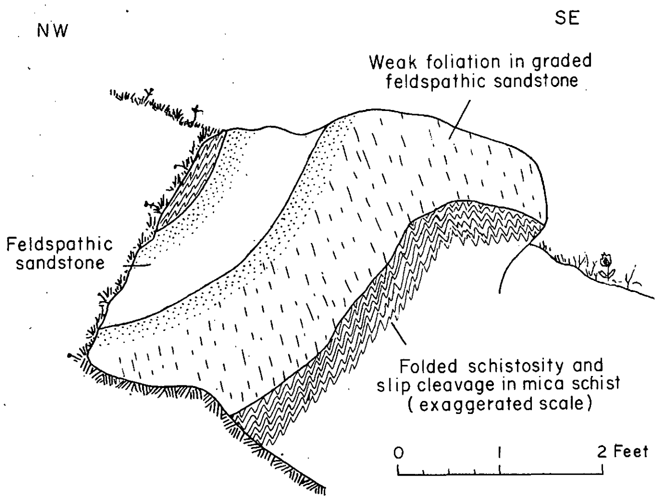


FIGURE 36.—Section of a second-generation fold in sandstone and interbedded mica schist. Older foliation in schist is crumpled on slip-cleavage surfaces. Overturned graded sandstone beds show weak schistosity subparallel to slip cleavage in schist. Thunderhead sandstone on Indian Creek, due east of Bryson Place.

conglomerate is commonly folded, and thus it appears to be somewhat older than the second-generation folds rather than contemporaneous as it is farther northwestward. Younger foliation in these rocks is generally indistinct and is characterized by diminution in the grain size of quartz and micas rather than by further recrystallization. Quartz pebbles in both the Great Smoky and Snowbird groups are flattened in the primary foliation; but elongate pebbles are found largely in the crests and troughs of second-generation folds where their long dimension is parallel to the fold axes. Elongation of these pebbles seems to be due to slicing of the flattened pebbles along slip-cleavage planes subparallel to the axial planes of the cleavage folds.

Throughout the Dellwood-Cherokee belt, minor second-generation structural features in the Ocoee series are reflected by similar features in the basement rocks. Low-dipping foliation is folded and cut by later and more steeply dipping foliation parallel with the slip cleavage in the overlying rocks. The earlier foliation of the basement rocks, especially in the Campbell Creek anticline and Walker Bald syncline, is subparallel to that in the Ocoee series, and many fold patterns in the basement rocks are similar to those in the Ocoee.

Second-generation minor folds and foliation in the rocks of the Ocoee series and in the basement rocks developed concurrently with the rise of north-northeastward-trending master folds in the basement rocks after episodes of folding, low angle faulting, and regional metamorphism. Although this deformation was accompanied or followed by considerable further recrystallization in the southwestern part of the report area, shearing was increasingly cataclastic toward the northeast, especially in the basement rocks. The structural trends of these features are so different from those of the folds in the foothill belt to the north that they suggest a fundamental change in the regional tectonic pattern, although the full extent and significance of such change is not yet known.

JOINTS

Joints of many kinds and diverse attitudes are abundant throughout the report area. Some display systematic geographic orientation or relation to rock type or structure; others are random in their occurrence, and their relation to larger structural features is not known. Chief among them are (1) a system of strike joints best developed in areas of relatively simple structure north of the mountain crest, (2) transverse joints including several sets found in various parts of the area, (3) joint swarms of various orientations, and (4) late northwestward-trending joints mainly in the southeastern part of the area, showing minor movement apparently related to the Oconaluftee fault.

Strike joints are characteristic of southward-dipping sandstone beds in the Roaring Fork and Thunderhead sandstones in the northwestern part of the report area. These joints strike east-northeastward parallel with the strike of the beds and dip generally southeastward, although vertical attitudes are common and northwestward dips occur. They are generally inclined 50°–70° to the bedding, so that in beds dipping 30° S. they are nearly vertical. In a few places joints in northward-dipping beds dip as low as 30° S. They are commonly filled with quartz and thus form veins an inch or so wide in the sandstone beds tapering to paper-thin wedges in the more schistose interbeds.

These joints and veins are generally curved as they pass from massive sandstone into finer grained more schistose beds (fig. 37). The curvature is always toward the cleavage in the schistose rocks, and the amount is proportional to intensity of the cleavage and the amount of mica present. The fractures do not penetrate far into the schistose beds and become nearly parallel to the cleavage before they disappear. They seem to be shear joints that originated in the sandstone at a large angle to the bedding and were deflected into the cleavage of the schistose interbeds. By continued shear along the cleavage, the fractures were apparently widened in proportion to the angle between them and the cleavage, and were filled with substances from the adjacent rocks, mainly quartz accompanied by minor amounts of carbonate, chlorite, and ilmenite.

Similar joints and veins occur in the more massive beds of the Thunderhead sandstone, where their sys-

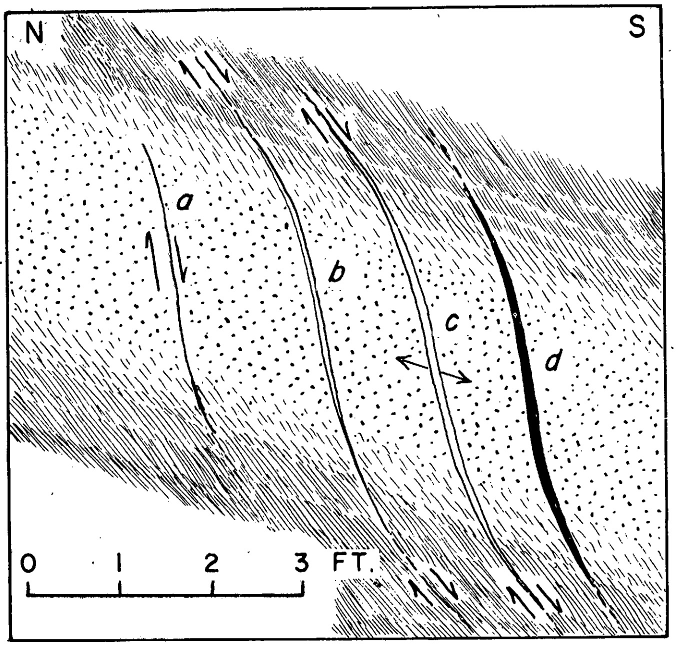


FIGURE 37.—Diagram of curved strike joints and quartz veins in moderately dipping feldspathic sandstone and schistose metasiltstone, Roaring Fork sandstone. *A*, Curved or refracted shear joint. *B*, and *C*, Curved joints opened by shearing parallel to schistosity and extension parallel to bedding. *D*, Joint filled with quartz.

tematic relation to bedding is useful in the structural interpretation. On the north slope of Mount Mingus, where thick massive sandstone beds are nearly vertical, the presence of gently dipping strike joints was the first clue to their attitude. Usually thick quartz veins occupy steep strike joints in moderately dipping sandstone beds of the Thunderhead sandstone on the Clingmans Dome road.

Systematic transverse joints are also conspicuous in the more massive sandstone beds of the Roaring Fork and Thunderhead sandstones in the northern part of the report area. These joints strike northward at large angles with the strike of the beds and are nearly vertical. They are widely spaced, several feet to many feet apart, and are not so abundant as strike joints. They also penetrate all the beds in a given outcrop. Very few are mineralized, and they seem to have originated later than the strike joints, after quartz mineralization had largely ceased. Prominent transverse joints, together with strike joints, make angular cliffy exposures in the Thunderhead sandstone and such pinnacles in the Anakeesta formation as the Chimneys.

Transverse joints are more abundant than strike joints in the much-folded rocks in the southeastern part of the report area, where many appear to be a-c extension joints normal to fold axes. They are widespread and uniformly distributed.

Similar to the a-c joints in attitude but otherwise of different origin are steep northwestward-trending joints that form swarms, or groups, of closely spaced subparallel joints averaging less than a foot apart. They are especially abundant in both Ocoee and basement rocks northeast of Cherokee, where they have influenced the topography and are responsible for northwest segments of the rectangular drainage pattern in the lower part of Raven Fork. At many places they are coated with chlorite and hematite and are moderately slickensided with nearly horizontal striations. They are younger than most quartz veins, many of which are slightly displaced. The trend, movement pattern, and time relations of these northwestward-trending joints suggest that they are related to the Oconaluftee fault.

Other joints form swarms or zones a few feet or a few tens of feet wide, in which unusually abundant nearly parallel joints are spaced a few inches to a foot or so apart. These joint swarms dip variously at angles ranging from 40° to vertical but have no preferred strike. They occur sporadically throughout the area, are not mineralized, and probably resulted from various local concentrations of stress relatively late in the tectonic history of the region.

PALEOZOIC REGIONAL METAMORPHISM

The Ocoee series and older rocks of the Great Smoky Mountains were subjected, probably in early Paleozoic time, to regional dynamothermal metamorphism that increased regularly in intensity toward the south-southeast across a belt at least 35 miles wide. Rocks of the greenschist facies are dominant in the northwestern half of this belt, but they are succeeded southeastward by rocks of the albite-epidote-amphibolite and amphibolite facies. Most of the metamorphism occurred after the displacement on the Greenbrier fault, but its thermal peak had passed before the deformation that produced the north-northeastward-trending Ravensford and Cataloochee anticlines and the accompanying second-generation minor folds throughout the southeastern part of the area. Shale and argillaceous siltstone were converted to slate and metasiltstone at the north, to phyllite and fine- to medium-grained schists farther south, and to coarse-grained schists and gneisses along the southern border of the report area. Feldspathic sandstone and conglomerate, although showing metamorphic changes less readily, became foliated or gneissic in the southern part of the Great Smoky Mountains. Impure dolomite and dolomitic sandstone in the Anakeesta formation north and northeast of Newfound Gap are represented by lime-silicate rocks west of Bryson City.

The rocks of the basement complex were much affected by the same regional metamorphism; but, because of their fundamentally different origin and previous metamorphic history, the results of post-Ocoee metamorphism are more difficult to distinguish in them.

PROGRESSIVE DYNAMOTHERMAL METAMORPHISM OF THE OCOEE SERIES

The course of early Paleozoic regional metamorphism in the Ocoee rocks of the eastern part of the Great Smoky Mountains can be traced in the appearance southeastward of new textures, microstructures, and minerals in pelites, carbonatic sediments, and associated basic igneous rocks. The succession of these minerals and mineral assemblages is similar to that in metamorphic fold belts elsewhere in the Appalachian region (Billings, 1937, 1956; Hadley, 1942, 1950; Barth, 1936). The direction of increasing metamorphism is best displayed by isograds marking the first appearance of the key metamorphic minerals, biotite, garnet, staurolite, and kyanite, as shown in plate 3. The isograds also separate, approximately, areas of differing metamorphic facies (Turner, 1948, p. 54–107). Rocks of the greenschist facies lie north of the garnet isograd, the biotite isograd separating rocks of the muscovite-chlorite subfacies from the warmer biotite-chlorite subfacies. Between the garnet and staurolite isograds, the dominant mineral assemblages are those of the albite-epidote-amphibolite facies, and south of the staurolite isograd they belong to the staurolite-kyanite subfacies of the amphibolite facies. These facies have been redefined as the quartz-albite-epidote-almandine subfacies of the greenschist facies and the staurolite-quartz subfacies of the almandine amphibolite facies, respectively (Turner, 1958, p. 218 and 229). Rocks of the sillimanite-almandine subfacies, representing the hotter part of the amphibolite facies, are not found in the area studied, but they do appear a few miles farther southeast.

For descriptive purposes the metamorphosed rocks of the Ocoee series are here classified according to the zone concept. Thus the area north of the biotite isograd, where metamorphic biotite is absent, is the chlorite zone; and the area between the biotite and garnet isograds, where biotite is present but not garnet, is the biotite zone. The garnet zone, lying between the garnet and staurolite isograds, contains both chlorite and biotite but not staurolite, which is represented in the more aluminous rocks of the zone by chloritoid. In the Great Smoky area, as elsewhere in the Appalachians, staurolite appears somewhat before kyanite so that both staurolite and kyanite zones are present.

CHLORITE ZONE

Rocks of the chlorite zone are limited to a narrow belt along the northern border of the report area, although they extend several miles farther north in adjacent quadrangles. They include principally rocks of the Pigeon siltstone and Roaring Fork sandstone, in which fine-grained rocks are dominant. The more argillaceous rocks are slate or metasiltstone with varying degrees of slaty cleavage depending mainly upon the original clay content. Original clay minerals were entirely reconstituted to sericite (the term "sericite" is used for fine-grained white mica, which is largely muscovite but includes paragonite in some rocks), and chlorite and silt-size quartz and feldspar have become granoblastic. Sand-size particles generally retain their detrital shapes and sizes, although their outlines are somewhat modified by recrystallization of the matrix. Detrital flakes of muscovite and chlorite are fairly common, but detrital biotite, has been altered to chlorite (Hamilton, 1961, p. A–36). Metamorphosed siltstone and sandstone are strongly feldspathic and contain abundant epidote, which was at least in part formed during metamorphism; the typical low-temperature metamorphic assemblage sericite-chlorite-albite-epidote is therefore prevalent in the rocks of the chlorite zone in the area. Although much of the sphene (table 7, analyses 1, 2, 10) is detrital, some of it probably represents metamorphic combinations of CaO and TiO_2 released by destruction of other minerals, perhaps of plagioclase and biotite.

BIOTITE ZONE

The biotite zone, in the south part of the foothills belt and the north part of the mountains, includes large areas of pelitic and arenitic rocks of the Great Smoky group, as well as of the Rich Butt sandstone, Roaring Fork sandstone, and Pigeon siltstone. Slaty cleavage occurs in the pelitic rocks, much as in the chlorite zone, but the most aluminous rocks have progressed to micaceous phyllite with a marked silvery sheen. Sandstone and conglomerate are not obviously foliated except in restricted zones of unusual shearing, but they show increasing microscopic evidence of internal shearing and concurrent recrystallization of matrix material.

Mineral assemblages of the chlorite zone continue largely unchanged into the northern part of the biotite zone with the important addition of biotite, which first appears as microscopic grains in feldspathic sandstone just south of the Gatlinburg fault zone. Between there and the Grenbrier fault, however, biotite is sparse, and most of the rocks retain their green color and chlorite content for several miles south of the biotite isograd. Biotite is developed at the expense of chlorite most fully in feldspathic sandstone, and chlorite is completely replaced by biotite in some sandstones north of the Greenbrier fault. Biotite formed much less readily in the more pelitic rocks, appearing as small scattered porphyroblasts in strongly chloritic rocks almost to the Greenbrier fault. In the Roaring Fork sandstone and Pigeon siltstone near the biotite isograd on the Pigeon River, green chloritic rocks are interlayered with grayer biotitic rocks. Thus, despite the theoretical incompatibility of muscovite, chlorite, and biotite in the biotite zone, assemblages including all three minerals are widespread in the rocks of the Snowbird group in the zone.

The persistence of chlorite seems to be related to the varying distribution of potassium feldspar (fig. 15), whose relation to metamorphic chlorite and biotite in the biotite zone is shown in figure 38. Chlorite is most abundant in rocks that contain the least potassium feldspar and is absent from most of those in which potassium feldspar amounts to more than a few percent. By analogy, many pelites whose grain size is too small to permit identification of the feldspars contain considerable biotite, whereas others do not. This evidence suggests that silt- or clay-size feldspar has influenced the development of biotite in these rocks also. Thus the presence of potassium in excess of that required to form muscovite has apparently promoted the formation of biotite in the progressive metamorphism of these rocks. Mass effects are apparently important, and a small amount of potassium feldspar is not enough to prevent the persistence of chlorite in the more micaceous rocks. In the sandstone, however, in which potassium feldspar far outweighs the micas, chlorite is rarely preserved in the biotite zone.

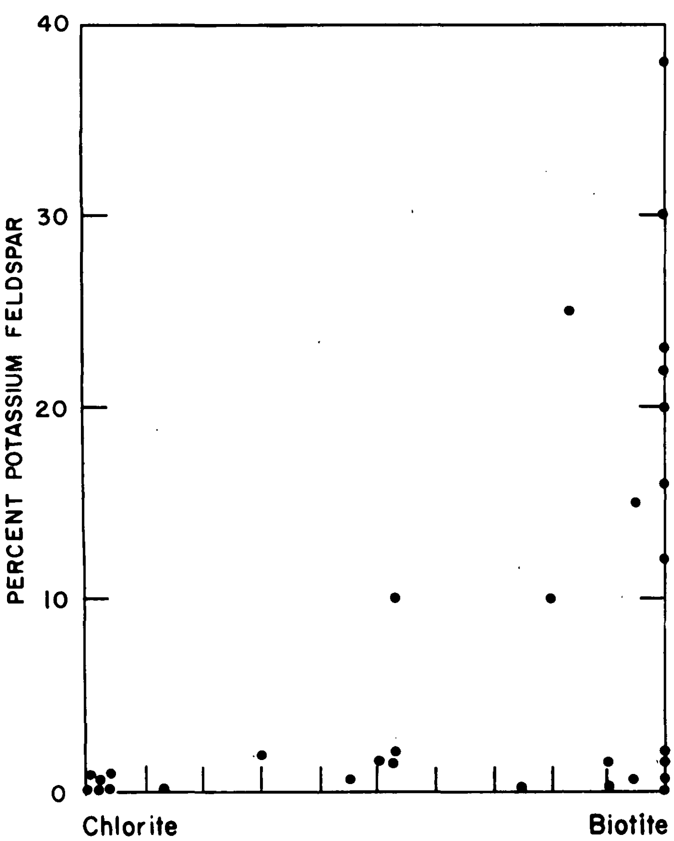


FIGURE 38.—Detrital feldspar and metamorphic biotite in sandstone and siltstone of the Snowbird group in the biotite zone. Relative proportions of biotite and chlorite are plotted against percentage of potassium feldspar as determined in thin sections.

In rocks lacking excess potassium in the biotite zone, part of the chlorite has actually increased in grain size and taken on to some extent a porphyroblastic habit similar to biotite. This porphyroblastic chlorite occurs mainly near the biotite isograd, as though representing initial growths that changed to biotite deeper in the biotite zone. Some chlorite, however, especially in biotite-muscovite schists in the Cataloochee area, has resulted from postthermal shearing and retrogression.

At the Greenbrier fault a marked change occurs in the color of both pelitic and arenitic rocks, for the rocks of the Great Smoky group south of the fault are almost wholly gray and biotitic rather than chlorite bearing. Although at first this change was ascribed to displacement of the metamorphic zones along the fault, it is controlled more by the potassic character of the Great Smoky group than by increased metamorphism.

Phyllite beds in the upper part of the Roaring Fork just north of the fault once contained porphyroblastic chloritoid or a closely related mineral, known only from tabular molds from which an iron-rich substance has been leached by weathering. The enclosing rocks are highly muscovitic, lack biotite, feldspar, and epidote, and are spangled by tiny brilliant plates of ilmenite. They are very similar to chloritoid-bearing rocks in the Anakeesta formation farther south.

Metadiorite intrusives in the biotite zone near the Greenbrier fault on Mount Winnesoka and Greenbrier Pinnacle, as well as on the north slope of Mount LeConte, are granoblastic mixtures of sodic plagioclase, green amphibole, chlorite, epidote, clinozoisite, and sphene. Biotite partly replaces chlorite at the margins of these bodies, where potassium appears to have been absorbed from the adjacent country rock.

GARNET ZONE

Rocks of the garnet zone occupy a belt, some 6 miles wide, that crosses the crest of the range obliquely and includes most of the Alum Cave syncline and parts of the Cataloochee anticlinorium and Ravensford anticline. The belt includes all the Anakeesta formation except the small area near Mount Guyot and that west of Bryson City. Pelitic rocks of the Anakeesta formation and Thunderhead sandstone in this zone range from shiny slate to phyllite and fine-grained schist, in which white mica increases southward from 0.02 to 0.2 mm in size. Porphyroblasts of biotite are considerably less than 1 millimeter in size, but those of garnet commonly are 1 or 2 mm and those of chloritoid are 3–5 mm. The foliation of pelitic rocks in the zone is much more commonly crinkled or bent by slip cleavage than in the areas farther north. Feldspathic sandstone and pebble conglomerate generally are only indistinctly foliated.

Garnet occurs sparsely in the slaty interbeds of the Thunderhead sandstone and is conspicuous in the dark pelitic rocks of the Anakeesta formation near the crest of Mount LeConte and eastward to Mount Sequoyah. As no megascopic garnet occurs in the small area of Anakeesta on Mount Guyot, this area is probably outside the garnet zone. Small porphyroblasts of almandine garnet found northeast of Mount Sterling in the dark argillaceous rocks of the Rich Butt sandstone and in feldspathic quartz-mica schist of the Roaring Fork sandstone mark the northern limit of the zone in the eastern part of the map area. Most rocks of the Longarm quartzite and Wading Branch formation contain either too much alkali or too little alumina to form garnet, and the garnet isograd cannot be located accurately in these rocks.

Typical mineral assemblages in the pelites and the more argillaceous sandstone contain muscovite, biotite, and quartz, with or without almandine garnet. In the carbonaceous and sulfide-bearing black slate of the Anakeesta in the northern part of the zone, garnet is a colorless variety rich in manganese (table 14, analysis 1). Where plagioclase feldspar can be recognized in the more pelitic rocks it is largely albite, although oligoclase appears in the southern part of the zone; epidote is generally absent.

An important assemblage, widespread in the Anakeesta formation in the northern part of the garnet zone, contains chloritoid, chlorite instead of biotite, and and garnet where chloritoid is sparse or absent. This assemblage is most prominent in the chloritoid slate member of the Anakeesta formation, but it also occurs in fine-grained argillaceous metasandstone of the sandstone member of the Anakeesta and in the Wading Branch formation northwest of Cove Creek Gap. The assemblage clearly represents the chloritoid-almandine subfacies of the albite-epidote-amphibolite facies, according to Turner (1948, p. 89), although the large amount of chlorite may be unusual. Here also the formation of biotite may have been prevented by a deficiency of potassium relative to alumina. Although no feldspar was identified in the chloritoid-bearing pelites, chemical analyses (table 11, analyses 4, 10) show that they are sodic enough to contain albite or paragonite or both. They are also deficient in calcuim; in the absence of biotite and sphene therefore, TiO_2 appears as abundant tiny plates of ilmenite (fig. 39*A*).

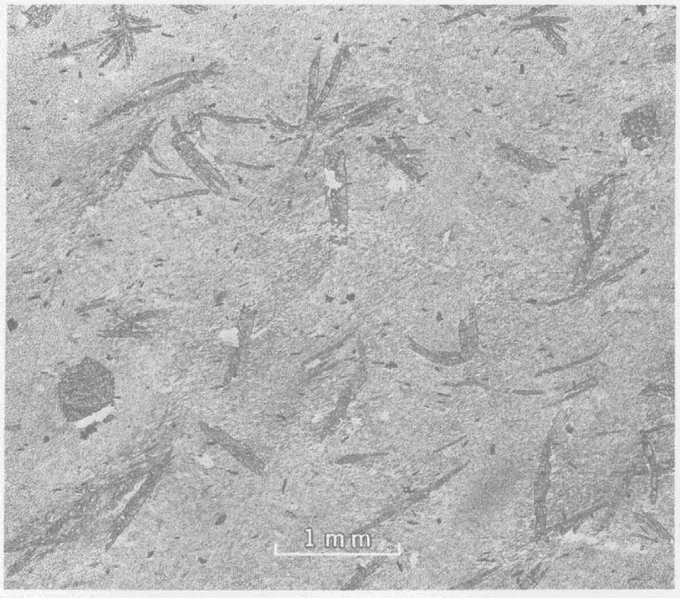
Although kyanite does not normally occur in rocks of the greenschist facies, it appears very sparsely in carbonaceous phyllite of the Anakeesta formation near Alum Cave and also, together with finely recrystallized graphite, in scarce quartz segregation veins in black slate near Eagle Rocks on the crest of the range. In both occurrences, the host rocks are rich in carbon, iron sulfide, and alumina and are deficient in iron available to form chloritoid.

Carbonate rocks occur in much the same area of the Anakeesta formation as the chloritoid-almandine-bearing pelites and contain everywhere the critical metamorphic assemblage dolomite-chlorite-quartz, with minor amounts of sericite and calcite. As this assemblage is normally limited to the low-grade greenschist facies, its presence here suggests high confining pressure during metamorphism, preventing the escape of CO_2 and the development of actinolite that would otherwise have occurred.

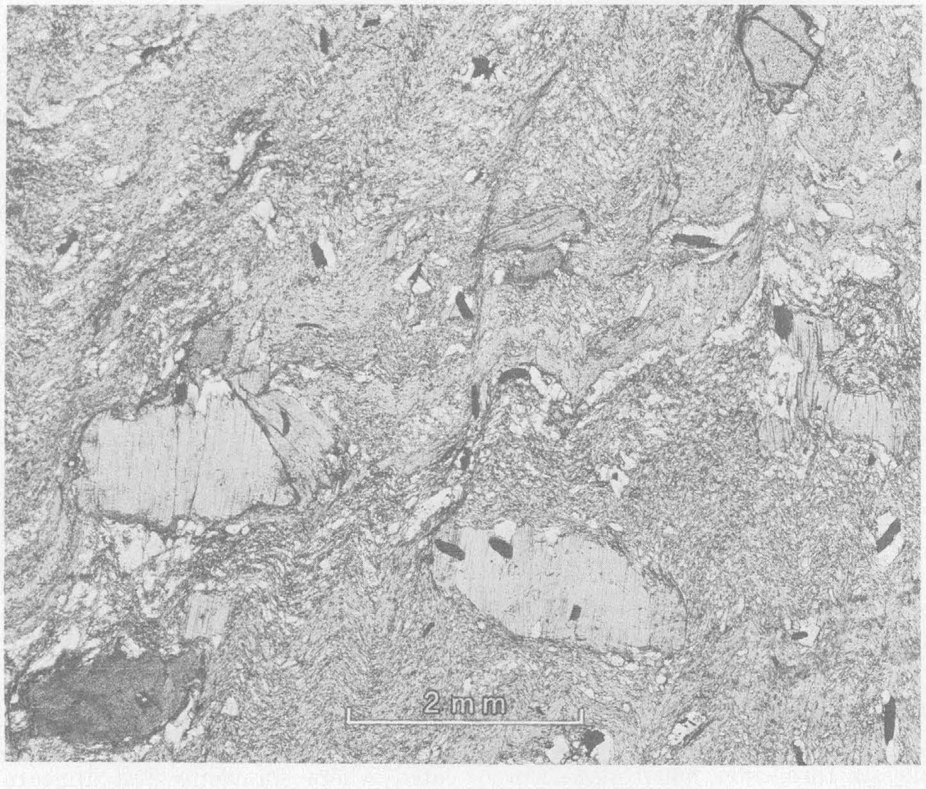
The dioritic and diabasic intrusive rocks on the north slope of Clingmans Dome were affected by the early Paleozoic dynamothermal metamorphism, although much of their original texture remains. The most altered rocks are greenish-gray schists composed of pale-green chlorite and sodic andesine, with varied amount sof carbonate, hornblende, biotite, and quartz. Much of the carbonate consists of small porphyroblasts of ankerite replacing chlorite and feldspars; chlorite replaces actinolitic amphibole and locally is distributed through plagioclase as though representing a recrystallized propylitic feldspar. The hornblende of the sheared rocks occurs sparsely as needlelike porphyroblasts penetrating the chlorite-feldspar groundmass, and it is darker than the actinolitic hornblende of the nonsheared rocks.

KYANITE AND STAUROLITE ZONES

The northern boundary of the staurolite zone is located where staurolite first appears in pelitic rocks, chiefly in the Thunderhead sandstone, as the chemical composition of most of the Snowbird group seems to be unfavorable for growth of either staurolite or kyanite. An exception is the basal phyllite of the Wading Branch formation, which forms kyanite schist in the Dellwood quadrangle. Also, a little staurolite



A. Chloritoid (tabular) and garnet (equant) in groundmass of quartz, sericite, and chlorite. Black specks are ilmenite. Chloritoid slate member of Anakeesta formation. Plane-polarized light.



B. Deformed biotite and garnet porphyroblasts in crumpled mica schist transected by slip cleavage (vertical). Thunderhead sandstone near Cove Creek Gap. Plane-polarized light.

FIGURE 39.—PHOTOMICROGRAPHS OF CHLORITOID, GARNET, AND BIOTITE PORPHYROBLASTS

occurs in a garnet-mica schist of the Roaring Fork sandstone southeast of the Catalooche Ranger Station and in the Straight Fork window southeast of Beech Gap.

The rocks of the kyanite and staurolite zones show the greatest reconstitution found in the Ocoee series in the area. Pelitic rocks are fine- and medium-grained porphyroblastic schists in most places, but coarse schist and feldspathic gneiss formed from the Ocoee series occur on Buck Mountain and North Eaglenest Mountain in the Dellwood quadrangle and in the vicinity of the Ela and Bryson domes. Muscovite ranges in size from 0.2 to 2 mm in the finer and medium-grained schists and is 3 or 4 mm in the coarsest rocks, in which it is commonly porphyroblastic. Biotite and garnet porphyroblasts are abundant, as large as 3 mm in some rocks (fig. 39*B*). The garnet in the pelitic rocks is mainly almandine, but garnet with considerable amounts of grossularite occurs in the more calcic metasedimentary rocks (table 14, and fig. 40).

TABLE 14.—*Compositions of garnet from the eastern Great Smoky Mountains, N.C.*

[Estimated from unit cell sizes and refractive indices in figure 40 and empirical data of Frietsh (1957, p. 46–47); n, negligible amount]

Analyses	Almandine	Pyrope	Grossularite	Spessartite	Andradite
1	20	5	----------	75	n
2,3	70	20	5	5	n
4	65	15	15	5	n
5,6	70	15	10	5	n
7,8	63	20	15	2	n
9	60	15	20	5	
10	55	15	25	n	5
11	50	15	30	5	
12,13	50	15	25	5	5
14	40	n	50	n	10

1. Pyritic carbonaceous phyllite, Anakeesta formation, garnet zone; U.S. Highway 441, 1 mile north of Newfound Gap.
2. Phyllite, Great Smoky group, staurolite zone, Chestnut Flat Ridge.
3. Phyllite, Great Smoky group, staurolite zone; Caldwell Fork, Dellwood quadrangle.
4–6. Mica schist, Great Smoky group, kyanite zone, Cataloochee Divide and Buck Mountain, Dellwood quadrangle.
7. Mica schist, Wading Branch formation, kyanite zone, near Soco Gap.
8. Mica gneiss, Great Smoky group, kyanite zone, the Plott Balsams, Dellwood quadrangle.
9. Two-mica gneiss, Carolina gneiss, near Trit Knob, Dellwood quadrangle.
10. Quartz-bearing garnet amphibolite, Carolina gneiss, near Purchase Knob, Dellwood quadrangle.
11. Diopside-bearing garnet amphibolite, Carolina gneiss, near Trit Knob, Delwood quadrangle.
12. Calc-silicate granofels, thin layer in mica schist, Great Smoky group, Cataloochee Divide, Dellwood quadrangle.
13. Calc-silicate granofels, thin layer in mica gneiss, Carolina gneiss, northeast of of Rock Hill school, Dellwood quadrangle.
14. Calc-silicate granofels, Carolina gneiss, near Trit Knob, Dellwood quadrangle.

Staurolite, although inconspicuous in the northern part of the zone, forms prismatic porphyroblasts, commonly 1–1½ inches long and locally as much as 3 inches long in the Catalooche Divide syncline and adjoining areas. Staurolite is also prominent near Rattlesnake Knob west of Smokemont. Kyanite, also sparse and inconspicuous in the northern part of the zone, occurs nearly as far north as staurolite in many places. It forms rectangular prisms, ½–1 inch long;

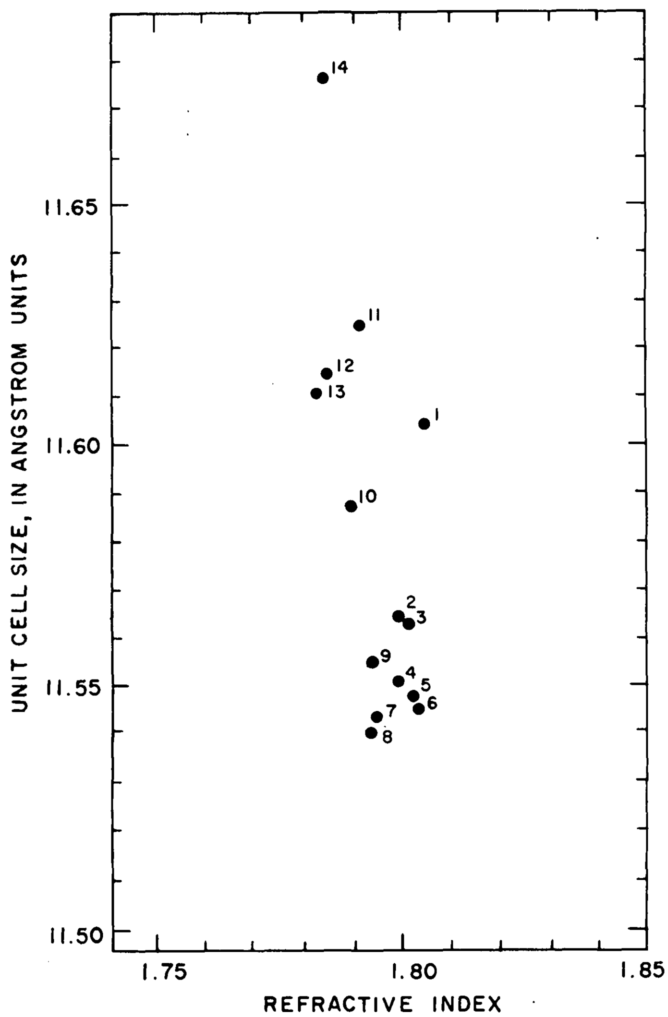


FIGURE 40.—Unit cell sizes and refractive indices of garnets from the Great Smoky Mountains, N.C. and Tenn. Numbers refer to analyses of samples given in table 14. Unit cell sizes obtained from X-ray powder photographs by Debye-Scherrer method with Cu radiation and Ni filter. Graphical method of Bradley and Jay (1932) used to obtain lattice spacing. Cell sizes are accurate to 0.001; refractive indices, obtained by oil immersion, are accurate to 0.002. Measured by R. Goldsmith.

in several places along the northern boundary of the zone these prisms have been altered to muscovite. Both kyanite and staurolite are prominent in the Anakeesta formation between Noland Divide and the Tuckasegee River; especially abundant and well-formed staurolite crystals are found in black schists near the mouth of Lands Creek west of Bryson City.

Kyanite and staurolite occur only in the most aluminous rocks of the Ocoee series, those with large amounts of alumina in excess of that required to form feldspar. When these rocks are plotted on a standard AKF diagram showing the relation between excess alumina, potassium oxide, and ferromagnesian oxides (fig. 41), it appears that typical pelitic rocks of the Snowbird group contain too little alumina with respect to alkalies and calcium to produce kyanite or staurolite.

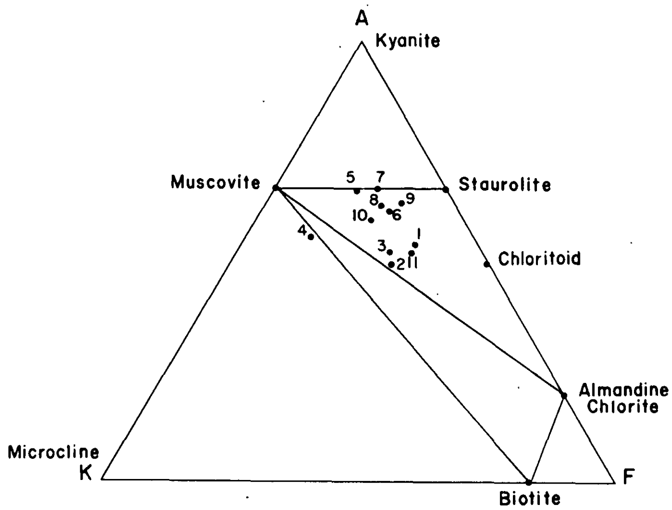


FIGURE 41.—AKF diagram for aluminous pelites of the Ocoee series, eastern Great Smoky Mountains. (1) Muscovite phyllite, chlorite zone, Laurel Creek, Wear Cove quadrangle. (2) Metasiltstone, Pigeon siltstone, chlorite zone. (3) Metasiltstone, Pigeon siltstone, chlorite zone. (4) Slate, Thunderhead sandstone, low garnet zone. (5) Black slate, Anakeesta formation, garnet zone. (6) Chloritoid meta- argillite, Anakeesta formation, garnet zone. (7) Chloritoid phyllite, Wading Branch formation, garnet zone. (8) Kyanite-staurolite-mica schist, Great Smoky group. (9) Kyanite-staurolite gneiss, Wading Branch formation. (10) Kyanite-muscovite schist, Wading Branch formation. (11) Kyanite-mica gneiss, Great Smoky group.

This relative scarcity of alumina accounts for the scarcity of those minerals in the Roaring Fork sandstone in the kyanite-staurolite zone. Kyanite and staurolite occur together in rocks of approximately the same composition as those containing chloritoid in the albite-epidote-amphibolite facies, but the reasons for the occurrence of kyanite are not wholly apparent, for none of the rocks falls outside the area where excess alumina can be contained in staurolite. Perhaps its occurrence is due to the abundance of biotite in the rocks of the kyanite-staurolite zone and the small amount of magnesia that can be accommodated in staurolite. Thus iron that would otherwise be found in staurolite is tied with magnesia in biotite.

In general, staurolite appears first whereas kyanite persists farther southward, so that rocks containing kyanite and garnet but not staurolite occur in the southeastern part of the Dellwood quadrangle. The rocks in the southeasternmost part of the report area therefore may represent the kyanite-muscovite subfacies of the amphibolite facies, in which staurolite is unstable and breaks down to kyanite and garnet (Francis, 1956, p. 355).

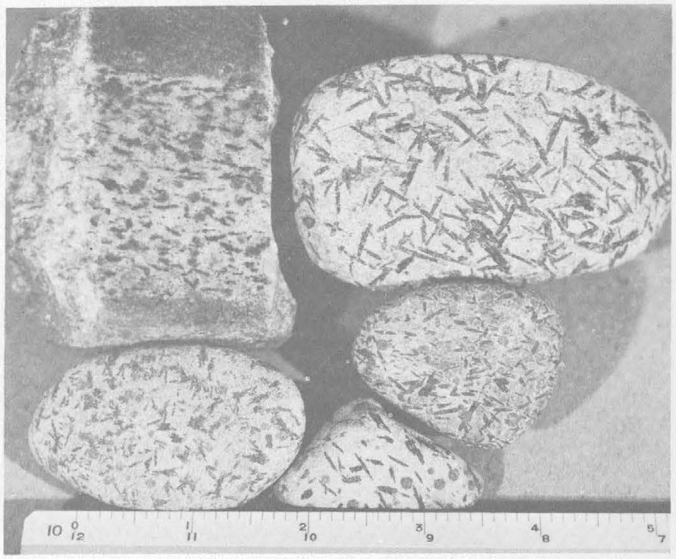
In the basal schist of the Wading Branch formation in the southwestern part of the Dellwood quadrangle kyanite occurs with abundant porphyroblasts of oligoclase feldspar and a marked decrease in white mica content. Comparable rocks in the biotite and garnet zones contain considerable amounts of paragonite, which becomes unstable at moderately high temperature even at high pressure (Geophysical Laboratory, 1954, p. 112). Thus kyanite and plagioclase in aluminous rocks of the Ocoee series probably formed at the expense of paragonite according to the reaction:

$$\underset{\text{Paragonite}}{NaAl_2AlSi_3O_{10}(OH)_2} + \underset{\text{quartz}}{SiO_2} \rightarrow \underset{\text{albite}}{NaAlSi_3O_8} + \underset{\text{kyanite}}{Al_2SiO_5} + \underset{\text{water}}{H_2O}.$$

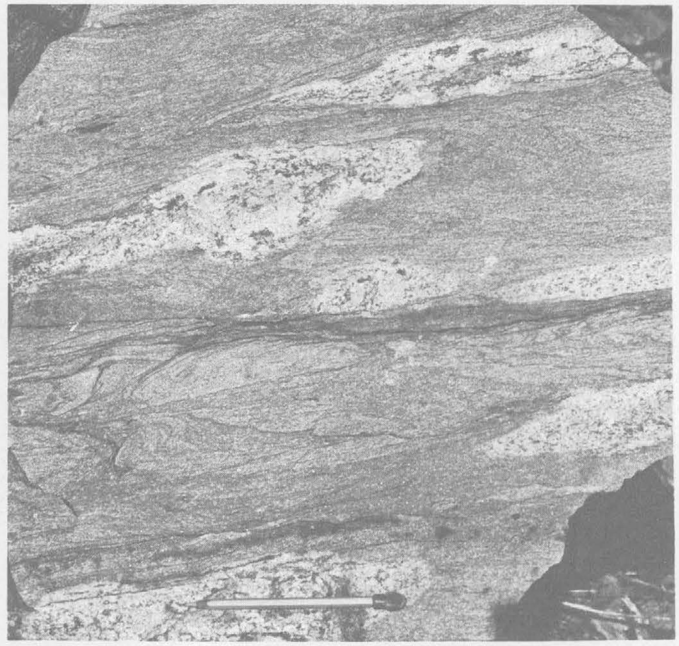
Although the more aluminous rocks are deficient in calcium, many feldspathic mica-quartz schists and matasandstones contain plagioclase, which ranges from sodic oligoclase to andesine, with or without epidote, irregularly throughout the kyanite and staurolite zones. More calcic plagioclase is found only in the highly calcic rocks described below.

Scattered thin sandstone beds in the Thunderhead sandstone throughout the kyanite and staurolite zones have been metamorphosed to distinctive light-colored calc-silicate granofels composed largely of quartz and plagioclase with varied amounts of biotite, garnet, hornblende, and clinozoisite. These are the "pseudodiorite" of Keith (1913), also described by Emmons and Laney (1926, p. 19–21) as having been formed from calcareous concretions and lenses in feldspathic metasandstone of the Great Smoky group in the Ducktown mining district. In the eastern Great Smoky Mountains such rocks generally form well-defined layers, a few inches to 3 feet thick, interbedded with fine-grained feldspathic metasandstone and mica schist. They form also, though less commonly, vaguely defined patches of light-colored granofels in coarser feldspathic sandstone (fig. 42 *B* and *C*). Similar rocks occur locally in the Anakeesta formation west of Bryson City and in the upper part of the Roaring Fork sandstone northeast of Cherokee.

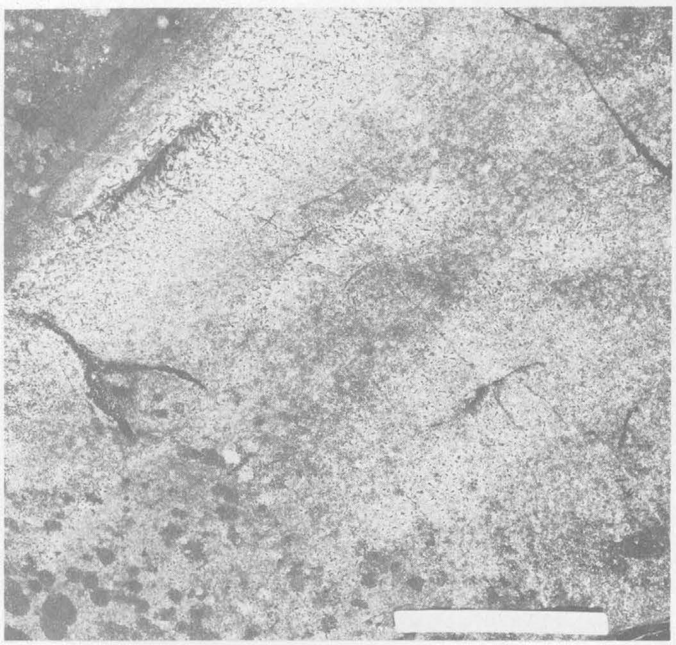
The granofels is generally granoblastic and is marked by conspicuous porphyroblasts of hornblende and reddish-brown garnet (fig. 42 *A* and *D*). Although the mineral assemblage is fairly constant, the proportions vary; quartz, for example, ranges from 20 to 75 percent, plagioclase from 15 to 50 percent, garnet from 2 to 7 percent, and clinozoisite from less than 1 to 25 percent. Biotite and hornblende together range from 3 to 20 percent, but they tend to be present in inverse proportions, rocks with abundant hornblende containing little or no biotite and vice versa. The proportion depends on the calcium content. Clinozoisite and sphene are more abundant in hornblendic granofels, in which feldspar is either calcic andesine or labradorite, whereas the feldspar of biotitic granofels is sodic andesine. The fact that the granofels of thin interbeds



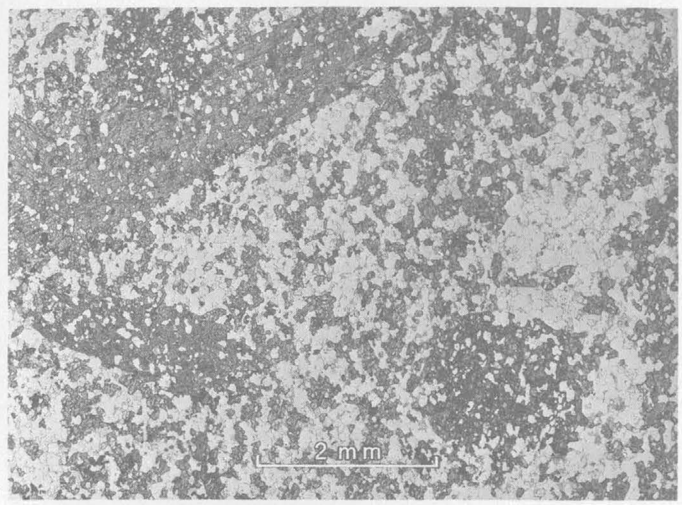
A. Stream pebbles of varied granofels in Thunderhead sandstone. Scale in inches.



C. Biotite-garnet-quartz-plagioclase granofels (lighter colored patches) in Roaring Fork sandstone, northwest of road 2 miles south-southwest of Big Witch Gap.



B. Gray biotitic metasandstone converted to patches of white quartz-plagioclase granofels with prominent hornblende porphyroblasts. Thunderhead sandstone in Bradley Fork, 2.8 miles above Smokemont Campground.



D. Photomicrograph showing sievelike porphyroblasts of hornblende and garnet with finer grained quartz and clinozoisite. Granofels in Thunderhead sandstone, Richland Mountain, 4 miles east of Newfound Gap.

FIGURE 42.—CALC-SILICATE GRANOFELS ("PSEUDODIORITE")

generally contains less quartz and more plagioclase than that forming concretions in sandstone layers suggests that the thinner beds may have been originally more aluminous and represent argillaceous limy sandstone.

Specimens taken just within and outside the margin of hornblende granofels in two concretionary bodies in biotitic feldspathic metasandstone (table 15) show that the concretions contain about twice as much calcium as the adjacent host rocks only a few inches away, a relation also found in the Ducktown area (Emmons and Laney, 1926, p. 19–20). In both occurrences biotite in the highly calcareous concretions has probably been converted to hornblende, and potassium has been eliminated, although garnet is relatively unaffected. Because disseminated biotite causes the gray color of the host rocks, the removal of biotite produces a bleached appearance (fig. 42*B* and *C*).

TABLE 15.—*Modal composition of granofels and host rock, Thunderhead sandstone, eastern Great Smoky Mountains*

[Analyses 1 and 2 are of granofels and host rocks respectively at 3,400 ft elevation on trail on southwest slope Richland Mountain. Analyses 3 and 4 are of granofels and host rock from metasandstone 1 mile northeast of Big Witch Gap]

	1	2	3	4
Quartz	36	20	70	75
Plagioclase	[1] 14	[2] 68	[1] 22	[2] 17
Muscovite	Tr	Tr	----	----
Biotite	----	8	----	3
Garnet	3	4	5	5
Hornblende	19	----	3	----
Clinozoisite	25	----	Tr	Tr
Sphene	3	----	Tr	----
Magnetite	Tr	Tr	Tr	Tr
Total	100	100	100	100

[1] Labradorite.
[2] Andesine.

In the Anakeesta formation along the Tuckasegee River west of Bryson City, dolomite beds are represented by lenses and pods of dark coarse-grained silicate rocks associated with graphitic schist and dark metasandstone. In outcrop they resemble ultramafic intrusives, but thin-section study shows that they are composed of tremolite, diopside, lime garnet, biotite, calcic plagioclase, and quartz; their dark color is largely due to disseminated graphite. They have been folded and pulled apart along fold limbs, much as the dolomite layers in the Anakeesta farther north, and in every way seem to be their counterparts in the kyanite-staurolite zone. Their mineral composition presumably varies according to the amounts of quartz, chlorite, feldspar, and other impurities in the original dolomite—the more aluminous and iron-rich rocks consisting of tremolite, garnet, and labradorite with minor amounts of biotite and sphene, and rocks with less alumina and iron consisting mainly of tremolite, diopside, and zoisite. An unusual colorless chlorite of relatively high birefringence, perhaps the magnesian species amesite, occurs in place of biotite in some specimens.

A significant accompaniment of the metamorphism in the kyanite and staurolite zones is the absence of the blue quartz which is so characteristic of the less metamorphosed parts of the Thunderhead sandstone farther north. Blue quartz grains persist in conglomerate and coarser sandstone to within a mile or two of the staurolite isograd but do not occur in similar rocks south of it. It is, of course, possible that blue quartz, which is sparse or absent in the lowermost part of the Great Smoky group to the north, was not deposited in the southeastern part of the area. Nevertheless, the fact that there is a parallel absence of blue quartz in the basement rocks strongly suggests that the blue color has been destroyed by recrystallization or annealing during metamorphism in the low-temperature part of the amphibolite facies.

Rocks of the Ocoee series along the southern border of the area, especially in the vicinity of the Ela and Bryson domes and on North Eaglenest Mountain and Hard Ridge in the Dellwood quadrangle, have been altered to coarse feldspathic paragneiss. A good example is exposed in a small quarry along a road on the western flank of the Ela dome, 0.7 mile north of the Tuckasegee River. Here interbedded feldspathic sandstone and pelite of the Great Smoky group have been converted to layered gneiss (fig. 43), in which the darker pelitic beds now consist of wavy micaceous segregation laminae between quartz-feldspar lenses similar in composition and texture to the metasandstone beds. Some "inflation" of the metasandstone beds has also occurred, and small pods of pegmatite have formed in both rocks.

In these rocks, muscovite is xenoblastic or porphyroblastic, rather than lepidoblastic as it is farther north, and it may exceed biotite in grain size. Both quartz and feldspar are coarsely recrystallized and foliation decreases, especially in metasandstone, which approaches granitoid texture. A few small granite pegmatites occur in the general area although not closely associated with the gneissic rocks.

PALEOZOIC METAMORPHISM OF THE BASEMENT COMPLEX

Although the basement complex consisted of recrystallized and variably granitized rocks long before the deposition of the Ocoee series, the imprint of post-Ocoee regional metamorphism is clearly seen in it. This is especially true in the northern parts of the complex, where granitic basement rocks were sheared at relatively low temperatures and downgraded rocks are abundant. Farther southeast, as in the Dellwood quadrangle, post-Ocoee metamorphic conditions were nearer those of the pre-Ocoee metamorphism, and their effects are less readily distinguished. In the basement rocks as a whole, however, regional shearing and progressive thermal reconstitution produced results parallel with those in the Ocoee series.

Basement rocks in the northeastern part of the area were metamorphosed in the biotite and garnet zones as defined in the nearby pelitic rocks. They consist, in part, of altered but little sheared rocks in which plagioclase is represented by saussurite and original biotite by pseudomorphs of chlorite or later green biotite. The more sheared rocks show strongly cataclastic textures in which all older minerals are crushed and sheared and new ones have formed. Of the major constituents, quartz, yielded most readily to shear, followed by micas, saussurite, epidote, and lastly potassium feldspar, which commonly remains as porphyroclasts.

FIGURE 43.—Gneissic metasandstone and schist showing extreme metamorphic reconstitution in the Ocoee series. The more argillaceous beds consist of segregation lenses of biotite schist and of quartz-feldspar rock similar in composition to the lighter colored metasandstone beds. Small lenses and pods of pegmatite have formed in both types of rock. Roadside quarry on southwest flank of Ela dome, 0.7 mile north of Pigeon River.

Within the biotite zone the plagioclase of the granitic rocks has been converted to saussurite or finely crystalline mixtures of epidote and white mica. Old biotite is either changed to green rutile-bearing biotite with little change of shape, or it is replaced by chlorite and new biotite. Old muscovite flakes are bent or crushed; new muscovite, fine grained and mostly lepidoblastic, has formed in saussurite, in sheared potassium feldspar, and along grain boundaries. Magnetite, inherited from the older mineral assemblage and presumably titaniferous, is much altered, marginally, to sphene. In some rocks the potassium feldspar is thickly studded with tiny flakes of hematite, giving rise to pink or orange color in hand specimens; but there is evidence that such alteration is considerably later than the shearing.

The basement rocks change little across the garnet isograd. New biotite is more commonly greenish brown rather than green and somewhat coarser, but green-biotite pseudomorphs after old biotite occur as far south as Shelton Laurel. New chlorite is largely found in microscopic shear zones of late origin. Plagioclase is represented by green saussurite in the northern part of the garnet zone, but in the Straight Fork window it has recrystallized to mixtures of oligoclase and muscovite that are not noticeably green. The zone-indicator mineral, garnet, appears only sparsely in the siliceous plagioclase-bearing flaser gneiss of the Straight Fork window in the southernmost part of the garnet zone as defined in the Ocoee rocks.

The first basement rock south of the staurolite isograd is the relatively mafic subaugen gneiss of the Ravensford body. One of the principal metamorphic changes observed in this rock, as compared with those of the biotite and garnet zones, is that green saussurite is replaced by granoblastic mixtures of oligoclase and epidote in the northern part of the body and by andesine and epidote in the southern part. No trace of old biotite remains; all biotite is new, fine grained, and olive green or reddish brown rather than green as in the biotite zone. Almandine garnet is more abundant, although still sparse. Cataclastic texture is still evident, but recrystallization is more pronounced, as described previously (p. B16).

Farther south, thermal effects of post-Ocoee metamorphism in the basement rocks cannot be easily distinguished from those of the earlier metamorphism. Post-Ocoee deformation was accompanied by considerable recrystallization in both the plutonic rocks and the Carolina gneiss, but the maximum temperature seems to have been about the same as that prevailing during the pre-Ocoee metamorphism. Thus the hornblende-andesine-epidote-garnet and biotite-muscovite-garnet-oligoclase assemblages common in the Carolina gneiss presumbly have not been much changed from their pre-Ocoee character. Rocks containing potassium feldspar and biotite in addition to hornblende, garnet, andesine, and epidote probably represent introduction of potassium during granitization in pre-Ocoee time and continued lack of metamorphic equilibrium during the post-Ocoee metamorphism. No assemblages containing staurolite were found; but kyanite, sparsely present in two-mica schist of the Carolina gneiss, may have resulted from post-Ocoee metamorphism. Plagioclase associated with epidote in the kyanite and staurolite zones ranges from oligoclase to calcic andesine without any clear relation to rock type or areal distribution, probably as a result of varying stress and lack of equilibrium during recrystallization.

RELATION OF THERMAL METAMORPHISM TO DEFORMATION

The thermal maximum of early Paleozoic metamorphism in the eastern Great Smoky Mountains was both preceded and followed by episodes of deformation in which chemical reconstitution was subordinate. The earlier of these two episodes consisted of folding and thrusting in the Ocoee series and the development of regional cleavage in its more argillaceous rocks. As suggested in the discussion of structure, it is uncertain whether slaty cleavage and schistosity formed everywhere at the same time; north-northeastward-trending schistosity in the Cataloochee anticline may have accompanied the growth of the north-northeastward-trending folds rather than the earlier deformation that produced the east-northeastward-trending folds in the foothill belt. On the other hand, cleavage in slate interbeds south of the Greenbrier fault on Greenbrier Pinnacle and Maddron Bald apparently was folded before the thrusting, and therefore existed for some time before the later deformation in the area. Neither petrographic field nor observations give conclusive evidence of two ages of slaty cleavage in the northern part of the area.

This earlier kinematic phase of metamorphism was followed by a hotter static phase in which porphyroblasts of chloritoid, biotite, garnet, staurolite, and kyanite formed in the more aluminous rocks, hornblende and garnet in the granofels, and tremolite and diopside in impure dolomite. Most of these mineral grains lie with diverse orientation in the schistose rocks without distortion of the preexisting metamorphic fabrics, although grains of chloritoid and kyanite lie in the foliation of some rocks. Confining pressure apparently remained high and possibly stress also, for some of the new minerals are not products of purely thermal metamorphism; the host rocks, however, were not noticeably deformed during the growth of porphyroblasts.

Both the early kinematic and static phases of regional metamorphism appear to be younger than the principal movement on the Greenbrier fault for the following reasons. First, slaty cleavage is not disturbed close to the fault as it certainly would be if the movement had occurred after metamorphism. Second, in two places west of the report area where the fault is exposed, gouge and fault breccia are recrystallized and fine-grained micas are developed (King, 1963). Third, the garnet and staurolite isograds cross the fault without displacement other than that attributed to the previously mentioned chemical differences between the rocks above and below the fault. For these reasons, the Greenbrier fault is considered to be an early and premetamorphic feature.

On the other hand, development of slip cleavage and second-generation folding associated with the north-northeastward-trending master folds occurred after the thermal peak of regional metamorphism had passed. Biotite and garnet porphyroblasts are commonly broken or rotated in rocks with strong slip cleavage (fig. 39 *B*), whose surfaces detour around the larger porphyroblasts and thus record their presence during the shearing. Slip-cleavage surfaces are also distorted around the larger kyanite and staurolite porphyroblasts seen in outcrops and hand specimens. These movements were not generally accompanied by important alteration of the porphyroblasts, garnets remaining fresh and biotite only slightly crushed. Minor amounts of quartz and chlorite formed in pressure shadows adjacent to garnet porphyroblasts; and biotite, muscovite, and potassium feldspar recrystallized along slip cleavage in the basement rocks, but no important mineralogic changes appear.

AGE OF DEFORMATION AND METAMORPHISM

The sequence of tectonic and metamorphic events in the eastern part of the Great Smoky Mountains is summarized in table 16, but dates for these events are known only within rather wide limits. Evidence of the age of the post-Ocoee deformation and regional metamorphism comes from two sources, one stratigraphic, the other based on radiogenic mineral ages; both place these events in early or middle Paleozoic time.

TABLE 16.—*Tectonic and metamorphic history in the eastern Great Smoky Mountains*

Precambrian		Metamorphism of sedimentary and igneous rocks that make up the Carolina gneiss culminating in plutonism along a northeastward-trending front, with maximum grade probably northwest of the present outcrop of basement rocks.
Ordovician?	Earlier post-Ocoee deformation	Early folding of the Ocoee series; eastward-trending folds in the foothill belt. Low-angle thrusting from south; Greenbrier, Dunn Creek, Snag Mountain and other low-angle faults. Development of low-angle foliation in basement rocks.
Middle or Late Devonian	Main regional metamorphism	Regional metamorphism, beginning possibly during the early folding and increasing in grade toward the southeast with a maximum in the kyanite zone. Regional schistosity and minor folds developed in the Ocoee series and probably in nonfoliated rocks of the basement complex producing augen gneiss. Synkinematic phase followed by static phase, with development of porphyroblasts. Subjacent intrusive bodies represented by pegmatite and trondhjemite.
	Later post-Ocoee deformation	Regional deformation; major north-northeastward-trending folds and accompanying minor folds and slip cleavage (second-generation folds). Metamorphic reconstitution restricted at temperatures somewhat lower than the thermal maximum; earlier structural features deformed and locally obliterated; continued recrystallization and minor amounts of alkali metasomatism along south border of report area. Mylonite zones in basement rocks in waning stage.
Late Paleozoic	Postmetamorphic activity	Late faulting: Great Smoky, Gatlinburg, Oconaluftee and other faults characterized by unrecrystallized gouge and striated surfaces. Folding of late thrust faults and mild deformation of structural features in the Ocoee series (evidence largely in the foothill belt north of report area).

Middle Ordovician rocks immediately northwest of the Blue Ridge province from southwestern Virginia to northern Georgia include abnormally thick clastic deposits (Neuman, 1955, p. 168–171), with local pebble and cobble beds that were derived from the southeast (Kellberg and Grant, 1956). The crustal disturbance reflected in these rocks, termed the Blountian phase of the Taconian orogeny (Rodgers, 1953, p. 94), lasted throughout most of Middle Ordovician time and was accompanied by vulcanism in its later stages. Rocks as old as the Chilhowee group of Cambrian and Cambrian(?) age were eroded, but no fragments of Ocoee or older rocks are known in the deposits. According to Kellberg and Grant (1956, p. 715), sandstone of the Chilhowee group had been altered to vitreous quartzite, and Cambrian limestone was well indurated and veined before erosion; this evidence suggests complete diagenesis and perhaps mild metamorphism by Middle Ordovician time. Although no direct correlation can be made between this episode of uplift and erosion and the deformation of the Ocoee series, the Blountian disturbance was the first major interruption of Paleozoic sedimentation in the region and thus may have included the first Paleozoic folding in the Great Smoky Mountains.

Some information about the age of post-Ocoee intrusive and metamorphic events comes from determinations of radiogenic elements in gneisses and pegmatite in and near the Greaty Smoky Mountains. Potassium-argon measurements made on muscovite and biotite from pegmatite and the enclosing Carolina gneiss near Spruce Pine, N.C., have indicated consistent ages around 340 million years, and a similar age was obtained on muscovite from pegmatite that cuts rocks of the Ocoee series at the Deep Creek mine on the northwest side of the Bryson dome (Long, Kulp, and Eckelmann, 1959, p. 594). Aldrich, Wetherill, Davis, and Tilton (1958, p. 1128) have found, however, that rubidium-strontium, lead-uranium, and lead-lead isotope ages of uraninite, muscovite, and feldspar from one of the pegmatites near Spruce Pine indicate a somewhat older and probably more reliable age of 375 million years for these pegmatites. Since the pegmatites of the Bryson City area probably accompanied the thermal maximum of post-Ocoee metamorphism, it follows that this metamorphism occurred 340 to 375 million years ago, in Middle or Late Devonian time according to the geologic time scale of Kulp (1961).

The Great Smoky and related faults involve rocks as young as Early Mississippian in the foothill belt northwest of the Great Smoky Mountains (Neuman and Wilson, 1960) and presumably are late Paleozoic.

SURFICIAL GEOLOGY

Surficial materials of various kinds form a relatively continuous and locally thick cover on the bedrock throughout the eastern Great Smoky Mountains. They may be conveniently classed as saprolite, or bedrock weathered in place; colluvium, whose only movement has been directly down the slope on which it was formed; and alluvial material transported some distance from its place of origin by other than direct movement by gravity. The saprolite and colluvial deposits mantle bedrock slopes without materially changing their form and were not mapped. The transported deposits, on the other hand, are characterized by constructional land forms readily identified on the ground and on the better quadrangle maps, and they are shown on plate 1. Altogether these deposits record a complex history of changing climate, soil formation, and erosion dating possibly as far back as the Tertiary period.

SAPROLITE

Deeply weathered, thoroughly decomposed bedrock that has not moved and retains bedrock structures almost intact is widespread in the lower parts of the report area. This saprolite is more abundant than fresh rock in the foothill belt and in the lowlands of the southern part of the area, and much structural and lithologic information was obtained from it. On interfluve ridges it is 60 or more feet thick, but the larger streams commonly flow on comparatively unweathered bedrock. Deep exposures of saprolite are not abundant; the best occur in cuts along Tennessee Highway 73 east of Gatlinburg and along U.S. Highway 19 along the Tuckasegee River and west of Soco Gap. Most of the saprolite in such exposures is yellowish orange, but its upper part is commonly red. The saprolite is mantled by soils which are generally thin and locally absent owing to repeated cultivation and erosion.

In the high mountainous parts of the area, the saprolite is thin and discontinuous. Commonly only the basal part of the saprolite is preserved, as for example along the Clingmans Dome road where coherent though variably weathered Thunderhead sandstone forms knobs and rounded residual blocks embedded in saprolite. Here the saprolite is yellowish brown, although scattered patches of strongly red saprolite or colluvium on the intermediate slopes suggest the former presence of a thicker and redder saprolite on the range. Thick saprolite is still preserved in intermontane basins several hundred feet above the present streams; a conspicuous example is in the Raven Fork valley between Ravensford and Big Cove, where, on ridges ranging in altitude from 3,000 to 3,400 feet, drilling preparatory to construction of the Blue Ridge Parkway revealed as much as 100 feet of rotten rock.

COLLUVIAL DEPOSITS

The colluvium is generally closely related to the bedrock on which it occurs. On the Pigeon siltstone and Roaring Fork sandstone in the foothill belt, for example, the colluvial mantle consists of unsorted sandy or clayey loam and angular rock fragments commonly including large blocks of little-weathered rock. The thickness of the mantle is inversely proportional to the steepness of its surface, and is greatest on the lower and gentler slopes where colluvial-alluvial aprons containing considerable amounts of moderately stratified slope wash spread out over the valley floor. In many places these aprons extend over alluvium on the valley floor, and at the mouths of short tributary valleys they commonly have convex surfaces characteristic of alluvial fans.

Where concentrated surface drainage begins at the heads of the steeper hollows, the movement of colluvium on the slopes above has evidently been accelerated, and small landslides are common. Elsewhere the colluvium has moved more slowly, but the amount of material moved is evidently large. Exposures in mine and prospect openings in nearby areas indicate that it has moved, in considerable part, by sliding on well-defined surfaces (Cameron, 1951, p. 7).

In the higher mountains underlain by the more massive rocks of the Great Smoky group, the colluvium is coarser and consists of large blocks that are loosely packed, their interstices being filled with smaller fragments, sand, clay, and organic matter. Runoff has commonly removed much of the interstitial material and flows in subsurface channels; a surprising amount of the drainage in the headwater valleys is thus underground.

Large areas in headwater basins and on the higher mountain slopes are covered with very large colluvial fragments forming block fields and block streams. These are especially prominent in the Thunderhead sandstone on the northern slopes of the Great Smoky Mountains (fig. 44). Blocks, as much as 20 feet long, are piled on one another with little or no interstitial material except the vegetative debris that mantles them. Many of these deposits are steep and resemble talus, except that they are not surmounted by cliffs and are elongated downslope rather than along it. The blocks have been produced by mechanical weathering

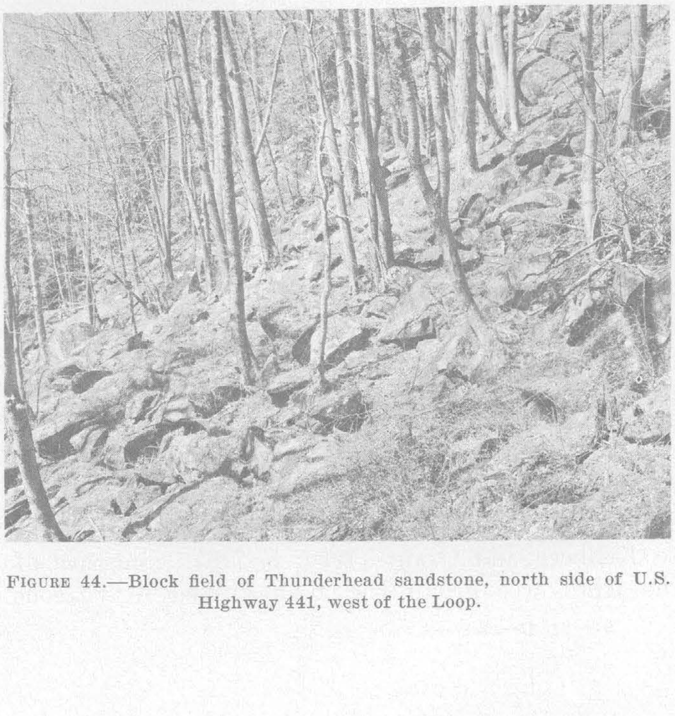
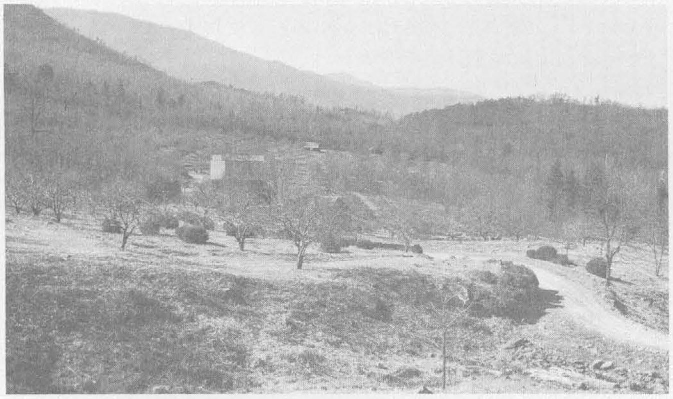


FIGURE 44.—Block field of Thunderhead sandstone, north side of U.S. Highway 441, west of the Loop.

of massive bedrock on the higher slopes, the resemblance to talus resulting from the removal of interstitial material by surface runoff. None of the block fields yielded any evidence of recent accumulation of blocks by falling or sliding; most of the fields are covered by large trees, indicating little change in the character of the slopes in recent time.

ALLUVIAL DEPOSITS

Bouldery alluvium derived from the higher parts of the range and deposited as thick fills in the valleys along its front is conspicuous in the northern part of the Great Smoky Mountains. These deposits occur in all valleys that drain appreciable areas of resistant rocks that make up the mountains; they are most noticeable on the headwaters of Webb, Dunn, and Cosby Creeks, where they form broad alluvial fans. Smaller deposits occur on the Little Pigeon River, on Roaring Fork, and at Cherokee Orchard (fig. 45*A*) northwest of Mount LeConte. These bouldery alluvial deposits occupy more than 15 square miles in the northern part of the report area and 2 of the largest cover more than 2 square miles each. In spite of their bouldery character, they furnish the best agricultural land on the northern slope of the mountains. They were extensively cultivated by the early settlers but at the time of the present investigation were devoted mainly to apple orchards.



A. Alluvial fan at Cherokee Orchard, 3 miles southwest of Gatlinburg. View west-southwest from the east side of the fan, where it is about a mile wide. Lower slopes of Bull Head at left; on left skyline is Sugarland Mountain beyond West Fork, Little Pigeon River.

B. Excavation in the same deposit in the town of Gatlinburg, showing many boulders of Thunderhead sandstone in red clayey matrix.

FIGURE 45.—SURFACE AND INTERNAL FEATURES OF ALLUVIAL DEPOSITS

The alluvium consists of large and small boulders mixed with much sandy or clay loam and smaller rock fragments, with little or no sorting (fig. 45*B*). Nearly all the larger fragments are Thunderhead sandstone, some of which are very large, especially in the higher and steeper parts of the deposits. One block near the road at Cherokee Orchard was at least 40 feet long before it broke into 3 pieces at its present location; another is 20 feet high, 25 feet wide, and 45 feet long and lies on the northwest slope of Greenbrier Pinnacle, 1.3 miles north of the nearest bedrock source; blocks only slightly smaller occur at many other places. The maximum size of boulders in the alluvium decreases abruptly downslope, but boulders, 3–5 feet in diameter, are common even at the lower margins of the fans.

The thickness of the alluvial deposits is undoubtedly varied, for the underlying bedrock has considerable relief, bedrock hills surrounded by alluvium are common, and streams have cut to depths of 70 feet in places without exposing the bedrock. Downstream the alluvium becomes gradually thinner, the surface on which it lies is more regular, and it merges with deposits not more than 20 feet thick on the floors of the larger valleys.

At the heads of alluviated valleys, such as that at Cherokee Orchard, the deposits apparently pass into coarse blocky colluvium of the mountain sides without noticeable break. The large blocks in the fans and aprons merely become more angular and abundant, and the alluvial surface gradually steepens until it merges with that of the colluvial mantle. Thus it is impossible to determine from surface features where alluvial processes become dominant in the downward movement of the surficial mantle. The great size of blocks in the alluvial deposits suggests, indeed, that no boundary exists and that solifluction was important or even dominant in forming much of the upslope part of the deposits.

The surface of the alluvial deposits is steep, ranging from 450 feet per mile south of Webb Creek to 700 feet per mile on the upper parts of the deposits on Cosby Creek and Roaring Fork and at Cherokee Orchard. It is also considerably eroded; modern and recent streams have cut channels, 5–30 feet deep, in many places, and recently abandoned channels with bouldery floors are common near the present streams. In the narrower valleys, especially those in the Snowbird group, the modern drainage commonly follows channels cut in the bedrock adjacent to the alluvial fill rather than in the fill itself. Tributary streams entering these valleys are thus deflected, forming paired inner valleys separated by a midvalley ridge of alluvium. A remarkable result of this occurs where Dunn Creek and one of the tributaries of Cosby Creek, which occupy the same valley along the Sevier-Cocke County line for 2 miles, diverge on the Dunn Creek fan and flow separately to the French Broad River at points 25 miles apart.

Most of the bouldery alluvium is derived from the thick-bedded and widely jointed Thunderhead sandstone, and the amounts of alluvium in the valleys draining the north slope of the mountains are approximately proportional to their drainage areas within the outcrop of the Thunderhead. Valleys that do not extend as far as the Thunderhead are not conspicuously alluviated and have established gradients well below their alluviated neighbors. This condition is most evident north of Piney Mountain east of Cherokee Orchard, where the head of Baskins Creek is 100 feet below the adjacent valley of Roaring Fork, and north of Greenbrier Pinnacle, where the alluviated floor of Timothy Creek is 150 feet higher than its nonalluviated neighbor to the west.

The bouldery alluvium was not all deposited at the same time, for deposits at two well-defined levels are separated by a considerable erosion interval. The alluvium at the head of Webb Creek northwest of Snag Mountain consists of two fans: a lower western one, whose surface is about 20 feet above the modern channel of Webb Creek, and an eastern one, about 60 feet higher. The two are separated in their lower parts by a scarp, on which 40 feet of bedrock is exposed and which indicates a lowering of local base level by at least 70 feet. The higher fan spilled eastward into the neighboring valley of Dunn Creek, where it caps interfluve ridges well above the surface of the Dunn Creek fan, and its eroded remnants can be traced up the valley of Webb Creek for nearly 2 miles.

Similar conditions exist on Cosby Creek 4 miles to the east, where the alluvial valley floor is bordered for several miles by gravel-capped ridges 60–120 feet higher. These are largely remnants of terraces cut off from the adjacent slopes by tributary streams graded to Cosby Creek. The largest remnant, extending for 2 miles along the west side of Cosby Creek, is about 60 feet above the valley floor at its north or downstream end and rises to 120 feet at its south or upstream end. Four other terrace remnants, less well preserved but about the same distance above the present drainage, are probably contemporaneous with the large remnant on Cosby Creek and the higher fan on Webb Creek.

The terraces on Cosby Creek and the remnants of the higher fan on Webb Creek are well exposed in roadcuts on Tennessee Highway 73. They lie on deeply weathered saprolite, formed on the Pigeon siltstone, and contain many friable or deeply weathered cobbles of Thunderhead sandstone, as well as much red clayey matrix and red or orange fragments of siltstone. In some places the upper few feet of the alluvium is red, but this color does not seem to be consistent or widespread. The underlying saprolite is more weathered than many fragments in the overlying alluvium and must have attained its present state well before the deposition of the alluvium. In contrast to the older alluvium in the higher fans and terraces, the deposits on the valley floors are fresher and commonly rest on relatively fresh bedrock; this evidence suggests that the saprolite cover was deeply eroded before the valley-floor deposits were laid down.

Soils on the older alluvium are generally thicker and better developed than on the younger, which is characterized by thin brown podzolic soils normally less than 18 inches thick. The older soils, although variably eroded, are commonly 3–5 feet thick. They are variably red, orange, or yellowish orange, and their upper zones are leached of clay and iron oxides. The older and younger alluvial deposits could probably be distinguished on this basis were sufficient exposures available; but alluvium capped by the older soil is not topographically distinguishable from presumably younger alluvium in many places.

Two or more stages of alluviation are also present in the southern part of the Great Smoky Mountains. Extensive cobbly and bouldery terrace deposits like those described occur 60–80 feet above the alluvial floor of the Tuckasegee River valley southwest of Ela and are abundant in the vicinity of Bryson City (Cameron, 1951, p. 7 and pl. 1). In Big Cove and in the Dellwood quadrangle farther east, plate 2, large fanlike deposits of alluvial and colluvial origin extend far up the slopes, especially on the rocks of the basement complex. Two sets of these deposits are distinguishable; the higher one is characterized by abundant reddish-brown clayey matrix and many rotten boulders of gneiss, in which only the more resistant schist and quartzose rocks are not decomposed, and the lower one consists of less-weathered fragments in a gray or brown matrix. The surfaces of both are steep, 800–1,000 feet per mile.

A few terrace remnants occur along Jonathans Creek a mile or two north of Dellwood. The highest of these, about 120 feet above the present valley floor, are characterized by pebbles and small cobbles of the most resistant rocks, mainly quartzite and vein quartz, and lie on eroded grayish-red saprolite. A lower terrace level, less well preserved, contains somewhat larger partially decomposed fragments of more varied rocks that are mixed with reddish-brown loamy soil. Contrary to conditions farther north, the older fanlike deposits appear to be graded to the lower rather than the upper terrace level; the latter therefore may be older than most of the other alluvial deposits of the region.

GEOMORPHIC SIGNIFICANCE

The surficial deposits, at least in the northern part of the Great Smoky Mountains, represent a former period of alluviation preceded and followed by regimes of dominant erosion. The cause for this alluviation seems to be the contribution of coarse colluvium from the higher parts of the mountains in amounts much greater than the capacity of the existing streams to transport. No such alluviation is going on today, and modern streams are largely engaged in removing the results of past deposition.

Many students of surficial deposits in the nonglaciated parts of the Appalachian region agree that the formation of colluvium and the alluviation of nearby valleys were accelerated during times of glaciation in eastern North America (Smith and Smith, 1945; Peltier, 1945; Denny, 1956, p. 54–55). This conclusion seems valid also for the Great Smoky Mountains. Alternate freezing and thawing in the surficial mantle probably occurred then over longer periods and to greater depth, but there seems to be no need to postulate increased rainfall as compared with the present 85 inches per year on the higher slopes. Precipitation as snow rather than rain would have retared gullying and allowed solifluction to dominate in forming the higher mountain slopes.

An important factor that may have affected the surficial mantle is the possibility that part of the Great Smoky Mountains was above timberline and unprotected by forest cover during the colder climates of the Pleistocene. Although this possibility has seemed unlikely to ecologists in the past, the effect of Pleistocene climates on the biological communities of the southern Appalachians is being increasingly recognized (Deevey, 1949, p. 1365–1375). The forest of spruce and fir that now clothes the higher parts of the Great Smoky Mountains with a lower limit of about 5,000 feet is so similar to the forests adjacent to timberline in the northeastern United States that, presumably, only a moderate cooling and southward migration of winter storm tracks would produce timberline conditions on Clingmans Dome and Mount LeConte. Indeed, the occurrence of spruce and fir pollen in peat bogs on the Atlantic and Gulf coastal plains indicates a former lowering of the spruce-fir forest by several thousand feet, possibly enough to put the greater part of the Great Smoky Mountains above timberline.

Geologic evidence suggests that block fields similar to those in the Great Smoky Mountains were formed above timberline in the northern Appalachians by frost action and solifluction during the waning stages of glaciation (Antevs, 1932, p. 38–43). If such processes were limited to areas above timberline in the Great Smoky Mountains, timberline would have been as low as 5,000 feet, for this is about the lower limit of upland block fields as distinct from accumulations of blocks that fill valley heads and probably have moved some distance from their sources. Moreover, insofar as solifluction aided by frost action is the principal mechanism in such movement and is retarded by a forest cover, it can be argued that timberline in the Smokies was considerably lower and may have been closer to 3,000 feet, the lower limit of abundant blocky colluvium in the larger valley heads.

G. M. Richmond (written communication), who studied the surficial deposits briefly, believes that the thicker soils on the older alluvial deposits may be middle-Wisconsin in age; they do not appear to be thick enough nor is the B horizon well enough developed to be older than Wisconsin. The two stages of alluviation therefore may be contemporaneous with early and late Wisconsin glaciation farther north. The saprolite is clearly older than either stage of alluviation and is probably a product of Tertiary weathering.

MINERAL DEPOSITS

The only mineral deposit of economic significance within the eastern Great Smoky Mountains are clay and feldspar deposits in the pegmatites near Bryson City (Cameron, 1951) and a small lead-zinc deposit at the east edge of the report area, known as the Redmond mine. The latter was described by geologists of the U.S. Geological Survey in 1943 and the results of this work were presented in an open-file report by Espenshade and others (1947). Additional information on the geological setting of the Redmond mine was obtained during the present investigation. As no description of the deposit or the workings has been formally published, the data of the previous report, condensed and combined with the more recent information, are presented here.

REDMOND LEAD-ZINC MINE

HISTORY

The Redmond ore deposit at Shelton Laurel, one-half mile north of Walters Lake near the east edge of the report area, was reportedly discovered by R. J. Rathbone about 1905. A shallow shaft 25–30 feet deep was sunk soon afterward; about 1925 another shaft was sunk by Rathbone and Adkins to a depth of 20 feet at the point which is now the north end of the opencut at the road (fig. 46). In 1929–30 the U.S. Smelting, Refining and Mining Co. made a brief exploration, deepening the Rathbone-Adkins shaft to about 40 feet and digging trenches to trace the ore deposit to the north. In 1934–35 a small amount of opencut work was done south of the Rathbone-Adkins shaft. The Haywood Mining Corp. completed the present opencut in 1939–40, and in 1940 shipped 44.5 tons of handpicked ore assaying 12.1 percent lead and 6.5 percent zinc to the Ozark Smelting and Refining Co., Coffeyville, Kans. No other production is recorded. In 1941, six core holes were drilled on the property, but only one of these supposedly penetrated the vein. The mine remained idle from that time until April 1, 1943, when the Haywood Mining Corp., aided by a loan from the Reconstruction Finance Corp.,

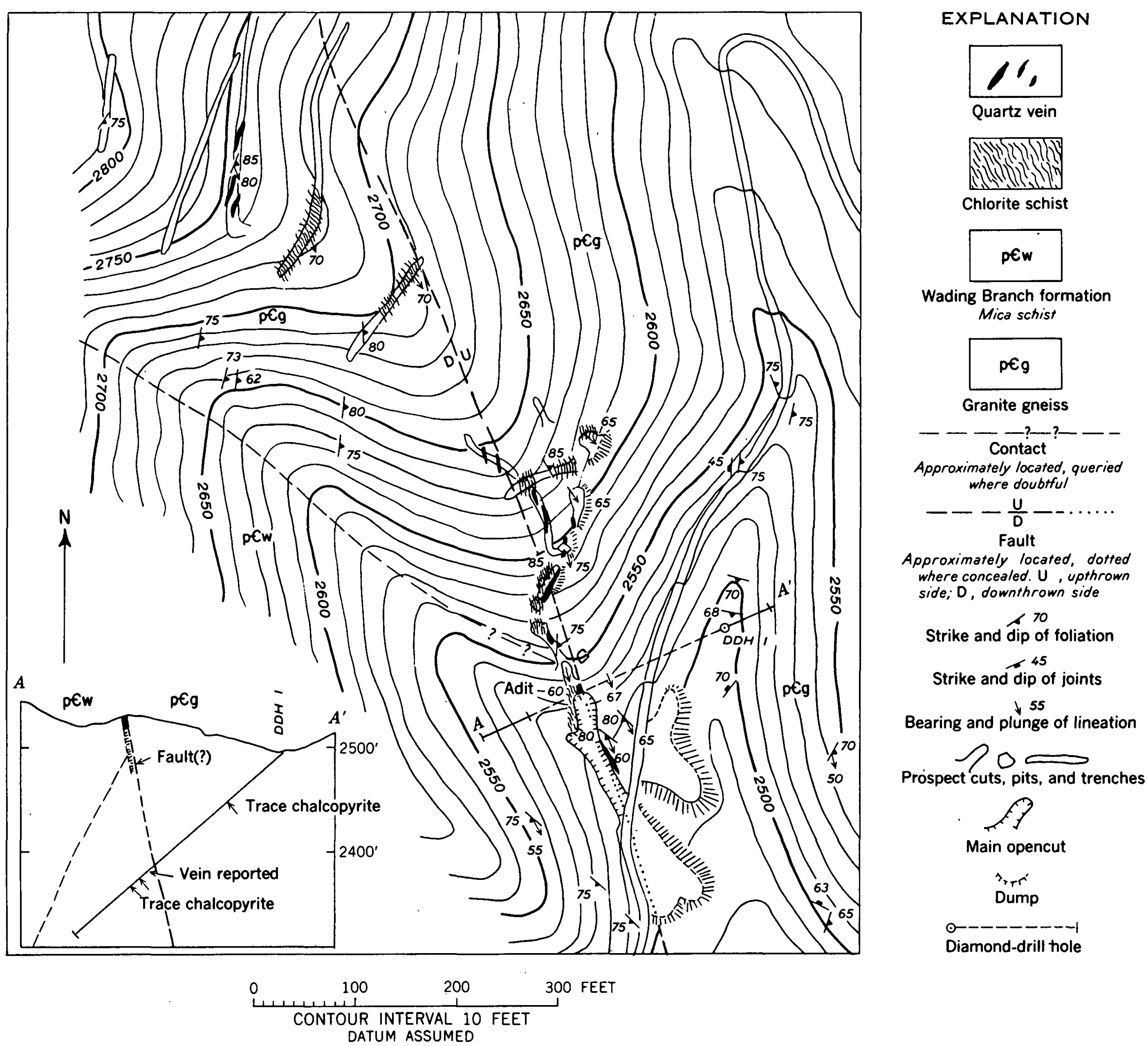


FIGURE 46.—Geologic map of the Redmond mine area, Haywood County, N.C. (After map by G. H. Espenshade, M. H. Staatz, and E. A. Brown, U.S. Geol. Survey, July 1943.)

began a drift from the north end of the opencut under the direction of B. D. Cassady of Waynesville. During exploration in 1943 the geology of the workings and adjacent area was studied in detail by the U.S. Geological Survey as part of the wartime investigation of mineral resources.

GEOLOGY

The Redmond ore deposit lies in much-sheared rocks of the basement complex near its contact with the Ocoee series in a region of considerable folding and faulting (see pl. 1). The Wading Branch formation of the Snowbird group crops out west and southwest of the mine, where it consists of fine-grained silvery quartz-mica schist, 150 or more feet thick, succeeded by 250 feet of medium- to coarse-grained gray biotitic metasandstone interbedded with feldspathic quartz-mica schist. It is well exposed along the road to Walters Dam. These rocks are overlain by light-colored feldspathic quartzite and arkose of the Longarm quartzite that forms most of the ridges between the mine and the lake. The basal schist of the Wading Branch formation forms prominent outcrops and appears to lie in place on the basement rocks. Neither the basal schist nor the metasandstone, however, occur east of the mine, where rocks of Longarm type are adjacent to the basement. Along the lower part of Laurel Creek, the Longarm is succeeded by dark-gray phyllite with abundant porphyroblasts of biotite and garnet, like the basal rocks of the Great Smoky group near Cove Creek Gap. Farther northeast along the transmission line and the road, rocks of Longarm, Wading Branch, and Great Smoky aspect are in considerable disorder and are tightly squeezed between bodies of basement rock.

Basement rocks near the mine are largely coarse gneissic granite consisting of large potassium feldspar anhedra and aggregates of quartz, plagioclase, and biotite or chlorite. They are variably sheared and, in places markedly so, as immediately east of the large opencut (fig. 46). In addition to foliation, linear features consisting largely of drawn-out mineral aggregates and striations occur nearly everywhere both in the country rocks and the ore deposits.

Within the granite northwest of the mine is a considerable body of garnet-actinolite rock representing much-altered peridotite or possibly an ancient tactite. It is poorly exposed but can be seen intermittently along the transmission line north of the mine, where it consists of fine-grained moderately gneissic dark-gray or purplish-gray rock weathering brown or black. The rock is composed largely of actinolite or tremolite and pink or pale-brown garnet with lesser amounts of quartz and some magnetite and chlorite. Part of the tapering southwest end of the body consists of pale-green actinolite-chlorite schist, and similar rock along the northeast side of the body consists of actinolite and plagioclase.

The garnet-actinolite rocks are bounded on the northeast by gneissic granite along a relatively straight line that trends N. 20° W. and projects approximately through the sheared and mineralized zone in the mine. This contact is probably a fault, for the base of the Ocoee series south of the mine is displaced several hundred feet along it. The fault was not recognized in the mine workings, but it probably separates sheared granite at the east side of the opencut from quartz-feldspar-mica schist at the west side.

Dark chlorite schist, exposed in prospect cuts and underground workings near the fault, is a common host rock for ore mineralization. Some of it apparently represents sheared and chloritized granite, but some is probably derived from the garnet-actinolite rock.

ORE DEPOSITS

Material on the dump and exposed in the workings suggests that the better-grade ore consists of massive fine-grained galena and dark-brown sphalerite mixed with finely-granular quartz. It also contains rounded inclusions of clear quartz, fluorite, and chlorite. A second type of ore, more abundant than the massive variety, consists of very fine-grained quartz with irregular veinlets of galena, sphalerite, chalcopyrite, and pyrite. Fine-grained white, gray, or purple fluorite is abundant in the quartz, occurring as seams several inches thick. Fine-grained white carbonate and scarce pyrrhotite locally accompany the ore. A third type of ore consisting of sheared garnet-tremolite gneiss partly replaced by sphalerite occurs in the prospect pit 250 feet due north of the adit entrance (fig. 46). Near the surface, the sulfides have been oxidized to a dark gritty mass which is probably mostly cerussite. Small crystals of green pyromorphite occur locally along cracks in the quartz, and coatings and impregnations of limonite, malachite, and azurite are also present.

The deposit as a whole is a system of disconnected sulfide-bearing quartz lenses of replacement origin, lying in a zone of sheared and chloritized rock along the fault described. The vein system is exposed for 250 feet north of the main cut, but the most abundant sulfides are found near the intersection of the fault with the basal schist of the Wading Branch formation. The exposed lenses are less than 100 feet in strike length and average 4–5 feet wide, the widest being 10 feet. They dip 80° E. to vertical. Linear features apparently inherited from small folds or cleavage intersections in the replaced rocks plunge 60° or more south-southeastward, as apparently do the lenses themselves. The downward extension of the quartz lenses is unknown but probably exceeds their strike length.

The quartz lenses of the vein system follow two trends, the predominant one being N. 20° W. to N. 30° W. and the other about N. 30° E. Two major lenses with these trends have been traced in the opencut and adit and are evidently the downward extension of lenses exposed in the three trenches immediately north of the opencut (fig. 46). A northwestward-trending part of the vein system has been opened by surface trenches between the 2,600- and 2,650-foot contours but has not been explored in the underground workings; it probably lies northwest of the small crosscut 60 feet from the adit face (fig. 47).

Exposures at the north end of the main cut show an irregular vein of massive sulfide, ranging in width from 8–14 inches, enclosed in a silicified zone about 6 feet wide, striking north-northwestward and dipping steeply northeastward. The footwall of this zone consists of fine-grained quartz-feldspar-mica schist, probably the basal part of the Wading Branch formation. Slaty cleavage in this rock is indistinctly folded, and the fold axes and associated linear features plunge steeply southward. Most of the silicified and sulfide-bearing material in the cut appears to have replaced this rock. The east, or hanging-wall, side of the cut consists of silicified schist and strongly sheared granite reduced to quartz-feldspar-biotite schist with fluxion structure and small porphyroclasts of feldspar. This rock extends east of the cut for 200 feet to less sheared and more easily recognizable granite.

The vein in the cut was reportedly intersected in a drill hole 150 feet beneath, where it lay entirely in granite (fig. 46). No core from this interval, however, was available in 1943, and its sulfide content is not known.

CONCLUSIONS

The exploration shows that the vein system dies out in the basement rocks north of the mine and that the principal ore deposits were found near where the fault cuts the basal schist of the Ocoee series. Accordingly, future exploration should be directed toward the intersection of the Ocoee-basement contact and the fault, which presumably plunges south-southeastward at a moderately steep angle beneath the alluvium-covered valley south of the mine. Because of the evident susceptibility of the chlorite schist and garnet-actinolite rock to sulfide mineralization, the possibility of sulfide deposits to the north along the faulted contact of the body of garnet-actinolite rock should be considered also.

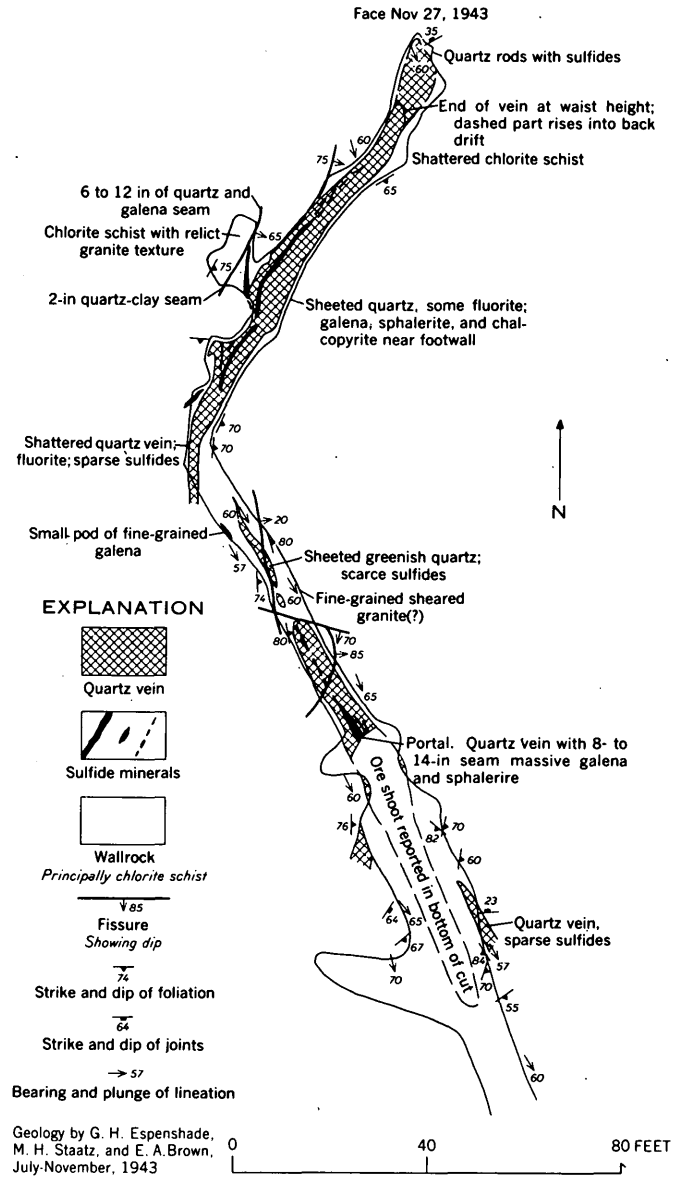


FIGURE 47.—Geologic map of the opencut and adit, Redmond mine, Haywood County, N.C., by G. H. Espenshade, M. H. Staatz, and E. A. Brown, July–November 1943.

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[Major references are in italic]

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