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Generalized Geologic Map of Bedrock Lithologies and Surficial Deposits in the Great Smoky Mountains National Park Region, Tennessee and North Carolina

By **Scott Southworth, Art Schultz, and Danielle Denenny**

ABSTRACT

Print Products
Bedrock Map (Low resolution)
Bedrock Map (High resolution)

Text
Text to Accompany Map (70 pages). This version of the report is Section 508 compliant.
Description of Map Units (Text file)

Data Products
Database [38-MB Access Database]

Other Accompanying GIS Files
Boundary Shape Files [45 KB] | Metadata
Bedrock and Surficial Geology Shape Files [.73 MB, 4.6 MB] | Bedrock Metadata, Surficial Metadata
Stream Shape Files [4.8 MB] | Metadata

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INTRODUCTION

The geology of the Great Smoky Mountain National Park (GSMNP) region of Tennessee and North Carolina (fig. 1) was studied from 1993 to 2003 as part of a cooperative investigation with the National Park Service (NPS). This work has been compiled as a 1:100,000-scale map derived from mapping done at 1:24,000 and 1:62,500 scale. The geologic data are intended to support cooperative investigations with NPS, the development of a new soil map by the Natural Resources Conservation Service, and the All Taxa Biodiversity Inventory (http://www.discoverlifeinamerica.org/) (Southworth, 2001). At the request of NPS, we mapped areas previously not visited, revised the geology where stratigraphic and structural problems existed, and developed a map database for use in interdisciplinary research, land management, and interpretive programs for park visitors.

Sedimentological, stratigraphic, structural, metamorphic, and surficial processes all have contributed to the complex modern distribution of rocks and the resultant map patterns of geologic units. This map shows the lithology of exposed and near-surface bedrock and unconsolidated surficial deposits. These form unique habitats and the substrate of the ecosystem of the Great Smoky Mountains. The map identifies rock units that may affect soil pH upon weathering, which in turn influences soil texture, surface water quality, and plant and animal distribution. This map shows geologic units classified according to dominant lithology (composition, mineralogy, and texture), rather than by age and stratigraphic position as shown on traditional geologic maps. Photographs of representative rock types are provided as a guide for field studies.

PREVIOUS INVESTIGATIONS

At the request of NPS, geologists from the U.S. Geological Survey (USGS) studied the rocks of the region between 1946 and 1954 and established the regional stratigraphic and structural framework (King and others, 1958) based on earlier work by Keith (1895, 1907). Detailed studies at 1:24,000 scale were done by Hamilton (1961) (north-central area), Hadley and Goldsmith (1963) (eastern area), King (1964) (central area), and Neuman and Nelson (1965) (western area). The results were published as chapters of USGS Professional Paper 349, with geologic maps at scales of 1:24,000 and 1:62,500 (fig. 2); that report should be consulted for its extensive data on the petrology and petrography of the rocks. A general report and geologic map compiled at 1:125,000 scale summarized the work (King and others, 1968). Subsequent geologic maps of the region have been published at 1:250,000 scale (Hadley and Nelson, 1971; Wiener and Merschat, 1992; Robinson and others, 1992). Some of the Mesoproterozoic rocks were studied by Cameron (1951) and Merschat and Wiener (1988), and Carter and Wiener (1999) studied similar rocks to the east. The Neoproterozoic rocks have been studied by Stose and Stose (1949), Espenshade (1963), King (1949), Rodgers (1953), King and others (1958), and Lesure and others (1977). The surficial geology was studied locally by Hadley and Goldsmith (1963), King (1964), Neuman and Nelson (1965), Southworth (1995), Southworth and others (1999), Schultz (1998, 1999), Schultz and others (2000), and was summarized by Southworth and others (2003).

METHODOLOGY

Field Mapping

Bedrock and surficial geologic units were compiled on 1:24,000-scale topographic base maps with 40-ft contour intervals. Bedrock contacts from previous published maps (fig. 2) were checked locally and revised where necessary. Geologic problems identified on the existing geologic maps were investigated and their interpretationS revised. New mapping mostly was along selected field traverses that utilized several thousands of miles of trails and roads that cross the area, but additional mapping also was done along traverses over hundreds of miles of hiking off trail. The discontinuous nature of bedrock units portrayed on the map is a function of deposits that interfinger, geologic structure, and poor exposure along strike.

Surficial deposits were mapped along selected field traverses by interpretation of aerial photographs and by interpretation of characteristic landforms on topographic maps. Conceptual models generated from strategic field traverses enabled us to recognize surficial units in areas away from field observations. Exposures of surficial deposits were provided by landslides and stream cutbanks, as well as roadcuts, and rare excavations. The surficial units are defined primarily by their constituent materials with some reference to known or interpreted origin and age.

Digitization

Bedrock units from 1:24,000-scale maps were scanned and reduced to 1:100,000 scale. The units were drafted at 1:100,000 scale with ink on mylar overlays that were then scanned, vectorized, and edited. Surficial geologic map units were inked at 1:24,000-scale on mylar overlays registered to latitude and longtitude coordinates of

7.5-minute quadrangles, and were scanned, vectorized, and edited. The 7.5-minute quadrangles were then mosaicked for presentation at 1:100,000 scale (Southworth and others, 2003).

Base map

The 1:100,000-scale base map is a mosaic that was generated by scanning the map separates of the Knoxville, Tenn., and Fontana Dam, N.C., 30- by 60- minute quadrangles, both of which have a contour interval of 50 m.. This base map was also overprinted on a shaded relief map derived from a 30-m interval digital elevation model (DEM) of the USGS National Elevation Dataset (NED). Because the 30- by 60-minute, 50-m-contour maps were extrapolated from the 7.5-minute, 40-ft-contour maps, the 1:24,000-scale unit polygons may not correspond directly with the generalized topographic contours on the 1:100,000-scale base map.

CLASSIFICATION OF MAP UNITS

Introduction

The depositional, stratigraphic, metamorphic, and structural history of the rocks in the study area is complex. It will be more fully summarized and portrayed on a traditional geologic map (Southworth and others, in press). Because the geology is so complex, this generalized presentation of lithologic and surficial units was developed. These data may be used for interdisciplinary studies of soil, plants, and animals, where the primary rock types are more important than the age, assigned formation names, metamorphic grade and age, and various structural features of the rock. The traditional detailed geologic information is presented as the List of Map Units. The lithologic and surficial data are portrayed in color on the map and are presented as the Explanation of Map Units. Map units that share the same color comprise similar rock types. Unit symbols within the colored polygons identify the geologic formation found in the List of Map Units.

Bedrock

Bedrock units can be classified based on their chemical and residual attributes that result from their different mineral abundance and composition (Robinson, 1997). These lithogeochemical (Peper and others, 2001) units influence soil type, acid neutralization capacity (ANC) of streams (a measure of their sensitivity to acidification), and may be a useful tool to better understand the distribution of plant and animal species (McNab, 1996; Southworth, 2001). Some of the units consist of homogeneous rock types, whereas others are very heterogeneous in nature, and are therefore complex. There are several lithogeochemical end members. Rocks rich in carbonate minerals (carbonate rock) and those rich in amphibole (mafic rocks), form basic alkaline soil. Soluble carbonate rocks, and rocks containing minor carbonate, may strongly buffer ground water and neutralize acid. Mafic rocks are richer in iron, magnesium, and calcium, and are more readily soluble than the relatively non-reactive and resistant quartzofeldspathic rocks producing deeper, richer soils. Rocks that are rich in sulfide minerals (carbonaceous sulfidic slate and metasiltstone), and quartz (siliciclastic) form acidic soils. Carbonaceous-sulfidic rocks may produce a reducing environment resulting in oxygen-depleted ground water. A reducing environment may immobilize metal ions, yielding sub-oxic and anoxic waters that favor bacterial reduction, and inorganic reduction of nitrate. RockS rich in feldspar (conglomeratic metasandstone and quartzofeldspathic gneiss) can weather to clay-rich soil.

The geologic units comprise three major lithologic groups in this region: (1) sedimentary and metasedimentary rocks, (2) metamorphosed igneous rocks, and (3) unconsolidated surficial deposits. Sedimentary and metasedimentary rocks include carbonate, siliciclastic, and graphitic and sulfidic siliciclastic rocks. Carbonate rocks are very soluble, acid-neutralizing rocks and include limestone, dolomite, marble, metalimestone, metadolomite, and some calcareous siliciclastic rocks. Siliciclastic rocks include 1) metasiltstone, shale, slate, and phyllite, 2) quartzite and quartz sandstone, 3) feldspathic metasandstone and conglomerate, 4) feldspathic metasandstone, conglomerate, slate, phyllite, metasiltstone, metashale, and schist, and 5) quartz-muscovite schist. Siliciclastic rocks are generally neutral, but those rich in carbonate or sulfidic minerals may not be. Siliclastic rocks which may contain graphite (carbon) and sulfide minerals include 1) feldspathic metasandstone, conglomerate, metasiltstone, slate, phyllite, and schist, and 2) metasiltstone, slate and phyllite. Metamorphosed igneous rocks include 1) mafic and ultramafic rocks, 2) felsic rocks, and 3) mafic and felsic rocks mixed. The mafic rocks include metadiabase, metadiorite, greenstone, and amphibolite.

The ultramafic rocks include dunite, metaperidotite, and metagabbro. All of these rocks tend to be slightly calcareous where they have been metamorphosed under greenschist-facies metamorphic conditions. Metamorphic reactions convert calcic plagioclase to albite + quartz + calcium carbonate + epidote minerals. Carbonate minerals occur as disseminated grains and veins. Amphibolite and gabbro typically contain minor carbonate from hydrothermal alteration or metamorphic reactions. Metamorphosed ultramafic rocks include talc schist that contains grains and veins of secondary carbonate minerals. Felsic rocks include a variety of granitic gneisses. These rocks are mostly mixtures of quartz and feldspar, and have little mineral content that would buffer or reduce the pH of water. Mixed felsic and mafic rocks have the attributes of both, and they cannot be differentiated in the field or portrayed on the map.

This map has limitations because it is based on generalized geologic maps and descriptions of geologic map units, which commonly consist of more than one rock type. Because of lithologic heterogeneity, unresolved at the scale of our geologic maps, the map units could misrepresent the local lithology. Examples of this are the dolomite and metasandstone pods in the sulfidic slate of the Anakeesta Formation at Alum Cave, and the dolomitic pods and sulfidic slate matrix in the boulder conglomerate of leucogranite in the Thunderhead Sandstone. In addition, physical characteristics of rocks other than mineralogy affect rock solubility and susceptibility to weathering. These include degrees of lithification, primary or secondary porosity and permeability, grain size and texture, character of bedding or layering, and structural foliations, and grade of metamorphism.

Surficial Deposits

The surficial deposits in the GSMNP have resulted from three main agents and processes: running water (alluvium and terrace deposits), chemical and physical weathering (sinkholes and residuum), and gravity on slopes (colluvium, debris flows, and prehistoric debris fans) (Hadley and Goldsmith, 1963; King, 1964; Neuman and Nelson, 1965). The surficial units of Southworth and others (2003) are reclassified here as unconsolidated sediments with high porosity: alluvium, terrace deposits, sinkholes, residuum, colluvium, debris flows, and debris fans. The map portrays only major unconsolidated deposits, so small surficial deposits that contain transported materials different from the underlying unit could potentially influence local areas in ways not discernible from the map. Most surficial deposits in the map area are residual saprolite and soils (not shown) derived locally from weathering of the underlying bedrock. Major exceptions include flood-plain and terrace deposits along the rivers, and some rock debris deposits that transect markedly different bedrock units.

GENERAL GEOLOGIC SETTING AND PHYSIOGRAPHY

The study area is centered on the GSMNP in the western Blue Ridge Province (fig. 1), but includes a small part of the Tennessee Valley of the Valley and Ridge Province (in the northwest). The regional drainage is westward to the Tennessee River and the Gulf of Mexico. The mountains of the region rise more than 4,600 ft (1,400 m) above adjacent valley floors, and steep slopes in places reach as much as 18 to 28 degrees. The mountains are covered by a temperate rainforest sustained by a mean annual rainfall that ranges from 65 to 98 in. (165 - 250 cm). Slopes are mostly covered with soil and residuum 6 to 32 ft (2 -10 m) deep, and thick vegetation helps to make the slopes more stable. The relatively flat lowlands and coves were clearcut to support agriculture during early settlement in the 1800s.

Highlands Section of the Western Blue Ridge Province

The highlands section predominantly is underlain by coarse metasedimentary rocks of the Neoproterozoic Great Smoky Group, though lesser quantities of Mesoproterozoic gneiss and metasedimentary rocks of the Neoproterozoic Snowbird Group (King and others, 1968) also are present. The area has steep topography with elevations ranging from about 1,000 ft (305 m) along the Little Tennessee River to about 6,643 ft (2,025 m) on Clingmans Dome.

Foothills Section of the Western Blue Ridge Province

The foothills section is characterized by rolling hills with elevations ranging from about 800 ft (244 m) along the Little Tennessee River to about 3,069 ft (~1,000 m) on Chilhowee Mountain and 4,077 ft (1,243 m) on Cove Mountain. Scarps along faults locally form the boundary between the highlands and foothills sections, and coves developed in the tectonic windows of the Great Smoky thrust fault are found here. The bedrock of the foothills is predominantly fine- to coarse-grained sedimentary rocks of the Neoproterozoic Walden Creek Group, fine-grained sedimentary rocks of the Neoproterozoic Snowbird Group, lower Cambrian sandstone of the Chilhowee Group, Ordovician Jonesboro Limestone, and minor metasandstone of the Great Smoky Group. In contrast to the higher-grade metamorphic rocks in the highlands, the rocks of the foothills section are either low-grade greenschist-facies or not metamorphosed. Coarse-grained and quartz-rich rocks hold up the high knobs, such as Webb Mountain, Shields Mountain, Green Mountain, and Chilhowee Mountain, while carbonate rocks and soft siltstones underlie the valleys and coves.

Tennessee Valley of the Valley and Ridge Province

The eastern part of the Tennessee Valley of the Valley and Ridge province is underlain by Ordovician limestone interbedded with siliciclastic rocks. Sandstone and shale beds underlie linear hills with elevations ranging from about 900 ft (274 m) to 1,400 ft (427 m) on Bays Mountain.

ROCKS OF THE HIGHLANDS SECTION OF THE BLUE RIDGE PROVINCE

Mesoproterozoic Basement Complex

Mesoproterozoic rocks of the study area are the southwestern-most part of the French Broad massif (Rankin and others, 1989). The basement rocks are a polymetamorphic complex of paragneiss, migmatite, and orthogneiss that were locally mylonitized and partly melted (migmatized) in the Mesoproterozoic and Paleozoic. Orthogneiss grades into migmatitic gneiss (Cameron, 1951; Hadley and Goldsmith, 1963) that presumably was derived by partial melting and local mobilization of the orthogneiss (Hadley and Goldsmith, 1963; Kish and others, 1975). A suite of plutonic rocks, with compositions of mostly quartz monzonite, granodiorite, augen gneiss, and granite, intrudes paragneiss and contains xenoliths of paragneiss. Biotite and epidote are the principle mafic minerals, but granodiorite contains orthopyroxene.

Paleozoic deformation, uplift, and erosion have exposed the basement gneiss in 6 antiforms and along several late Paleozoic thrust faults. In the eastern part of the map area the Harmon Den slice is along the Cold Springs fault (to the north), and the Hurricane Mountain belt is to the south (Hadley and Goldsmith, 1963). These structures merge to the northeast, and are herein called the Pigeon River belt. The Dellwood-Cherokee belt and the Straight Fork window (Hadley and Goldsmith, 1963) merge together and herein are called the Qualla-Dellwood belt and the Cherokee-Raven Fork belt, respectively. The Qualla-Dellwood belt consists of antiforms in Maggie Valley and Dellwood, with intervening synforms. The Ela dome and the Bryson City dome are west of Cherokee. The Cove Mountain slice is a fault-bounded outlier of gneiss near Wear Cove, Tenn. Another small body of gneiss along the Blue Ridge Parkway, northeast of Cherokee, may also be a small dome (Hadley and Goldsmith, 1963).

The rocks are subdivided into units based on petrology, foliation, and Super High Resolution Ion Microprobe (SHRIMP) U-Pb zircon geochronology (Southworth and Aleinikoff, in press). Paragneiss units include amphibolite (Ya), ultramafic rocks (Yu), hornblende-biotite gneiss (Yh), migmatitic biotite gneiss (Ym), and unmapped bodies of calc-silicate granofels. Orthogneiss units include granitic gneiss (Yg), granodiorite (Ygd), leucocratic granitic gneiss (Yl), biotite augen gneiss (Ybg), and porphyritic granite (Ypg). Two structural/metamorphic units are recognized; 1) mylonitic gneiss derived from orthogneiss, and 2) migmatite derived from paragneiss. Ultramafic and mafic rocks, hornblende-biotite gneiss, biotite gneiss, Spring Creek Granitoid Gneiss, monzogranitic gneiss, biotite augen gneiss, and mylonitic gneiss are found within the park.

New work by Carrigan and others (2003) and Ownby and others (2004) on crystallization and inheritance data of Mesoproterozoic rocks of the Blue Ridge in North Carolina and Tennessee can be used to organize and correlate the rocks into several groups. The oldest (undated) rocks are the migmatitic gneiss group, called Group 1. Group 1 rocks contain the oldest dated meta-igneous rocks (Group 2) that have crystallization ages of 1,194 to 1,192 Ma. The Group 2 rocks were recycled during later magmatic events, as Group 3 rocks contain ~1,190- and ~1,180- Ma inherited zircons from Group 2 rocks. Gneisses of Group 3 crystallized between 1,178- and 1,117 Ma. Orthogneisses of Group 4 crystallized between 1,081 and 1,029 Ma. A major deformation event occurred between formation of Group 3 and Group 4 rocks, between 1,117 and 1,081 Ma.

Paragneiss

Introduction

Paragneiss mostly occurs in the areas near Dellwood and the Ela dome but some also occurs near Whittier (south end of Qualla-Dellwood belt) and at the southern end of the Bryson City dome. The gneiss is characterized by mafic and felsic layers that may be migmatite segregations and (or) primary compositional beds of the protolith (Hadley and Goldsmith, 1963; Kish and others, 1975). The protolith of the paragneiss has been interpreted as interstratified volcanic and sedimentary rocks (Hadley and Goldsmith, 1963). The dominant sedimentary protolith probably included argillaceous and quartzose graywacke. Rocks rich in hornblende were probably derived from iron-rich dolomitic rocks or from andesitic to basaltic tuffs. Calc-silicate rocks were probably derived from calcareous sedimentary rocks. Amphibolite was probably derived from both intrusive rocks and mafic segregations in metamorphosed sedimentary or volcanic rocks.

The dominant paragneiss units are biotite gneiss (Yb) and hornblende-biotite gneiss (Yh). Amphibolite and ultramafic rocks are probably restites (oldest rock), the hornblende and biotite gneisses are migmatites of sedimentary protoliths, and the orthogneisses is the product of melting (Cameron, 1951). Biotite gneiss and hornblende gneiss, commonly migmatitic, occur together (east to west) in the Dellwood dome, the Ela dome, and in the southern part of the Bryson City dome. Roadcuts on State Route 19 between Cherokee and Soco Gap show biotite augen gneiss with xenoliths of biotite gneiss and metagraywacke (Hadley and Goldsmith, 1963).

Ultramafic and Mafic Rocks

Mafic and ultramafic rocks occur as xenoliths and layers within gneiss, granitoids, and migmatites. Metamorphosed ultramafic rocks (Yu) (fig. 3 *A*) are found within biotite augen gneiss in the Pigeon River belt (Hadley and others, 1955), in the Qualla-Dellwood belt (Maggie Valley and east of Soco Gap), near Smokemont in the Cherokee-Raven Fork belt, and in biotite gneiss and leucocratic metagranite of the Bryson City dome (Cameron, 1951; Hadley and Goldsmith, 1963). These rocks are shown on the map by “x’s”, labeled Yu. Hadley and Goldsmith (1963) described a body of ultramafic rock 1,000 ft across near the crest of Hurricane Mountain at the east border of the map area. At least four bodies of the ultramafic rocks are found immediately beneath the Greenbriar fault. These dark, rusty-weathered rocks are poorly exposed, so little is known about the contact relations. They are composed of chlorite, actinolite, tremolite, hornblende, biotite, garnet, quartz, and magnetite, with some iron-rich olivine. The high magnesium content and absence of feldspar suggests that they are altered peridotite (Hadley and Goldsmith, 1963). Two narrow belts of rock on the western margin of the Bryson City dome are massive to schistose, medium- to very coarse-grained metaperidotite comprised of tremolite, anthophyllite, and chlorite that grades into biotite gneiss, hornblende schist, hornblende-biotite schist, and biotite schist (Cameron, 1951). A small body of massive, medium-grained, biotite-hornblende metagabbro in the Bryson City dome is comprised of plagioclase and clinopyroxene. This mottled rock is partly replaced by hornblende, biotite, and microcline, and it may grade into biotite-hornblende gneiss and schist (Cameron, 1951). To the east, Merschat and Wiener (1988) and Carter and Wiener (1999) describe mafic granulite (7 - 36 percent hornblende, mostly retrograded to amphibolite and biotite schist), massive amphibolite, talc-bearing amphibolite, and talc bodies within paragneiss and orthogneiss.

Amphibolite (Ya) (fig. 3 *B* and *C*) occurs as dark pods and layers, centimeters to several meters thick, within the hornblende-biotite gneiss, biotite gneiss, and migmatite. Mesoscopic and map-scale bodies are within biotite gneiss and biotite augen gneiss. The largest body of amphibolite is 900 ft wide and 2,000 ft long near Dellwood, and a slab-like body of amphibolite 5 ft thick and 25 ft long within biotite granite gneiss north of Big Cove (Hadley and Goldsmith, 1963). The granoblastic, fine- to medium-grained amphibolite is composed of green to brownish-green hornblende and subordinate amounts of plagioclase, with biotite, quartz, and minor amounts of epidote, sphene, ilmenite, apatite, and almandine. Well-developed foliation is defined by streaks and lenses of aligned hornblende, garnet, pyroxene, and biotite (after hornblende). Amphibolite in biotite gneiss at the south end of the Ela dome consists of coarse-grained brownish-green hornblende (60 percent) and brown biotite (20 percent). Clinopyroxene in the cores of hornblende grains suggests it may have originated as an intrusion of diorite or gabbro (Kish and others, 1975). Abundant float of amphibolite occurs at the extreme north end of the Cherokee-Raven Fork belt.

Hornblende-Biotite Gneiss

Hornblende-biotite gneiss (Yh) includes dark hornblende-biotite gneiss, biotite-hornblende gneiss, quartz-bearing hornblende gneiss, layered amphibolite containing little or no biotite, and granoblastic calc-silicate granofels (Hadley and Goldsmith, 1963). The foliation in these rocks is defined by subparallel olive-brown biotite and hornblende crystals that make up 20 to 50 percent of the rock, and a leucosome rich in garnet (fig. 4

A). Thin layers and pods of amphibolite composed of plagioclase and hornblende (more than 50 percent) are within the hornblende-biotite gneiss. Hornblende-biotite gneiss is well exposed on Purchase Knob near Dellwood and on the east side of the Ela dome.

Migmatitic-Biotite Gneiss

Migmatitic biotite gneiss (Ym) is light- to medium-gray, medium- to coarse-grained gneiss that contains biotite schist, muscovite-biotite gneiss and associated schist, and mica-feldspar quartz gneiss (Hadley and Goldsmith, 1963). Biotite gneiss is composed largely of quartz, plagioclase, and reddish-brown to olive-brown biotite (2 to 30 percent), with subordinate amounts of potassium feldspar and muscovite. The gneiss ranges from weakly to well-foliated porphyroblastic gneiss, with foliation defined by subparallel flakes and streaks of biotite, and lineated quartz and feldspar. Muscovite-biotite gneiss and associated schist occur as layers intercalated with quartzose gneiss within the biotite gneiss and rarely within the hornblende gneiss. The muscovite-biotite gneiss is light- to medium-gray, medium-grained, inequigranular, and composed of quartz, calcic oligoclase, and biotite, with less abundant muscovite, almandine, and kyanite. Foliation is defined by coarse flaser structures of muscovite and biotite concentrations around lenses of quartz and oligoclase. The muscovite-biotite gneiss and associated schist closely resemble the kyanite-grade pelitic rocks of the Neoproterozoic Great Smoky Group. Mica-feldspar-quartz gneiss is extensively interlayered with muscovite-biotite gneiss but is more quartzose and less micaceous. Biotite gneiss underlies much of the Ela and Dellwood domes, and is found in the southern part of the Bryson City dome.

Migmatitic biotite gneiss is well exposed along the roadcuts at the south end of the Ela dome (fig. 4 *B* and *C*). The migmatite is interpreted to be biotite gneiss and biotite schist leucosomes of leucocratic metagranite. In the eastern part of the study area, younger plutonic rocks contain inclusions of migmatitic paragneiss (Hadley and Goldsmith, 1963). The composition of the granitic leucosomes is similar to that of the host rock, but varies from place to place. This suggests that they were derived from a local source (anatexis) rather than from a common magma (Hadley and Goldsmith, 1963). In the Cherokee-Raven Fork belt and the Qualla-Dellwood belt west of Soco Gap, finer grained biotite-quartzofeldspathic gneiss and quartz-rich flaser gneiss are locally intercalated with (and locally contain inclusions of) metasandstone, quartz-feldspar-biotite-muscovite schist (metashale?), amphibolite, biotite schist, and ultramafic rocks (Hadley and Goldsmith, 1963). Within rocks of the biotite gneiss unit are mylonitic orthogneisses that yield a SHRIMP U-Pb zircon age of 1,117 Ma (Southworth and Aleinikoff, in press).

Migmatitic biotite gneiss is correlated with rocks mapped to the east by Carter and Wiener (1999) as Earlies Gap Biotite Gneiss, an interlayered sequence of biotite granitic gneiss and biotite gneiss, locally interbedded with amphibolite and felsic gneiss. Quartz-feldspar leucocratic neosomes crosscut gneissic foliation and are sheared, folded, and mylonitized (Merschat and Wiener, 1988). Sandymush Felsic Gneiss also is an interlayered sequence of granitic gneiss, biotite granitic gneiss, quartz dioritic gneiss, and biotite gneiss, locally interlayered with amphibolite and rare calc-silicate granofels (Merschat and Wiener, 1988).

Orthogneiss

Leucocratic-Granitic Gneiss

Leucocratic granitic gneiss (Yl) is a light-gray to white, fine- to medium-grained, sugary textured granitoid composed of microcline, microperthite, oligoclase, and quartz, with distinctive centimeter-wide dark clots of biotite, muscovite, and garnet. The composition ranges from granite to granodiorite. The rock is massive, with foliation defined by aligned clots of biotite. In the southern parts of the Bryson City and Ela domes, it occurs as leucosomes within migmatitic biotite gneiss as noted by Cameron (1951); the rocks are structurally and compositionally “mixed”. Dikes of leucocratic granite, fine-grained granite, granite porphyry, and porphyritic quartz monzonite intrude the leucocratic granite gneiss throughout the Bryson City dome. Sample BC-3-02 from the western end of the Highway 74 roadcut at the south end of the Ela dome yielded a SHRIMP U-Pb zircon age of 1,194 Ma (Southworth and Aleinikoff, in press), making this the oldest dated rock in the western Blue Ridge. The migmatitic biotite gneiss is even older, however, based on crosscutting relationships.

Spring Creek Granitoid Gneiss

Spring Creek Granitoid Gneiss (Ysg), with mylonitic and protomylonitic foliation, is thrust on mylonitic monzogranitic gneiss (Ymp) east of the Pigeon River (Carter and Wiener, 1999). Spring Creek Granitoid Gneiss is a heterogeneous meta-igneous unit dominated by biotite granitic gneiss interlayered with biotite granodioritic gneiss, tonalitic gneiss, quartz monzodioritic gneiss, amphibolite, biotite gneiss, and biotite schist. Recent U-Pb SHRIMP analysis of zircon from a granitoid in this unit yielded an age of 1,178 Ma (P.Berquist, Vanderbilt, unpub. data, 2004). The protomylonitic and mylonitic foliations mark a regional thrust fault.

Granitic Gneiss

Granitic gneiss (Yg) is massive, well-foliated biotite granitic gneiss that occupies most of the Bryson City dome, where it is well exposed north and south of the Tuckasegee

River. Foliation is defined by lineated blebs and streaks of biotite. Granitic gneiss has the composition of granite and granodiorite, comprising mostly microcline, microperthite, plagioclase, quartz, biotite, and muscovite. Locally, dikes of massive porphyritic quartz monzonite intrude it (Cameron, 1951). The granitic gneiss unit has a SHRIMP U-Pb zircon age of 1,163 Ma (Southworth and Aleinikoff, in press).

Similar gneiss of quartz diorite to granite composition (Hadley and Goldsmith, 1963) occurs at the north end of the Qualla-Dellwood belt within biotite gneiss and hornblende-biotite gneiss. It is medium- to coarse-grained, massive to foliated, with coarse porphyroblastic augen of potassium feldspar, in a matrix of microcline, quartz, oligoclase, olive-brown biotite, and muscovite. In some places, granitic gneiss appears to grade into biotite gneiss, but elsewhere it cuts sharply across it along probable old faults (Hadley and Goldsmith, 1963). Granitic gneiss from a new road-cut in Cataloochee Estates, near the contact between augen gneiss and flaser and granitoid gneiss as mapped by Hadley and Goldsmith (1963), yielded a SHRIMP U-Pb zircon age of 1,168 Ma (Southworth and Aleinikoff, in press).

Monzogranitic Gneiss

Monzogranitic gneiss (Ymp) is a mylonitic monzogranite characterized by pink and purple feldspar and grayish-blue quartz grains (Carter and Wiener, 1999). The protomylonitic to mylonitic phases of this unit have been mapped from east of the Pigeon River westward into the Cataloochee area. A granitoid that may be associated with this belt of rock yielded a preliminary U-Pb zircon age of 1,148 Ma (P. Berquist, Vanderbilt, unpub. data, 2004).

Porphyritic Granite

Porphyritic granite (Ypg) is a coarse granitoid with rapikivi texture defined by 3-cm-long porphyroblasts of potassium feldspar. A near absence of biotite (0 - 5 percent) and coarse augen distinguish this unit from the biotite augen gneiss. Porphyritic granite intrudes biotite gneiss in the center of the Ela dome. Porphyritic granite from the roadcut north of the bridge that crosses the Tuckasegee River yielded a SHRIMP U-Pb zircon age of 1,056 Ma (Southworth and Aleinikoff, in press).

Granodiorite

Granodiorite (Ygd) is a weakly foliated, massive, medium- to coarse-grained, light- and dark-brown rock mottled with light-green centimeter-wide clots of quartz, feldspar, and orthopyroxene. It occurs between the Thunderhead Sandstone and Pigeon Siltstone as a lens bounded by thrust faults on the west side of Cove Mountain, just south of Wear Cove. The granulite-facies granoblastic texture is cut by brittle faults and fractures formed during chlorite-grade Paleozoic deformation. The eastern part of the rock body contains hornblende-biotite gneiss (Yh). Granodiorite from an old roadcut east of King Hollow Branch yielded a SHRIMP U-Pb zircon age of 1,040 Ma (Southworth and Aleinikoff, in press). This rock is correlated with the Max Patch Granite dated at 1,050 Ma by Calvin Miller, Vanderbilt University (Carl Merschat, NCGS, oral commun., 2004).

Biotite-Augen Gneiss

Biotite augen gneiss (Ybg) is dark, mottled, coarse-grained gneiss that consists of prominent white and pink microcline and oligoclase augen in a matrix of foliated quartz, plagioclase, and aggregates of biotite that make up 4 to 24 percent of the rock (fig. 5 *A*). The augen are porphyroclastic rods and lineated aggregates of feldspar and quartz several centimeters long. The bulk composition is granite and quartz monzonite. This rock is recognized from the Pigeon River west to the Cherokee-Raven Fork belt, and is also found in the Qualla-Dellwood belt. Leucocratic granite and aplite intrude the biotite augen gneiss, especially near the western margin of the Cherokee-Raven Fork belt along Oconaluftee River, and near Cataloochee in the Pigeon River belt. Hadley and Goldsmith (1963) referred to these rocks as the "Ravensford body". These rocks are L-S tectonites with distinctive linear rods and knots of feldpar porphyroclasts that resulted from mylonitization, probably during Paleozoic deformation (fig. 5 *B*). Biotite augen gneiss on the north side of the bridge over Raven Fork at the head of Big Cove yielded a SHRIMP U-Pb zircon age of 1,029 Ma (Southworth and Aleinikoff, in press), making it one of the youngest dated Grenvillian rocks in the Blue Ridge.

Mylonitic Gneiss

Mylonitic gneiss (Ymg) is a strongly foliated and lineated biotite-rich quartzofeldspathic gneiss that ranges from 20 to 60 m thick along the contact of the rocks of the Great Smoky Group on the north and northwest margin of the Bryson City dome. Cameron (1951) called this the "border gneiss" and recognized the sheared nature of the rocks. Kish and others (1975) described the rock as a recrystallized protomylonite and suggested that the rocks may be related to a fault that places the younger cover rocks above the older basement rocks. Kish and others (1975) noted the similarity of the rock to the coarse-grained "Bryson Gneiss" exposed 200 m to the east. The mylonitic gneiss has pink feldspar and blue quartz and resembles the mylonitic rock of the monzogranitic gneiss (Ymp) seen east of the Pigeon River.

Neoproterozoic Ocoee Supergroup

Introduction

Our current understanding of the Neoproterozoic stratigraphy of the region is based on King and others (1958), who subdivided this supergroup rock sequence into the Snowbird, Great Smoky, and Walden Creek Groups. These rocks are restricted to the southern Appalachians from North Carolina south to Georgia, and are one of the largest Neoproterozoic rock assemblages in North America. Several "unclassified formations" of rocks (King and others, 1958), as well as rocks assigned to different formations by various authors working in different parts of the GSMNP region, have been revised by Southworth and others (in press).

Snowbird Group

Introduction

The Snowbird Group consists of six successive formations. In ascending order these are: the Wading Branch Formation, Longarm Quartzite, Roaring Fork Sandstone, Pigeon Siltstone, Metcalf Phyllite, and Rich Butt Sandstone. The Wading Branch Formation and Longarm Quartzite are exposed mostly in the southeastern part of the highlands, where together their thickness ranges from a veneer to about 2,000 ft (King and others, 1968). The Roaring Fork Sandstone and Pigeon Siltstone are exposed mostly in the northeastern part of the highlands and southern foothills, where together they are as much as 17,000 ft thick (King and others, 1968). These rocks are lithologically similar, have intertonguing stratigraphic relations, and are obviously current bedded. Rocks of the Wading Branch Formation grade upward into the overlying Longarm Quartzite. The Longarm Quartzite transitions upward into the Roaring Fork Sandstone, which in turn grades upward into the Pigeon Siltstone. The Pigeon Siltstone in turn transitions into the overlying Rich Butt Sandstone. Locally, rocks of the Wading Branch Formation, Longarm Quartzite, and Roaring Fork Sandstone each unconformably overlie Mesoproterozoic basement gneisses, and the rocks of each of the lower formations do not occur everywhere together. West of the Pigeon Forge fault, Metcalf Phyllite is a tectonic variety of the Pigeon Siltstone (King and others, 1968), so it is part of the Snowbird Group.

Wading Branch Formation

The Wading Branch Formation (Zwb) consists of heterogeneous light and dark sedimentary rocks that rest unconformably on Mesoproterozoic gneiss. The type locality is Wading Branch Ridge, northwest of Walters Lake. The basal rocks include phyllite, sandy slate, quartz-sericite-muscovite schist, and quartz-pebble conglomerate (fig. 6 *A*). The fine-grained rocks can be green due to chlorite, green-speckled with small porphyroblasts of chloritoid, garnet, or magnetite, or silver due to muscovite. The fine-grained rocks range from 10 to 1,500 ft thick, and grade upward to become interbedded with coarse pebbly feldspathic metasandstone that contains lenses of quartz-pebble conglomerate 1 to 3 ft thick. The rocks are poorly sorted, with individual beds ranging from a few inches to several feet thick. Characteristic outcrops are along the Pigeon River just west of Harmon Den.

Longarm Quartzite

The Longarm Quartzite (Zl) is a sequence of predominantly light-colored, medium-grained, and current-bedded quartzites and arkoses that ranges from about 50 ft to as much as 5,000 ft thick. The type locality is along the Pigeon River at the north end of Longarm Mountain, where the resistant rock underlies ridges. The Longarm Quartzite is conspicuously light-colored with pink, blue, and purple crossbeds (fig. 6 *B, C*). This unit weathers to a distinctive light-colored sandy soil. The quartzite is interbedded and gradational with dark, fine-grained sandstone in the upper part. Where sandstone predominates over quartzite, the unit is called the Roaring Fork Sandstone. Rare current-ripple marks and slump folds suggest sediment transport was to the northwest. Characteristic outcrops can be seen along Ravenfork. The quartzite is a good dimension stone that was quarried near Ravens Ford and used in construction of the Oconaluftee Ranger Station and other GSMNP structures.

Roaring Fork Sandstone

The Roaring Fork Sandstone, named after exposures along Roaring Fork southeast of Gatlinburg, is greenish-gray, medium- to fine-grained metasandstone interbedded with laminated metasiltstone and phyllitic to slaty metasiltstone (Zrf) (fig. 7). Prominent beds of fine-grained feldspathic metasandstone (Zrfs) were mapped south of Gatlinburg (King, 1964). Fresh rocks are green due to chlorite, but they weather to brown and yellow clayey soil. The lower part of the formation contains light-colored quartzite beds in transitional areas where it grades upward into or intertongues laterally with the Longarm Quartzite. Thick-bedded feldspathic sandstone occurs in beds ranging from 1 to 80 ft thick, although most commonly they are 5 to 10 ft thick. These beds contain sharply truncated crossbeds and large-scale slump folds (fig. 7 *B*) (Hadley and Goldsmith, 1963). Lenticular laminated metasiltstones contains ripple marks and soft-sediment folds. The upper part of the Roaring Fork Sandstone contains muscovite-quartz phyllite, slate with porphyroblasts of biotite, illmenite, and chloritoid, and abundant vein quartz. The top of the formation grades into the Pigeon Siltstone as the sandstone beds diminish. The Roaring Fork Sandstone ranges in thickness from several hundred feet in the southeast area to 7,000 feet in the type area. Characteristic outcrops can also be seen along the Pigeon River south of Hartford, and southeast of Waterville. Accessible outcrops are along the Roaring Fork Motor Trail and along the Little Pigeon River on the road to Greenbriar Cove.

Pigeon Siltstone

The amount of metasiltstone in the upper part of the Roaring Fork Sandstone increases upward and once it is predominant, the rocks are called the Pigeon Siltstone, named for the exposures along the Little Pigeon River. The Pigeon Siltstone (Zp) consists of very uniform, massive, greenish metasiltstone marked by dark- and light- laminae (fig. 8 *A*). This unit ranges from 10,000 to 15,000 ft thick. To the north the rocks are green due to chlorite, and to the south they are darker due to biotite. The rocks weather to yellow and reddish-brown clayey soil as seen in the roadcuts east of Gatlinburg. Everywhere the rocks have a pervasive cleavage, commonly at a high angle to bedding. The massive metasiltstone beds range from 1 to 30 ft thick, with current bedding and ripples, convolute bedding, load casts, slump folds (fig. 8 *B*) and scour–and-fill structures, but no graded beds (Hamilton, 1961). The metasiltstone contains very fine-grained quartz and feldspar sand grains that increase in abundance east-southeastward (Hamilton, 1961). Interbedded fine-grained feldpathic metasandstone beds (Zps), about 5 ft thick east of Pigeon Forge, are similar to those in the underlying Roaring Fork Sandstone (King, 1964). Rocks of the Pigeon Siltstone thin and coarsen eastward, where they intertongue with rocks of the Roaring Fork Sandstone. The upper-most rocks of the Pigeon Siltstone are gradationally overlain by the Rich Butt Sandstone at the east end of the park. Near the Dunn Creek fault, the metasiltstone contains abundant laminae of brown-stained iron-bearing ankerite and calcite. Near Bird Creek and the Dunn Creek fault are clasts of carbonate rocks intercalated with calcareous siltstone, which are interpreted to be slump blocks with load structures. Characteristic outcrops of Pigeon Siltstone can be seen along the Little Pigeon River.

Metcalf Phyllite

The type locality of the Metcalf Phyllite is Metcalf Bottoms on the Little River (King and others, 1958). King (1964) recognized that the Metcalf shared many lithologic characteristics with the Pigeon Siltstone. He suggested that the rocks were probably equivalent, even though the Metcalf was thoroughly foliated, much contorted, and pervasively sheared over wide areas. Chemical analyses of the Metcalf Phyllite and Pigeon Siltstone are surprisingly alike, so they are differentiated on the map primarily because the Metacalf had greater physical metamorphism (King, 1964). Rocks of the Pigeon Siltstone can be traced west of the Pigeon Forge fault to Cove Mountain, where shearing along faults has converted the finely laminated dull-green metasiltstone with slaty cleavage (Pigeon Siltstone) to lustrous gray-green, sericite- and chlorite-rich phyllite containing several cleavages that characterizes the Metcalf Phyllite (Zm). Along the Little River, well-developed shear-band cleavage (King, 1964) shows top-to-the- northwest motion (fig. 9*A*). Ar-Ar geochronology suggests that white-mica grew in the shear-band cleavage about 350 My during faulting (M.J. Kunk, USGS, oral comm., 2004). Early laminae, which may be bedding, strike perpendicular to faults, but penetrative cleavage and shear-band cleavage are parallel to faults (fig. 9 *B*). Where strain is less severe, laminated metasiltstone is preserved that resembles the Pigeon Siltstone. Characteristic outcrops can be seen along the Little River from Metcalf Bottoms west to Cades Cove and along the road to Tremont and Tuckaleechee Cove. Several klippe of Metcalf Phyllite are in Tuckaleechee Cove where the Great Smoky fault juxtaposes them on Ordovician rocks.

Rich Butt Sandstone

Coarse-grained rocks that share features of both the Snowbird Group and the Great Smoky Group were not classified by King and others (1958), but here they are classified as part of the Snowbird Group. The rocks on Rich Butt Mountain, a spur on the north side of Mount Cammerer, were termed Rich Butt Sandstone by King and others (1958). The Rich Butt Sandstone intertongues laterally with and lies gradationally above the Pigeon Siltstone. The Rich Butt Sandstone (Zrb) consists of light, medium- to fine-grained feldspathic metasandstone (fig. 10) and conglomeratic arkose interbedded with thinly laminated dark metasiltstone. The metasandstone is thin- to thick-bedded, ranging from 1 to 20 ft, with graded bedding. These beds contain fewer current-bedding features than the underlying rocks. The metasandstone beds locally contain fragments of the dark metasiltstone. Local beds of ankeritic metasandstone and carbonaceous and sulfidic metasiltstone southeast of Big Creek resemble rocks of the Anakeesta Formation but are here considered part of the Rich Butt Sandstone. Rocks on Webb Mountain and Big Ridge also are probably equivalent to the Rich Butt Sandstone (Hamilton, 1961). In the southern foothills, there are two conspicuous subunits in the Rich Butt Sandstone (Hamilton, 1961). Thin-bedded fine-grained feldspathic metasandstones and laminated metasiltstones (Zrs) that characterize the lower part are 600 to 1,000 ft thick. They can be seen along Warden Branch near Webb Mountain and along Indian Camp Creek near Big Ridge. The upper unit is composed of thick graded beds of coarse-grained feldspathic metasandstone and dark metasiltstone (Zr) that are about 3,000 ft thick. These rocks are best exposed along the west fork of Jones Branch at Webb Mountain and along Indian Camp Creek near Big Ridge. They contain detrital tourmaline like the rocks of the Great Smoky Group.

The composition, accessory minerals, and bedforms suggest that these rocks represent a vertical transition between the rocks of the Snowbird Group and the Great Smoky Group. At the east end of the park, the Rich Butt Sandstone is as much as 4,000 ft thick. Elsewhere, the unit is mostly truncated by faults. Characteristic outcrops can be seen on the southeast side of Big Creek near Mount Sterling.

Great Smoky Group

Introduction

King and others (1958) defined the Great Smoky Group as the sum of the metasedimentary rocks of the Elkmont Sandstone, Thunderhead Sandstone, and Anakeesta Formation, in ascending order. The laterally complex interfingering of sandstones and slaty rocks, combined with a complex structural and metamorphic history, poor exposure, and difficult terrain, make formational subdivisions problematic and somewhat arbitrary. Great Smoky Group rocks in North Carolina are structurally and stratigraphically above those in Tennessee, so formation names to the north are stratigraphically lower in the section. Therefore, rocks in North Carolina have different formation names even though the rocks are somewhat similar lithologically. Throughout the Great Smoky Group, dominantly coarse clastic rocks are interbedded in the lower half with dark fine-grained rocks, and in the upper half with light and dark schist. The coarse clastic rocks contain distinctive calcareous concretions that are calc-silicate granofels.

The contacts of the Cades Sandstone with all adjacent rock units are faults, so its stratigraphic position has always been uncertain (King and others, 1958). We assign the

Cades Sandstone to the Great Smoky Group, and interpret it to be a facies of the Thunderhead Sandstone. Following Robinson and others (1992) and Wiener and Merschat (1992), rocks stratigraphically above the Anakeesta Formation, in ascending order, are the Copperhill Formation, Wehutty Formation, Grassy Branch Formation, and Ammons Formation, all part of the Great Smoky Group. The base of the Elkmont Sandstone is fault-bounded but the top is gradational with rocks of the overlying Thunderhead Sandstone (King, 1964). The transition can be either rapid, as seen from Greenbriar Pinnacle west to Brushy Mountain (Hadley and Goldsmith, 1963), or gradual as in the western part of the study area (Neuman and Nelson, 1965). The Elkmont, Thunderhead, and Cades Sandstones are facies of clastic turbidites in different areas of the same basin, and, except for minor lithologic differences, they are genetically one and the same unit. The upper part of the Thunderhead Sandstone grades into the overlying Anakeesta Formation (Hadley and Goldsmith, 1963). Dark metasiltstone beds increase in abundance and become thicker toward the base of the Anakeesta, as is seen on Mount Le Conte and near Mount Guyot. Rocks of the Thunderhead Sandstone grade into rocks of the Copperhill Formation where rocks of the Anakeesta Formation are absent. The lower part of the Copperhill Formation is graphitic and sulfidic slaty rocks and the upper part is muscovite schist. The base of the Wehutty Formation is a sharp contact marked by graphitic and sulfidic rocks that overly metagraywacke of the Copperhill Formation. Rocks of the Grassy Branch Formation are conformable and gradational above rocks of the Wehutty Formation. Rocks of the Ammons Formation grade above rocks of the Wehutty Formation and Grassy Branch Formation and they grade upward into rocks of both the Dean and Nantahala Formations (Mohr, 1973), possibly along an unconformity.

Elkmont Sandstone

Named after exposures in the community of Elkmont, the Elkmont Sandstone (Ze) forms the base of the Great Smoky Group (King and others, 1958), above the Greenbriar fault. Most of the Elkmont Sandstone is composed of feldspathic metasandstone interbedded with dark metasiltstone layers (Ze) (fig. 11). The metasandstone is diagnostically fine-grained, thin-bedded, and weathers a rusty color. Some coarse-grained metasandstone and metaconglomerate (Zes) was mapped by King (1964) near Elkmont, and similar rocks occur throughout the formation. The Elkmont Sandstone occurs from Greenbriar Pinnacle westward to Chilhowee Lake, and from Cove Mountain south to the top of the mountain south of Cades Cove. Although poorly exposed away from creeks, rivers, and roadcuts, the Elkmont Sandstone holds up the steep mountain above Cades Cove. The rocks range in thickness from about 2,000 ft beneath Greenbriar Pinnacle, to about 5,000 ft at Elkmont, to about 9,000 ft south of Cades Cove. The base of the formation is not preserved because it is truncated by the Greenbriar fault and Gatlinburg fault southwest of Cades Cove. Southwest of Thunderhead Mountain to beyond Calderwood Lake, the massive, thick-bedded nature of the Thunderhead Sandstone diminishes, making the contact between the Elkmont and Thunderhead Sandstones approximate at best. Characteristic outcrops of Elkmont Sandstone are best seen along the Little River.

Thunderhead Sandstone

Named after exposures on Thunderhead Mountain (King and others, 1958), the Thunderhead Sandstone consists of massive, thick-bedded, metaconglomerate and graded beds of coarse-grained metasandstone that are interbedded with dark metasiltstone (fig. 12

A). The principal rock is light- to medium-gray metasandstone composed of colorless quartz, blue quartz, and white potassium feldspar grains, commonly with pebbles of leucogranite and clasts of dark metasiltstone and slate (fig. 12 *B*). In many places the metasandstone contains subspherical concretions several inches in diameter. Where metamorphosed, these sedimentary deposits were called pseudodiorite (Keith, 1913), because of the igneous-looking texture. Goldsmith (1959) described and named these metamorphic rocks granofels.

As noted by King and others (1958), these rocks are best exposed on Mount Le Conte, and they are the most prominently exposed rocks of the Ocoee Supergroup. The thick, gently south-dipping resistant rocks form prominent cliffs and ledges along the northern slope of the Great Smoky Mountains. The Thunderhead Sandstone occurs from Mount Sterling west to Calderwood Lake, and from Cove Mountain south to Mount Le Conte. It is about 6,000 ft thick on Mount Le Conte and thickens to about 8,000 ft near the type locality.

Several distinct lithologic units are mapped within the Thunderhead Sandstone. The majority of the formation consists of thick, graded beds of coarse-grained feldspathic metasandstone and metaconglomerate interbedded with dark graphitic metasiltstone and slate (Zt). These rocks are best seen on the slopes of Sugarland Mountain and Mount Le Conte along and above Highway 411. Between Elkmont and Metcalf Bottom, the sandstone becomes thinner bedded with abundant metasiltstone interbeds (fig. 13 *A*), which are truncated by channel deposits of coarse sandstone (fig. 13 *B*) and conglomerate (fig. 13 *C*).

Thick beds of dark graphitic metasiltstone and slate are mapped as dark metasiltstone (Zts) (fig. 14). Such units occur near Mount Guyot, Mount Le Conte, Sugarland Mountain, and Shuckstack. Dark slate and laminated metasiltstone with subordinate thin interbeds of metagraywacke, metasandstone, and metaconglomerate (Lesure and others, 1977), exposed in the extreme southwest part of the map area, are assigned to slate of the Thunderhead Formation (Zts). These intensely folded rocks commonly have 2 cleavages and were called the Boyd Gap Formation by Wiener and Merschat (1992).

Boulder conglomerate that consists of meter-diameter, rounded leucocratic granite clasts in a matrix of quartz and feldspar, locally with large boulders of dark slate and dolomite, is mapped as a separate unit (Ztb) (fig. 15). These distinctive boulder beds are found along Big Creek near Walnut Bottom and along the Appalachian Trail near Cosby Knob, both in the east part of the park. The boulder bed in Big Creek is interbedded with a dark metasiltstone unit, and the nearly horizontal beds make a wide outcrop pattern. Another boulder bed mapped on the west side of Calderwood Lake by Lesure and others (1977) also may have a wide outcrop pattern due to a low dip angle. Similar boulder beds occur in the Cades Sandstone (Neuman and Nelson, 1965).

Cades Sandstone

The Cades Sandstone (Zc) (King and others, 1958) consists predominantly of medium-grained to conglomeratic metasandstone (fig. 16) interbedded with dark metasiltstone (fig. 17). These beds are well exposed at Abrams Falls. Neuman and Nelson (1965) mapped sequences of dark metasiltstone (Zcs), as much as 2,000 ft thick, in the extreme northwest limit of the outcrop belt above the Rabbit Creek fault. Similar rocks occur throughout the formation and may be as much as 500 ft thick, but were not differentiated by Neuman and Nelson (1965). Distinctive beds of pebble conglomerate and boulder conglomerate (Zcb) as much as 50 ft thick occur locally. The conglomerate consists of pebbles, cobbles, and boulders of quartzite, gneiss, and leucocratic granite as much as 20 in.in diameter, are crudely graded and oriented parallel to bedding. They are supported in a matrix of coarse sand and feldspar. These rocks are best seen in Panther Creek and along the Ace Gap Trail.

The contacts of the Cades Sandstone with all adjacent rock units are faults, so its stratigraphic position has always been uncertain (King and others, 1958). The medium- to coarse-grained metasandstone in part resembles the Elkmont Sandstone, but is generally thinner bedded, has a wider range of grain sizes, and a finer grained matrix (Neuman and Nelson, 1965). The Cades Sandstone is also finer grained and thinner bedded than the Thunderhead Sandstone (King, 1964). The Cades Sandstone contains fragments of granitic rock and mappable beds of dark metasiltstone and boulder conglomerate, like the Thunderhead Sandstone. The Cades contains more clasts of dark slate than the Elkmont, but like the Elkmont Sandstone it contains only sparse blue quartz. Along Little River, the Cades Sandstone contains less conglomeratic rock and more dark pyritic slate than the Thunderhead Sandstone. However, King (1964) described the southwestern phase of Thunderhead Sandstone as fine-grained metasandstone with thickening interbeds of dark argillaceous rocks. In a klippe just south of Little River, belts of Cades Sandstone and Thunderhead Sandstone come together. Here, the uncertain relations were interpreted (King, 1964) to be Thunderhead thrust on Cades. This klippe extends westward to the Cades Sandstone on Cades Cove Mountain. The large mass of Thunderhead Sandstone to the southeast has been detached along the Gatlinburg fault system from the main mass of rock that underlies Thunderhead Mountain. The Cades Sandstone is here interpreted to be a northwestern facies of the Thunderhead Sandstone. These rocks were thrust onto the Pigeon Siltstone along the leading edge of the Greenbriar fault, which also resulted in formation of the Metcalf Phyllite. The Greenbriar fault cut down-section in the hanging-wall, preserving the Elkmont Sandstone on the Snowbird Group as seen along the highlands. Alternatively, the Elkmont, Cades, and Thunderhead Sandstones all could be facies of clastic turbidites in different areas of the same basin and, except for minor lithologic differences, could be one and the same unit.

Anakeesta Formation

The Anakeesta Formation (King and others, 1958) was named after dark, fine-grained rocks that form craggy pinnacles with steep slopes. This formation contains a greater variety of rocks than any other formation in the highlands. The rocks when fresh are characteristically dark due to the presence of graphite, but abundant sulfide minerals readily weather to stain exposures with a rusty-red color (fig. 18). The dominant rock unit is dark graphitic and sulfidic slate, metasiltstone, and phyllite, with local thin beds of metasandstone and metagraywacke (Za). Depending on metamorphic grade and composition, the laminated metasiltstone and phyllite have porphyroblasts of biotite, chloritoid, or garnet. The Anakeesta Formation contains mappable units of light, coarse-grained to conglomeratic, 1- to 10- ft-thick, metagraywacke beds (Zag), interbedded with metasiltstone in sequences as much as 50 ft thick (fig. 19). These are abundant in the middle part of the formation west of the Oconaluftee fault, and smaller bodies are in the upper part of the formation east of the Oconaluftee fault. These coarse rocks can be seen near Morton Overlook north of Newfound Gap. Although resembling similar rocks in the underlying Thunderhead Sandstone and overlying Copperhill Formation, some of the coarse beds are black like the enclosing slaty rocks. The dominantly fine-grained rocks are well exposed on The Chimneys, at Alum Cave, in roadcuts leading to Newfound Gap, along the Appalachian Trail east of Newfound Gap, and in places such as "the Jumpoff" and Charlies Bunyon.

The slaty rocks grade upward from the metagraywackes interbedded with slates that characterize the upper part of the underlying Thunderhead Sandstone. However, on the north side of Mount Le Conte, the base of the Anakeesta Formation consists of a chloritoid slate unit (Zac) that is distinctively light gray, fine grained, and siliceous (quartz and sericite), with dark, thin, tablet-shaped porphyroblasts of chloritoid, and small shiny plates of ilmenite (fig. 20). The chloritoid porphyroblasts are randomly oriented because they grew statically. These rocks are well exposed near Myrtle Point but also are found in areas east of the Oconaluftee fault.

Light, fine-grained metasandstone, ankeritic metasandstone, chloritoid metasiltstone, and ankeritic sandy dolomite (Zas) form the base of the formation on the east side of Mount Le Conte near Laurel Top. In contrast to the metasandstone of the underlying Thunderhead Sandstone, these clastic rocks are finer grained and thinner bedded, with a matrix containing abundant ankeritic dolomite. At the base of the formation just east of Thunderhead Mountain, ankeritic metasandstone is well exposed in the bed of a creek (fig. 21). Elliptical voids, 5 to 10 cm across, make up about 50 percent of the exposed surface.

Within the larger slaty unit are thin bodies of dark, fine-grained dolomite, sandy dolomite, and pisolitic dolomite (Zal) (fig. 22). They range from 1 to 3 ft thick and are interbedded with either slate or metasandstone. These small bodies are shown on the map by an "x". They can be seen along the north side of Newfound Gap Road, in roadcuts downstream from the bridge over Walker Camp Prong (Hadley and Goldsmith, 1963), and in the cliff at Alum Cave. The dark bodies of dolomite can be recognized readily by their dissolution texture. An unusual pisolitic dolomite on Mount Le Conte, 8 to 12 in. thick, contains pisolites of quartz and calcite 1 to 10 mm in diameter (Hadley and Goldsmith, 1963). The pisolites resemble *Girvanella* algae, but the absence of any internal organic structures suggests instead that spheroidal inorganic precipitate was incorporated into the clastic material (Hadley and Goldsmith, 1963).

The rocks of the Anakeesta Formation are preserved in the Alum Cave syncline (Hadley and Goldsmith, 1963), but the internal and enclosing strata do not extend across the limbs of the fold. The massive Thunderhead Sandstone on the northwest slope of Mount Le Conte does not exist south of Newfound Gap, and neither do the basal units of the Anakeesta. The stratigraphy and related structures suggest that the rocks are part of a complex intertonguing depositional prism of strata that has been folded and faulted to form a synclinorium. Erosion preserves mostly a homoclinal southeast-dipping sequence of rock.

Copperhill Formation

Rocks that overlie the Anakeesta Formation have been called the Copperhill Formation (Hurst, 1955; Wiener and Merschat, 1992). They occupy a stratigraphic position higher than the Thunderhead Sandstone, with which they were previously correlated (King and others, 1958; Hadley and Nelson, 1971). East of Thunderhead Mountain, King (1964) recognized rocks stratigraphically above the Anakeesta Formation that he called the "Unnamed Sandstone".

Although most of the rocks closely resemble turbidite deposits of the underlying formations of the Great Smoky Group, there are a few distinct differences. The dominant lithologies are massive and coarse metagraywackes and metaconglomerates (fig. 23 *A*), which are interbedded with quartz-garnet-muscovite phyllites and schists that are locally sulfidic (Zch). Thin beds of metagraywacke also occur throughout the formation (fig. 23 *B*). The medium- to thick-bedded metagraywacke has distinctive calcareous concretions or calc-silicate granofels (Goldsmith, 1959) ("pseudo-diorite" of Keith, 1913) like the rocks of the Thunderhead Sandstone. Collectively, these rocks resemble the Thunderhead as mapped along strike to the northeast by Hadley and Goldsmith (1963) and King (1964). The Thunderhead Sandstone and Copperhill Formation are probably one and the same, distinguished only by the presence of intervening slaty rocks that intertongue laterally to the southwest.

Interbedded with metagraywacke west of Hazel Creek is dark slaty metasiltstone interbedded with metagraywacke (Zchsl) (fig. 24). These graphitic and sulfidic slaty rocks host the massive sulfide deposits of the Fontana copper mine, and they locally are stained rusty-orange due to iron sulfides. The largest occurrence of this unit is within the Eagle Creek shear zone, where the rocks resemble some of the rocks of the Anakeesta and Wehutty Formations.

Interbedded with metagraywacke east of Hazel Creek is light-brown quartz-muscovite schist and phyllite (Zchs) (fig. 25). Locally the phyllite is graphitic and sulfidic.

The schist contains porphyroblasts of garnet, kyanite, or staurolite, depending on metamorphic grade. A garnetiferous metasiltstone west of Clingmans Dome is transitional between the dark slaty rocks in the lower part of the formation and the schists in the upper part of the formation. The protolith of this unit is inferred to have been an aluminous, clay-rich siltstone and shale.

Wehutty Formation

Rocks of the Wehutty Formation (Zwe) (Hernon, 1969) outline the Murphy synclinorium, a large fold that plunges southwest from the area north of Bryson City. These rocks are predominantly muscovite-kyanite-staurolite schist interbedded with metagraywacke, metaconglomerate, and metasandstone. The rocks are dark because they contain abundant graphite and pyrrhotite, and they weather rusty colored as seen in roadcuts along Lakeshore Drive. These rocks are somewhat similar to rocks of the Anakeesta Formation, which led Hadley and Goldsmith (1963), King and others (1968), Hadley and Nelson (1971), and Mohr (1975) to assign them to that unit. Cross-sections (Hadley and Goldsmith, 1963; Hadley and Nelson, 1971), however, demonstrate that these rocks occupy a higher stratigraphic and structural position than the Anakeesta Formation at its type locality. Therefore, we designate these rocks as the Wehutty Formation after Weiner and Merschat (1992) and Robinson and others (1992).

Mohr (1973) mapped about 1,200 m of the following ascending sequence of rock in this unit: schist, metagraywacke, schist, metagraywacke, and schist. Black mica schist makes up about 90 percent of the section, while metagraywacke, tremolite schist, marble, quartz-chlorite schist and metasiltstone, and graphite-apatite schist make up the remainder (Mohr, 1973). The metagraywacke is thinner and darker in color than similar rocks in the underlying Copperhill Formation. Transitional between the schist and metasandstone facies are laminated schist and light-gray metagraywacke. These rocks are similar to the upper part of the Copperhill Formation, and they also contain abundant calc-silicate granofels. These strata are continuous over long distances and are well exposed along Lakeshore Drive (fig. 26).

Grassy Branch Formation

The Grassy Branch Formation (Zgb) (Mohr, 1973) is metasandstone with subordinate muscovite schist and metagraywacke that grades upward to dark porphyroblastic muscovite schist and metasandstone. The metagraywacke and laminated schist in the lower part are similar to rocks of the upper part of the Copperhill Formation and range from 100 to 300 m in thickness. The schist contains porphyroblasts of garnet, biotite, chlorite, and staurolite, commonly altered to sericite and chlorite (Mohr, 1973). These rocks are well exposed at the type locality on the north bank of Alarka Creek at its confluence with Grassy Branch.

Ammons Formation

The Ammons Formation (Zam) (Mohr, 1973) consists of metasandstone and muscovite schist interbedded with abundant metasiltstone in the lower part (Mohr, 1973). The upper part is dark graphitic and sulfidic mica schist and metasiltstone, interbedded with metagraywacke, metasiltstone, muscovite schist, and local beds of metaquartzite and garnet-biotite porphyroblastic mica schist. The lower beds are exposed on a cliff on the Little Tennessee River between the mouths of Lemmons Branch and Battles Branch. The upper beds can be seen on Route 28 between the Nantahala River and the Swain-Graham County line. The top beds are exposed along Route 28 along Horse Branch, but they are not differentiated on the map. The metasandstones are finer grained than those in the underlying formations of the Great Smoky Group. These rocks display well-preserved soft-sediment deformational features of turbidite deposits, as well as the oxidation minerals magnetite, pyrite, and epidote.

Rocks of the Foothills Section of the Western Blue Ridge Province

Neoproterozoic Walden Creek Group

Introduction

The Walden Creek Group was named for rocks exposed along Walden Creek east of Pigeon Forge in the foothills of the western Blue Ridge. King and others (1958) subdivided this assemblage of sedimentary rocks into the Licklog, Shields, Wilhite, and Sandsuck Formations (in ascending order). Rocks of the Sandsuck Formation are not within the map area. Intact stratigraphic relations east of Pigeon Forge (Hamilton, 1961) have been used to classify the rocks found west of Pigeon Forge, because the sequence has been disrupted by significant structural movement. These rocks are separated from the rocks of the Snowbird, Great Smoky, and Chilhowee Groups mostly by faults. They are floored by the Great Smoky fault (thrust onto the Chilhowee Group) and they are roofed by the Dunn Creek fault (overthrust by the Snowbird Group) and Rabbit Creek fault (overthrust by the Great Smoky Group). Northeast of the map area, Oriel (1950) and Ferguson and Jewell (1951), suggest that rocks of the Walden Creek Group conformably overlie rocks of the Snowbird Group. Hamilton (1961) described transitional relations across the Dunn Creek fault. Thigpen and others (2004) suggest that rocks of the Wilhite Formation grade with rocks of the underlying Dean Formation, which they assign to the Great Smoky Group.

The base of the Licklog Formation is faulted, so only a few hundred feet of the formation is present. The top appears to intertongue with and be conformably overlain by conglomerate of the Shields Formation (Hamilton, 1961), which ranges from 2,000 to 2,500 ft (610-763 m) thick. Rocks of the Wilhite Formation are transitional above the coarse-grained rocks of the Shields Formation (King, 1964). The limestone and shale unit of the Wilhite Formation is concordantly overlain by siltstone and sandy limestone of the Sandsuck Formation. At the northeast end of Chilhowee Mountain, the upper sandstone and quartz-pebble conglomerate of the Sandsuck Formation appear to be channel deposits that were truncated and unconformably overlain by the Cochran Formation (King, 1964).

Rocks of the Walden Creek Group are found along the Foothills Parkway between Wear Cove and Walland, near the west end of the parkway near Chilhowee Lake, and in the western part of the national park in the lower Abrams Creek drainage. This group of rocks is perhaps the most diverse, heterogeneous, and controversial with respect to interpretation, within the entire Ocoee Supergroup.

Licklog Formation

The Licklog Formation (Zll) (King and others (1958), named after Licklog Hollow, consists of a poorly exposed sequence of siltstone and shale beds interbedded with some fine- to coarse-grained sandstone and pebble conglomeratic sandstone beds a few feet thick. The rocks are best exposed along the Little Pigeon River near the Dunn Creek fault. Rocks of the Licklog Formation are found near Shields Mountain east of Pigeon Forge and above the Great Smoky fault on the north side of Wear and Tuckaleechee Coves. North of these coves, beds of conglomeratic sandstone (Zllc) are within the dominant siltstone unit.

Shields Formation

Named for the rocks exposed on Shields Mountain near the Little Pigeon River, the Shields Formation (King and others, 1958; Hamilton, 1961) consists of thick-bedded sandstones and conglomerates that are overlain by and intertongue with siltstone, shale, and slate. The basal rocks of the formation are distinctive coarse polymictic conglomerates of polymictic pebbles and cobbles interbedded with pebbly sandstone (Zsc) (fig. 27). Conglomeratic rocks previously assigned to the Wilhite Formation (Neuman and Nelson, 1965), are here assigned to the Shields Formation as advocated by Hadley and Nelson (1971). Conglomeratic rocks on the northwest slope of Cove Mountain at Raven Den, previously identified as Thunderhead Sandstone (King, 1964), are here assigned to the Shields Formation. These distinctive rocks are best seen in roadcuts along Shields Mountain, northwest of Kinzel Springs, and along the bluffs at Chilhowee Dam. Most clasts are rounded milky-quartz pebbles that average 1 in. in diameter, but there are also pebbles of quartzite, granite, chert, siltstone, and limestone. The coarse basal rocks grade upward into laminated siltstone, shale, and slate (Zsh), which compose the majority of the formation, but locally these rock types are interbedded. They occur from Pigeon Forge east to Bearwallow Mountain near Richardson Cove, and west of Pigeon Forge to Kinzel Springs. They are best seen along State Highway 321 at Kinzel Springs. Coarse sandstone and siltstone beds (Zss) are transitional and intertongue between the conglomerate and silty rocks, especially east of Pigeon Forge. Thin beds of argillaceous limestone within siltstone (Zsl) are mapped along the Dunn Creek fault near Bird Creek.

Wilhite Formation

The Wilhite Formation was named after rocks exposed along Wilhite Creek and Long Branch (King and others, 1958), in the eastern part of the northern foothills. In the type area, Hamilton (1961) described about 1,500 ft (458 m) of metasiltstone and sandstone of the Dixon Mountain Member, which are overlain by about 2,000 ft (610 m) of siltstone that grades upward to limestone conglomerates of the Yellow Breeches Member. West of the Pigeon Forge fault, King (1964) described a 1,750 ft (534 m) thick lower unit of siltstone, interbedded with quartzite, sandstone, and conglomerate, and an approximately 1,750- ft- (534m) thick upper unit of shale and slate interbedded with limestone. Farther west, Neuman and Nelson (1965) mapped about 10,000 ft (3 km) of siltstone, interbedded with about 2,500 ft (763 m) of quartz-pebble conglomerate and quartzose sandstone.

Regionally, the Wilhite Formation can be broken into 3 main units: 1) shale, siltstone, and slate (Zw); 2) clastic rocks interbedded with calcareous clastic rocks (Zwlc); and 3) limestone and shale (Zwl). Fine-grained metasiltstone (Zw) predominates. To the northeast, carbonate rocks are interbedded with the fine-grained rocks (Zwlc), and eventually carbonate rocks predominate (Zwl).

Most of the Wilhite Formation is composed of fine-grained shale, metasiltstone, and slate (Zw) (fig. 28). In the eastern part of the map area, it is typically a laminated metasiltstone with thin interbeds of sandstone, limestone, and dolomite. Typical outcrops are along Dunn Creek. In the central part of the map area, the rocks are mainly laminated metasiltstone and slate with interbeds of quartzite, sandstone, and conglomerate in the lower part, and shale and slate interbedded with limestone in the upper part. Typical outcrops are along Cove Creek. In the western part of the map area, the dominant rocks are laminated metasiltstone, fine-grained sandstone, conglomerate, and carbonate rocks. The laminated metasiltstone has laminae of ankerite. Conglomerate and sandstones are interbedded with the finer grained rocks. The conglomerates are graded and comprise about 80 percent vein-quartz clasts. They resemble rocks of the underlying Shields Formation. The largest clast observed is a sandstone boulder 5 ft (1.5 m) long and 3 ft (1 m) wide (Neuman and Nelson, 1965). Carbonate rocks range from layers a few inches to 150 ft (46 m) thick within both metasiltstone and conglomerate horizons, and include limestone breccia and fine-grained laminated limestone (fig. 29). Some limestone bodies are olistoliths, or blocks and clasts deposited in mudflows (Hanselman and others, 1974). Characteristic outcrops are along Chilhowee Lake. Happy Valley appears to be a karst valley even though no limestone is exposed.

From near Crockettsville east to Sol Messer Mountain, clastic rocks are interbedded with carbonate rocks (Zwlc). Gray metasiltstone and sandstone contain interbeds of gray limestone, dolomite, and ankeritic dolomite, and as much as 1,500 ft (460 m) of this sequence is exposed along Long Branch.

Limestone and shale (Zwl) are mapped near Pigeon Forge and Crockettsville. Thick gray limestone beds are commonly sandy and conglomeratic, and are interbedded with shale and siltstone. The limestone conglomerate consists of subangular chips and slabs of limestone, about 8 in. long, as well as other kinds of rock fragments that are arranged subparallel to bedding. The matrix is sandy limestone. Coarse conglomerate near Chavis Creek where the section is about 500 ft (153 m) thick, contains dolomitic limestone clasts as much as 5 ft (1.5 m) long. Good exposures of the limestone and shale occur along Cosby Creek, in roadcuts near Jones Cove, and in old quarries near Pigeon Forge.

Paleozoic Rocks

Paleozoic rocks are exposed in the foothills of the western Blue Ridge province and in the Tennessee Valley of the Valley and Ridge province. Within the foothills, the Paleozoic rocks are found along the northern border above the Great Smoky fault, and within tectonic windows (Calderwood, Cades, Tuckaleechee, and Wear Coves) through the Great Smoky fault. The oldest Paleozoic rocks are Early Cambrian clastic rocks in the western part of the foothills above the Great Smoky fault. The Foothills Parkway crosses these rocks near Cosby and from Walland to Chilhowee Lake.

Early Cambrian Chilhowee Group

The sequence of quartzites and interbedded siltstone and shale that are well exposed on Chilhowee Mountain, Green Mountain, and Stone Mountain, were subdivided by Keith (1895) and King and others (1944) into (ascending order): the Cochran Formation, Nichols Shale, Nebo Quartzite, Murray Shale, Hesse Quartzite, and Helenmode Formation. The rocks on Chilhowee Mountain lie between the Great Smoky fault and the Miller Cove fault. The structure of the rocks is a southeast-dipping homocline with synclines formed in the footwall of the Miller Cove fault. The quartzite units hold up subparallel ridges, and intervening swales are floored by shale. Expsoures of the Hesse and Nebo Quartzites form prominent cliffs along Chilhowee Mountain. Several late, steeply dipping cross-faults disrupt the folded strata, as seen west of Miller Cove. Green Mountain is also a southeast-dipping sequence of rocks beneath the Dunn Creek fault. The rocks in the upper part of the Chilhowee Group (Ccu) (Nebo Quartzite, Murray Shale, Hesse Quartzite, and Helenmode Formations) have not been differentiated here.

The basal rocks of the Cochran Formation are transitional and lie conformably above similar coarse-grained rocks of the Sandsuck Formation of the Walden Creek Group. The lower contact of the Nichols Shale with underlying quartzite of the Cochran Formation is sharp. The upper contact with the overlying Nebo Quartzite is transitional between shale and quartzite. The contact between the Nebo Quartzite and the overlying Murray Shale appears to be sharp. The contact of the Murray Shale with the overlying Hesse Quartzite is abrupt but locally transitional (Neuman and Nelson, 1965). In the upper Hesse Quartzite, quartzite interbedded with shale grades upward into shale and siltstone interbedded with sandstone of the Helenmode Formation. At the top of the Chilhowee Group, the Helenmode Formation grades upward into shaly dolomite shale of the overlying Shady Dolomite. Unlike the rocks of the Ocoee Supergroup that are restricted to the western Blue Ridge of the Southern Appalachians, the rocks of the Chilhowee Group extend the entire length of the western Blue Ridge province, from northern Georgia to southern Pennsylvania.

Cochran Formation

The Cochran Formation (Cc), named after rocks near Cochran Creek, consists of a basal gray conglomerate overlain by maroon pebbly arkose that is interbedded with maroon shale and siltstone. These lower rocks grade upward into light-gray arkose, cross-bedded sandstone, and quartzite. Concretions of gray hematite, 1 to 4 in. in diameter, distinquish quartzites of the Cochran from the overlying Nebo and Hesse Quartzites. The base of the formation is placed at the base of the thick conglomeratic feldspathic sandstone that overlies a thin fissile siltstone assigned to the Sandsuck Formation. The upper contact of quartzite sharply overlain by Nichols Shale is exposed at the top of Chilogatee Gap. The rocks of the Cochran Formation can be seen on the south side of Green Mountain, and extensively along the west slope of Chilhowee Mountain, but they also occur on the east side of Chilhowee Mountain at the north end of Happy Valley.

Nichols Shale

The Nichols Shale (Cn), named after rocks exposed along Nichols Branch of Walden Creek, consists of greenish-gray, argillaceous to silty, well-laminated fissile shale with some layers of sandstone and quartzite. The sandstone is feldspathic, and large flakes of detrital muscovite are exposed on bedding surfaces. This unit is exposed at Chilogatee Gap and also in an old quarry north of Walland on the east side of the Little River. Ribbon-like impressions in shale have been interpreted as trace fossil burrows near Chilogatee Gap (Neuman and Nelson, 1965).

Nebo Quartzite

The Nebo Quartzite (Cnb), named after rocks exposed near Mount Nebo Springs, consists mostly of thin-bedded white quartzite. The basal rocks are green sandstone that is rich in chlorite. Clean quartzite beds mostly less than 1 ft thick are crossbedded. The quartzite ranges in thickness from 200 to 400 ft (fig. 30 *A*) over a distance of 15 mi. Peculiar to this rock unit are closelyspaced, narrow cylindrical tubes perpendicular to bedding that terminate at bedding planes (fig. 30 *B*). These tubes are the trace fossil *Skolithos linearis,* which are burrows of intertidal to shallow subtidal worm-like organisms.

Murray Shale

The Murray Shale (Cm), named for Murray Branch of Walden Creek, is mostly greenish-gray argillaceous to silty shale (fig. 31 *A)* that sharply overlies the Nebo Quartzite. The shale is interbedded with fine-grained feldspathic and glauconitic sandstone in the upper half of the formation (fig. 31 *B*). The thickness of the formation ranges from 350 ft at Murray Gap to 550 ft at Chilogatee Gap, over a distance of about 5 mi.

Hesse Quartzite

The Hesse Quartzite (Ch), probably named after the Hesse Creek tributary of the Little River, is mostly medium- to coarse-grained quartzite with well-rounded grains cemented by silica. The quartzite beds are generally 2 to 4 ft thick with local crossbeds. The formation is about 500 to 600 ft thick. *Skolithos linearis* tubes are abundant in some beds, but they are fewer in number, and generally not as long as those seen in the Nebo Quartzite. Like other quartzite units within the Chilhowee Group, the Hesse Formation forms dip slopes along Chilhowee Mountain along the Foothills Parkway (fig. 32).

Helenmode Formation

The Helenmode Formation (Chm) was named after the Helenmode Member of the Erwin Formation, found about 40 mi to the northeast (King and others, 1944). Rocks of the Helenmode Formation consist of gray silty shale and siltstone interbedded with thin quartzite beds at the base and coarse sandstone near the top.

Lower Cambrian Shady Dolomite

The Shady Dolomite (Cs) is a 1,000-ft-thick sequence of thick-bedded dolomite that includes a few interbeds of dolomitic shale in the upper third of the formation

(Neuman and Nelson, 1965). The dolomite can be either crystalline, thick-bedded and massive, or thin-bedded and laminated. The dolomite commonly contains irregular masses of fine-grained chalcedony chert. The Shady Dolomite occurs north of Cosby, where it underlies broad valleys as well as knobs that are as much as 600 ft high. The Shady Dolomite also occurs on the southeast side of Chilhowee Mountain from its northeast end southwestward to Top of the World Estates. A small outlier of dolomite north of Walden Creek has been interpreted to be Shady Dolomite exposed in a tectonic window (King, 1964). The shaly dolomite and dolomitic shale are mapped as separate units (Css) on either side of the Little River gap on the south side of Chilhowee Mountain. Residuum of Shady Dolomite is clay and massive boulders of jasperoid. Shady Dolomite is well exposed along roadcuts of Route 73/321 near the entrance to the Foothills Parkway near Miller Cove (fig. 33).

Lower Cambrian Rome Formation

The Rome Formation (Cr) consists of fissile, laminated, red and maroon shale, calcareous siltstone, and fine-grained sandstone (Neuman and Nelson, 1965). Although generally weathered, poorly exposed, and covered by surficial material, the red rocks are exposed in the core of the synclines north and south of Miller Cove, and northeast of Cosby.

Igneous Rocks

Metadiabase, Metadiorite, and Related Altered Rocks

Mafic igneous rocks (Pzd) intrude the metasedimentary rocks of the Ocoee Supergroup in the Highlands Section of the Blue Ridge Province (Laney, 1907; Espenshade, 1963; Hadley and Goldsmith, 1963; King, 1964; Southworth, 1995). Twelve chemical analyses of these rocks suggest compositions of subalkalic basalt and diorite (Southworth, 1995). The metadiabase intruded rocks of the Great Smoky Group and Snowbird Group (Hadley and Goldsmith, 1963). The metadiabase dikes are altered by metamorphism and foliated, indicating they were emplaced prior to metamorphism (440 to 415 Ma) and deformation. The metadiorite dikes are medium- to coarse-grained, porphyritic to aphanitic, with large hornblende and plagioclase phenocrysts as much as 1 in. long (fig. 34 A and B). The northeast trending dikes from near Fontana Dam to Clingmans Dome are several bodies that were transposed into the regional foliation within the Eagle Creek shear zone. There are multiple dikes, as seen on the north side of Clingmans Dome, and in the scattered distribution of the dikes in the highlands. The largest body of rock is about 350 ft thick and 2 mi long and parallels cleavage (Hadley and Goldsmith, 1963). Outcrops of the igneous rocks rarely are exposed, but float occurs as distinctive dark round cobbles with pitted rinds. Cobbles and boulders rounded by streams show diagnostic green variegated megacrystic texture. Residual soil is a conspicuous red saprolite with sparse vegetation.

Chloritic greenstone found in several locations is interpreted to be altered metadiabase. Greenstone with masses of epidosite (fig. 35 *A*) (Southworth, 1995) is adjacent to carbonate-chlorite schist and felsic rocks on the southeast bank of Ecoah Branch, opposite the Fontana Copper mine. The fine-grained greenstone is composed principally of saussuritized plagioclase, quartz, actinolite, epidote, and chlorite. Locally the rock is vesicular with quartz-filled amygdules. Epidosite masses of quartz and epidote nodules are as much as 1 ft long. Greenstone float occurs north of Mount Le Conte, and beneath the Greenbriar fault in 3 locations near Greenbriar Pinnacle (Hadley and

Goldsmith, 1963). A greenstone dike 130 ft thick strikes east and dips 60 degrees south in the Rich Butt Sandstone along Big Creek near Mount Sterling (Hadley and Goldsmith, 1963). The greenstone is probably altered metadiabase locally associated with metamorphic fluids in shear zones.

Associated with the greenstone is carbonate-chlorite schist. Well-foliated carbonate-chlorite schist is exposed in the Eagle Creek shear zone adjacent to thrust faults (Southworth, 1995), adjacent to metadiabase at Flint Gap and north of Clingmans Dome, and as float west of the Fontana Copper mine and west of Soapstone Gap. The rock is probably chloritized and altered metadiorite (Espenshade, 1963; Hadley and Goldsmith, 1963). It is characteristically vuggy in outcrop, containing rhombehedral cavities as much as 0.2 in. in diameter due to dissolution of ankerite that is seen in fresh specimens. The carbonate-chlorite schist is composed predominantly of chlorite with lesser quartz and talc, which produces a soft rock that can be scratched with a fingernail and has a greasy luster. It is probably the namesake for "Soapstone Gap" on Pinnacle Ridge.

Near the greenstone along Ecoah Branch is a light-gray, fine-grained, laminated quartz-plagioclase rock that contains angular blocks and fragments as much as 1 ft across (fig. 35 *B*). The blocks and fragments are composed of medium- to coarse-grained porphyritic metavolcanic rock, of intermediate composition, that has equant feldspar phenocrysts as much as 0.2 in. in diameter. Elsewhere, angular blocks of the felsite occur as breccia in a fine-grained quartz-plagioclase laminated matrix. Fine-grained laminated tuff grades into crystal tuff containing abundant zoned plagioclase phenocrysts as much as 1 in. across, lapilli tuff containing angular fragments of crystal tuff, and tuff breccia containing subrounded blocks of crystal tuff up to 10 in. long. The felsic rocks may be hydrothermally altered igneous rocks associated with the metadiabase and greenstone.

Pegmatite

Small pegmatite bodies of two distinct ages are found in the southern and southeastern parts of the map area. Pegmatite, aplite, and pegmatitic granite associated with plutonism and metamorphism of the Grenvillian orogeny are found in the Mesoproterozoic gneisses. These foliated pegmatites have pink potassium feldspar and green epidote. In contrast, younger tabular dikes and sills of white, massive, unfoliated pegmatite intrude the Mesoproterozoic gneiss and rocks of the Neoproterozoic Great Smoky and Snowbird Groups. They are found only where Paleozoic metamorphism was kyanite-staurolite grade, especially east and southeast of Dellwood, and from Bryson City east to around Cherokee. In these areas, the pegmatite intrudes both the basement and cover rocks around the tectonic windows of the Greenbriar fault. It occurs in and along the margin of these windows, but is especially concentrated along the western margin of the Bryson City window. The pegmatite is homogeneous, zoned, and consists of white oligoclase, white perthite, quartz, muscovite, and sometimes biotite (fig. 36) (Cameron, 1951); the muscovite books are as much as 2 to 4 in. across. The pegmatite bodies range in size from 1 in. thick and 12 in. long to about 200 ft thick and 500 ft long. The large bodies at Bryson City were mined for feldspar from the 1930s to the 1940s (Cameron, 1951). Most of the pegmatite is unfoliated, and appears to intrude the mylonitic rocks of the Greenbriar fault. However, some pegmatite is pre- to syn-kinematic, as it is parallel to foliation and is folded. The northward elongation, steep westward dip, and steep pitch to the southwest (Cameron, 1951; Hadley and Goldsmith, 1963), suggest that the pegmatites are folded with the Bryson City dome and Murphy synclinorium. They may be related to reactivation of the Greenbriar fault during metamorphism, but they have subsequently been folded with the late fold phase.

Vein Quartz

Dikes of vein white quartz intrude virtually all of the metamorphosed rocks of the region. They occur as pods, lenses, and veins as much as 30 ft thick. Some of the largest are along thrust faults in the Eagle Creek shear zone (fig. 37 *A*) (Southworth, 1995). Some of the the vein quartz is foliated, isoclinally folded, and boudinaged (fig. 37 *B*), while other vein quartz is massive and not foliated. Brecciated vein quartz locally suggests late brittle faults. Boulders of vein quartz as much as 15 ft in diameter are common in creek beds where fine-grained rocks of the Great Smoky Group and Metcalf Phyllite were sheared and fluids introduced during metamorphism (fig. 37 *C*).

Trondhjemite

Dikes of trondhjemite occur in the Mesoproterozoic gneiss and Neoproterozoic rocks east and southeast of Dellwood, within the Soco-Cherokee belt, and around Bryson City. These dikes range in width from 2 in. to 10 ft, but most are 2 to3 ft wide. They are not shown on the map. They are light gray, and have equidimentional grains, 0.25 to 0.5 in. across, of calcic oligoclase, quartz, biotite, and magnetite.

Paleozoic Rocks of the Tennessee Valley and within the Tectonic Windows of the Foothills of the Western Blue Ridge

Introduction

Cambrian and Ordovician rocks underlie the Tennessee Valley to the northwest of the map area. The oldest rocks are Lower Ordovician Jonesboro Limestone and Middle

Ordovician Blockhouse Shale, exposed in five tectonic windows through the Great Smoky fault. There are no Silurian rocks. At the base of the Mississippian strata are about 10 ft of black shale considered to be Chattanooga Shale of Devonian to early Mississippian age. The youngest Paleozoic rocks are clastic rocks of the Lower Upper Mississippian Greasy Cove Formation beneath the Guess Creek fault, in the easternmost Tennessee Valley.

Rocks within the Tectonic Windows

Six tectonic windows have been recognized in the GSMNP region. From southwest to northeast, they are the Calderwood, Cades Cove, Big Spring Cove, Whiteoak Sink, Tuckaleechee Cove, and Wear Cove windows. Limestone in the windows “is tectonically disordered, lacking distinctive fossils or lithologic features that would indicate their exact stratigraphic position” (King, 1964), so it has not been subdivided into mappable units (Neuman and Nelson, 1965), except for the Jonesboro Limestone (Oj) (Rodgers, 1953) and Blockhouse Shale (Obl). Thin units of Lenoir Limestone are included with the Jonesboro Limestone.

The coves are underlain by carbonate rocks which have dissolved by physiochemical processes to form closed basins surrounded by mountains. Whiteoak Sink is actually part of the Tuckaleechee Cove window, but is separated from it by Scott Mountain. The western part of the cove at Calderwood was breached by the Little Tennessee River. Big Spring Cove was confirmed to be a tectonic window by a drill core in 1951 (King, 1964), and the limestone penetrated at a depth of 45 ft (15 m) was interpreted to be Lower Ordovician Jonesboro Limestone. The rocks in the Calderwood window, Cades Cove, and Big Spring Cove are classified exclusively as Jonesboro Limestone. The rocks in Tuckaleechee and Wear Coves are assigned to the Jonesboro

Limestone, Blockhouse Shale, and Lenoir Limestone. Tuckaleechee Cove contains several intraformational thrust sheets that locally duplicate strata, especially near the north and south margins of the window. In Wear Cove, Jonesboro Limestone is thrust on Blockhouse Shale along the margins of the window. Jonesboro Limestone is exposed again in the center of the cove in two anticlines.

Lower Ordovician Jonesboro Limestone and Middle Ordovician Lenoir Limestone

The Jonesboro Limestone (Oj) is dominantly gray, fine-grained limestone in 6 in to 3-ft-(1 m) thick beds marked by thin wavy clay, silt, and chert partings. Less abundant are massive limestone containing fossils and quartz sand grains and dolomite with cross- hatch patterns of calcite-filled joints. Irregular masses of black and white nodular chert locally form residuum. Disseminated chert stringers are seen in a few outcrops. Jonesboro Limestone is best exposed in Tuckaleechee Cove, where about 2,000 ft (610 m) of folded and faulted limestone is exposed. The Jonesboro Limestone is overlain by the Middle Ordovician Lenoir Limestone (Safford and Killebrew, 1876) along an erosional unconformity that has as much as 140 ft (43 m) of relief (Bridge, 1955). The Lenoir Limestone (Ol) consists of gray, cobbly argillaceous limestone and limestone conglomerate. About 25 ft (8 m) of Lenoir Limestone in Tuckaleechee Cove is included with the Jonesboro. Locally the basal rocks of the Lenoir are limestone conglomerate composed of detritus eroded from older rocks. An 8-ft- (2.5 m) thick bed of limestone conglomerate containing angular fragments of limestone 0.75 in. long is exposed along State Highway 73 at the south side of Tuckaleechee Cove.

Middle Ordovician Blockhouse Shale

The Blockhouse Shale (Obl) (Neuman, 1955) is a dark, finely laminated, fissile calcareous shale. Thin, 3- to 5- ft- (1 to 1.5 m) thick beds of cobbly argillaceous limestone occur locally at the base. They are the Whitesburg Limestone Member of Ulrich (1929). Local 10-ft-(3 m) thick beds of calcareous sandstone also occur a little higher in the section. The limestone and sandstone are too thin to be shown separately on the map. The shale is folded and contains abundant slickensides. The Whitesburg Limestone Member of the Blockhouse Shale disconformably overlies the Lenoir Limestone. The top of the Blockhouse Shale is truncated by the Great Smoky fault, but in the Tennessee Valley it grades upward into the Tellico Formation. The Blockhouse Shale can be seen along Rich Mountain Road at the crest of Rich Mountain, where it is exposed beneath the Great Smoky fault.

Slices of Jonesboro Limestone along the Great Smoky Fault

Slices of the Jonesboro Limestone occur between the Blockhouse Shale and older rocks of the Ocoee Supergroup or Chilhowee Group along the Great Smoky fault. These slivers of rock range from a few feet thick and 100 ft long to several thousand feet thick and several miles long. A well-exposed slice 5 to 25 ft (1.5 to 7.6 m) thick occurs at the southern boundary of Tuckaleechee Cove along State Highway 73. Small slices of limestone and dolomite occur along the leading edge of the Great Smoky fault in the Tennessee Valley, the largest being just south of Cedar Bluff.

Middle Ordovician Tellico Formation and Bays Formation

Other Middle Ordovician rocks in the Tennessee Valley are the Tellico Formation and Bays Formation. Transitionally overlying the Blockhouse Shale are gray, sandy and silty calcareous shales with beds of calcareous sandstone, fine-grained sandstone, and impure limestone of the Tellico Formation (Ot) (Keith, 1895; Neuman, 1955). The light-gray shale is interbedded with darker shale of the Blockhouse Shale at the base. Along the Great Smoky fault, west of Pigeon Forge along the base of Chilhowee Mountain, the rocks assigned to the Tellico Formation also may include rocks of the Blockhouse Shale tectonically mixed along the thrust fault (Neuman and Nelson, 1965). These rocks underlie a broad area from Sevierville southwestward to beyond Blockhouse, and east of Pigeon Forge north of the Great Smoky fault. The Bays Formation (Ob) (Keith, 1895; Rodgers, 1953; Neuman, 1955) consists of red calcareous mudrock and siltstone, locally with coarse-grained feldspathic and light-gray quartzitic sandstone interbedded with red fine-grained sandstone. These rocks grade upward from rocks of the underlying Sevier Formation, that are shown only in cross section. The uppermost quartzite at the top of the Bays is discontinuous and unconformably overlain by the Chattanooga Shale. Neuman (1955) suggested that the oxidized rocks of the Bays Formation indicate a depositional environment that was occasionally drained. This contrasts sharply with the marine depositional environment of the rocks below the Bays.

Upper Devonian and Lower Mississippian (?) Chattanooga Shale

The thin, dark carbonaceous shale that overlies the rocks of the Bays Formation has previously been called the Chattanooga Shale (MDc) (Keith, 1895). This is because the shale is not calcareous and contains sulfide minerals and rusty concretions. Locally at the base, the shale is sandy and contains sandstones a few inches thick. However, the unit is mostly deformed into pods of shale with slickensided boundaries. These poorly exposed rocks are only about 10 to 25 ft (3 to 7.6 m) thick and extend northeastward from the west side of the map area near the base of Chilhowee Mountain. The outcrop belt is a swale, commonly covered with colluvium, that is marked by small borrow pits. These black rocks were locally exploited as coal, which they are not. Conodonts, linguloid brachiopods, and marine megafossils collected from black shale in the region suggest that some of these rocks may be Early Mississippian in age and not restricted to the true Upper Devonian Chattanooga Shale (Neuman and Nelson, 1965).

Lower Mississippian Grainger Formation, and Greasy Cove Formation

The Lower Mississippian Grainger Formation (Mg) (Keith, 1895) consists of siltstone and fine-grained sandstone that grade upward to coarser grained feldspathic sandstone and pebble conglomerate interbedded with silty shale. The lower three-quarters of the formation is described as a monotonous sequence of shale and sandstone, whereas the upper one-quarter consists of thick beds of coarse-grained rocks. Light-gray siltstone at the base of the Grainger sharply overlies the dark shale of the underlying Chattanooga Formation. The coarse-grained rocks in the upper part of the Grainger are similar to and grade into rocks of the overlying Greasy Cove Formation. The Lower Upper Mississippian Greasy Cove Formation (Mgc) (Neuman and Wilson, 1960) consists of interbedded gray calcareous shale, argillaceous limestone, fine-grained sandstone, red shale, and sandstone. The shale and limestone readily weather to a greasy, waxy clay residuum. Only the lower part of the formation is exposed along creeks due to abundant colluvium along the base of Chilhowee Mountain, and the upper part is truncated by the Great Smoky fault. The Mississippian rocks along the Guess Creek fault are so structurally deformed and tectonically mixed that they cannot be differentiated, so they are shown as Greasy Cove and Grainger Formations (Mgg).

Structure and Metamorphism

The complex stratigraphy of the GSMNP region was metamorphosed, structurally deformed, and tectonically assembled in several episodes over a period of about 909 m.y., from about 1,194 Ma in the Mesoproterozoic to about 285 Ma in the late Paleozoic Era. The rocks were metamorphosed and structurally deformed at depths of tens of kilometers within the crust some 100 km to the east of their present position (Hatcher, 1978), prior to being tectonically transported westward to their current locations. An argon-argon hornblende cooling age of 430 Ma (M.J. Kunk, USGS, oral commun., 2004) and 425 to 415 Ma (Dallmeyer, 1975), as well as U-Pb sphene growth at 440 Ma (J.N. Aleinikoff, USGS, oral commun., 2004), and U-Pb monazite growth between ~480 Ma (Moecher and others, 2004) and ~400 Ma (Kohn and Malloy, 2004), support deformation and metamorphism of rocks above the garnet isograd in the Ordovician between 480 and 400 Ma, and probably between 440 to 415 Ma. Between the Gatlinburg fault system (biotite isograd) and the southeast area of the map, the mean zircon fission-track age of 365 Ma (C.N. Naeser, USGS, oral commun.. 2004), and argon-argon white mica ages of 350 Ma (M.J. Kunk, USGS, oral commun., 2004) and 377 to 354 Ma (Connelly and Dallmeyer, 1993), all suggest Late Devonian deformation and metamorphism at 377 to 350 Ma. Fission-track analysis supports Pennsylvanian cooling related to emplacement of the Alleghanian Great Smoky fault system at 285 Ma, with possible Cretaceous (~145 Ma) or younger displacement along the Gatlinburg fault system (Naeser and others, 2004) (fig. 39).

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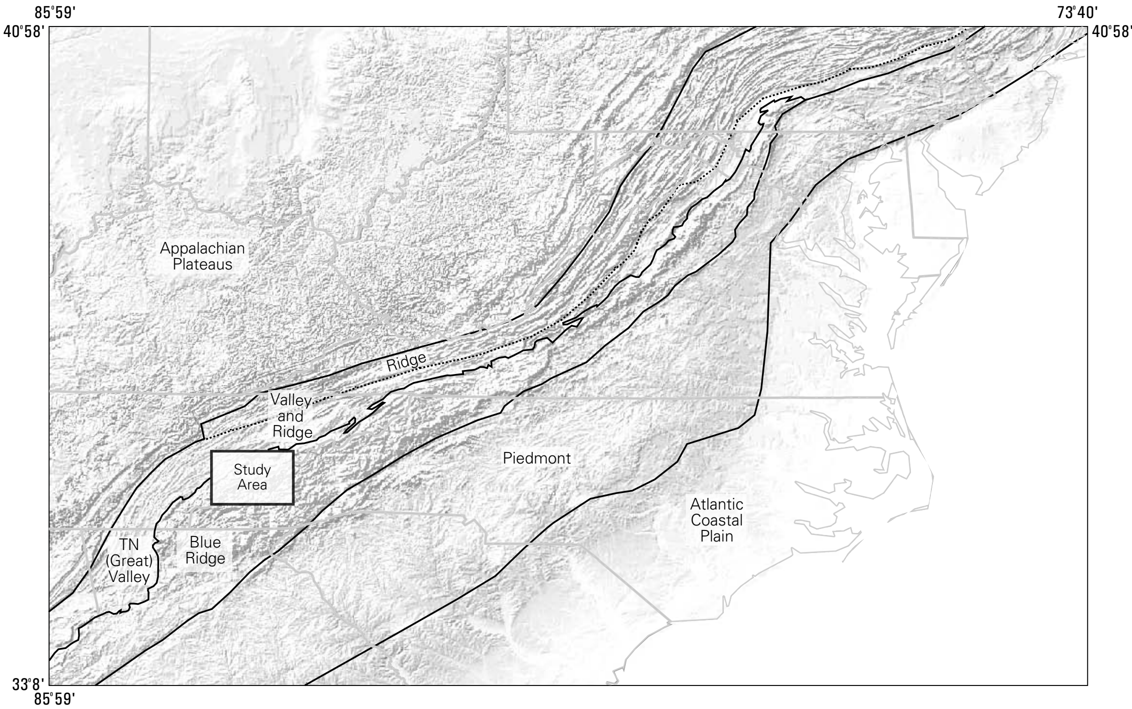

Fig. 1*A* Physiographic provinces of the Appalachian region. Study area is indicated.

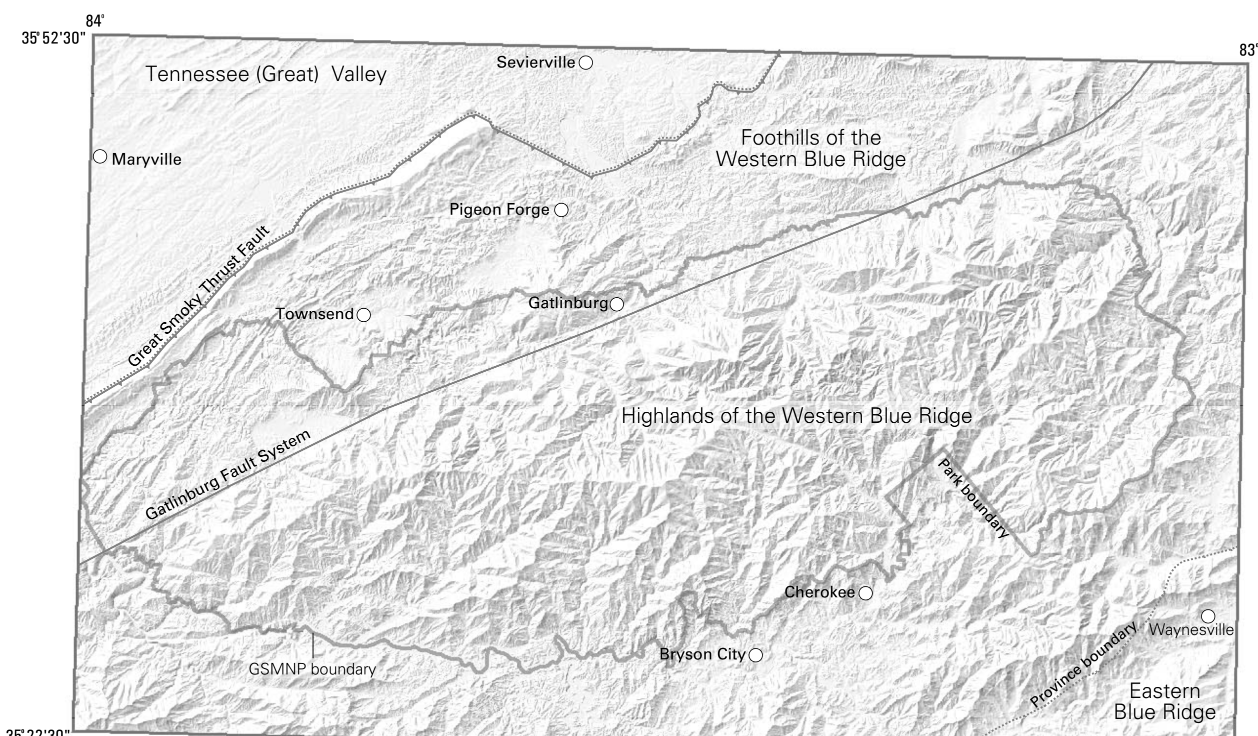

Fig. 1*B* Physiographic provinces of the study area.

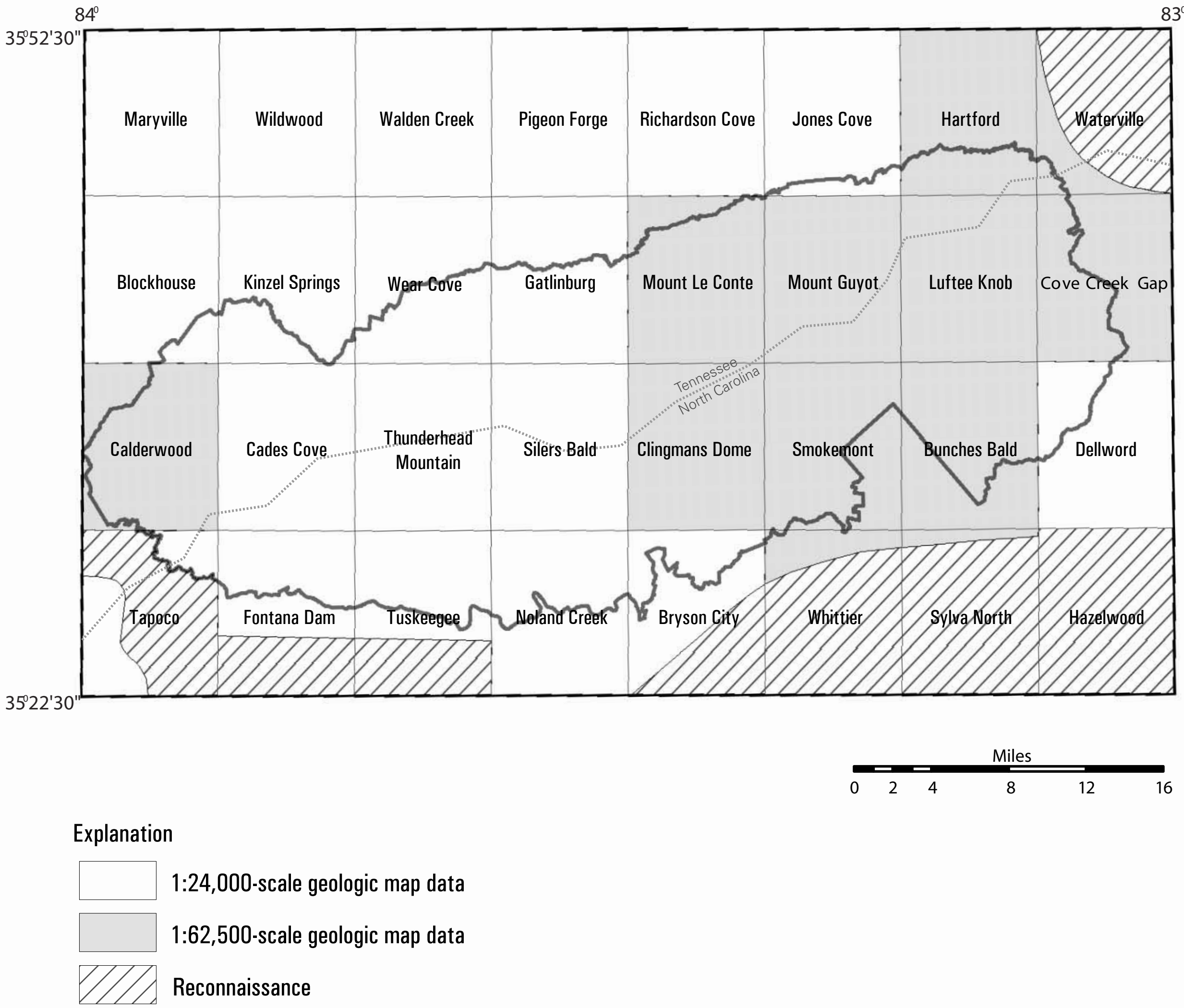

Fig. 2 Index to 7.5-minute topographic quadrangle maps and published geologic map data (see Table 1, sources of data) used in the 1:100,000-scale compilation of the Great Smoky Mountains National Park region.

Figure 3 Mafic and ultramafic rocks.

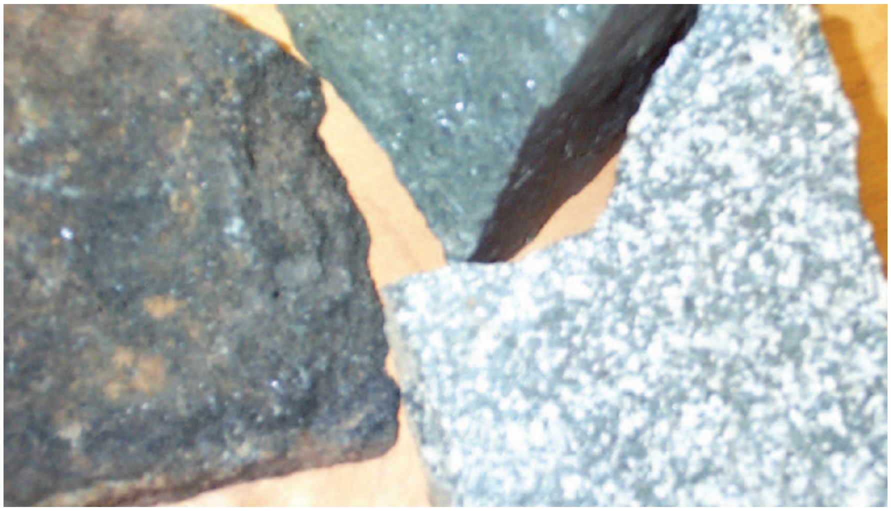

Fig. 3*A* Altered ultramafic rocks (Yu) include metagabbro and metaperidotite in the Bryson City and Smokemont, N.C., 7.5-minute quadrangles.

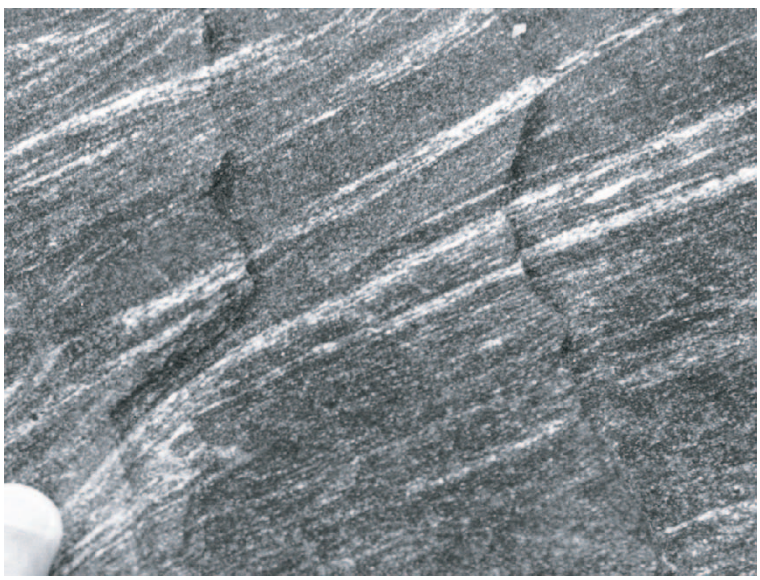

Fig. 3*B* Mafic rocks are foliated amphibolite (Ya) near Dellwood, in the Dellwood, N.C., 7.5-minute quadrangle. This photograph is of a small part of a body that is 900 ft wide and 2,000 ft long within hornblende-biotite gneiss. Fingertip for scale.

Fig. 3*C* Typical float of amphibolite that is abundant in the Raven Fork headwaters in the Bunches Bald, N.C., 7.5-minute quadrangle.

Figure 4 Paragneiss units.

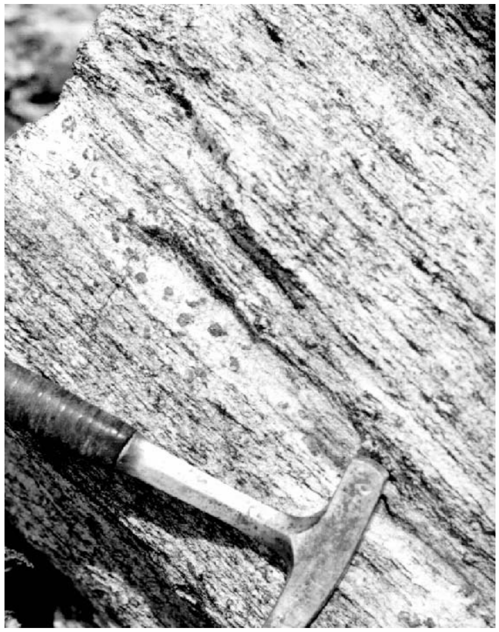

Fig. 4*A* Hornblende-biotite gneiss (Yh) with garnet-rich leucosome near Birdtown, Ela dome, in the Whittier, N.C., 7.5-minute quadrangle. Rock hammer for scale.

Fig. 4*B* Migmatitic biotite gneiss (Ym), leucocratic granitic gneiss, and amphibolite are interlayered near Bryson City in the Bryson City, N.C., 7.5-minute quadrangle. Roadcut is 60 ft high.

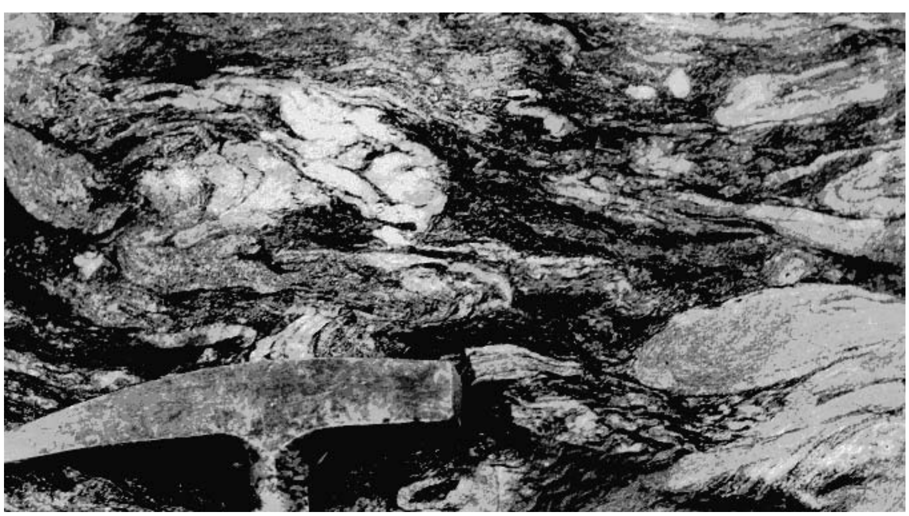

Fig. 4*C* Close-up of ***B***, showing outcrop-scale mixing. Rock hammer for scale.

Figure 5 Biotite augen gneiss (Ybg).

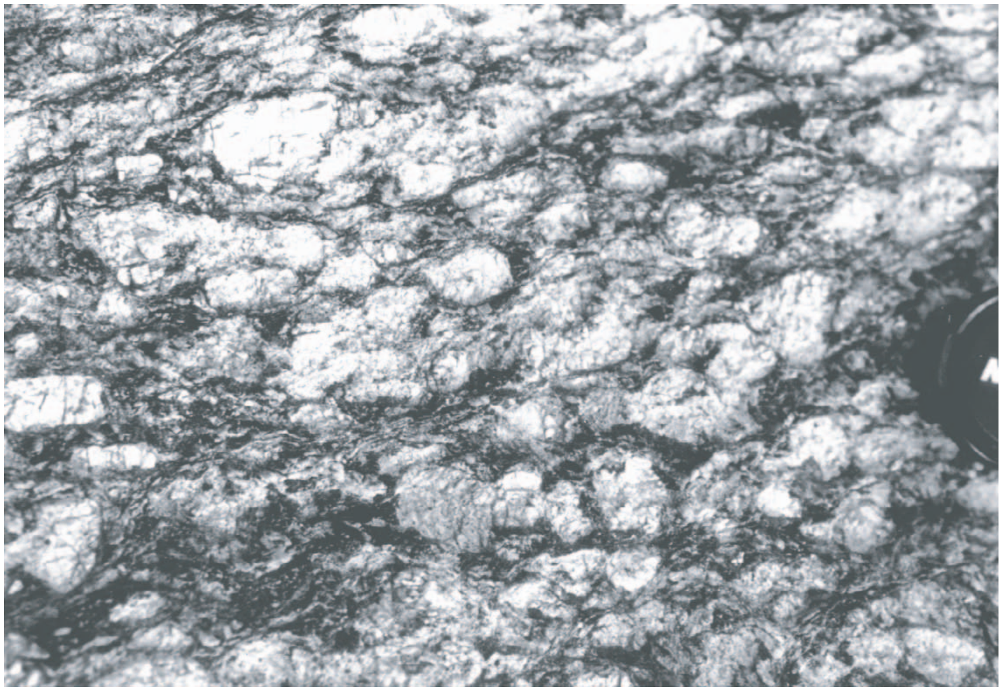

Fig. 5*A* Megacrystic biotite augen gneiss at Big Cove, N.C., yielded a SHRIMP U-Pb zircon age of 1,029 Ma (J. Aleinikoff, USGS, written commun.(19XX)), making it one of the youngest dated Grenvillian rocks in the Blue Ridge.

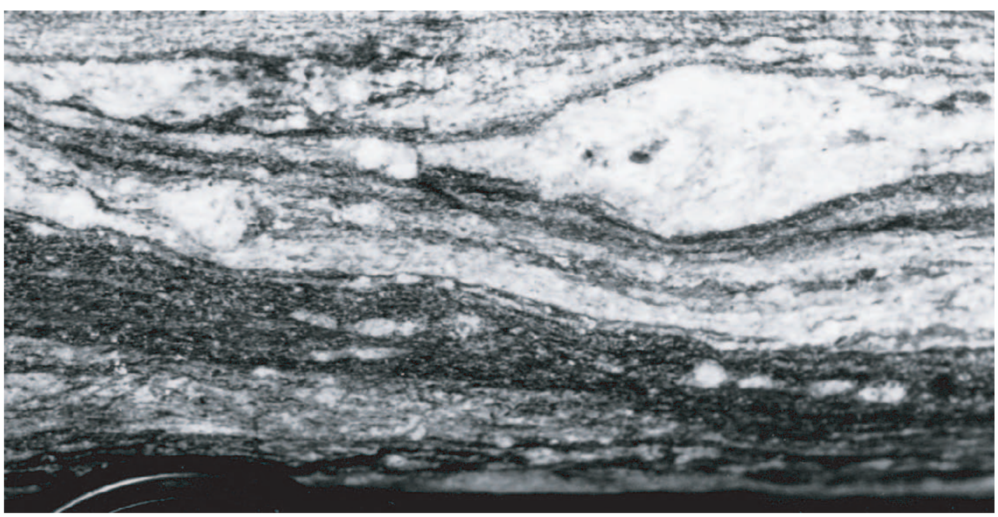

Fig. 5*B* Mylonitic biotite augen gneiss is abundant in the "gorge" of Raven Fork. Both locations are within the Smokemont, N.C., 7.5-minute quadrangle.

Figure 6 The oldest rocks of the Ocoee Supergroup are the Snowbird Group.

Fig. 6*A* The basal rocks are mostly phyllite and schist of the Wading Branch Formation (Zwb), shown here in the Smokemont, N.C., 7.5-minute quadrangle.

Fig. 6*B* In the absence of the Wading Branch Formation is the Longarm Quartzite (Zl).

Fig. 6*C* The quartzite has characteristic crossbeds, emphasized by dark blue-black heavy minerals. Both ***B*** and ***C*** are located in the Bunches Bald, N.C., 7.5-minute quadrangle.

Figure 7 Roaring Fork Sandstone (Zrf).

Fig. 7*A* Fine-grained metasandstone is interbedded with metasiltstone. Rock hammer for scale.

Fig. 7*B* The metasandstone is characterized by slump folds. Irregular partings to the left and right of hammer are folded beds. Outcrop habit is controlled by cleavage that strikes from upper left to lower right of photo. These rocks are located in the Mount Le Conte, Tenn.-N.C., 7.5-minute quadrangle.

Figure 8 Pigeon Siltstone (Zp) is transitional above rocks of the Roaring Fork Sandstone.

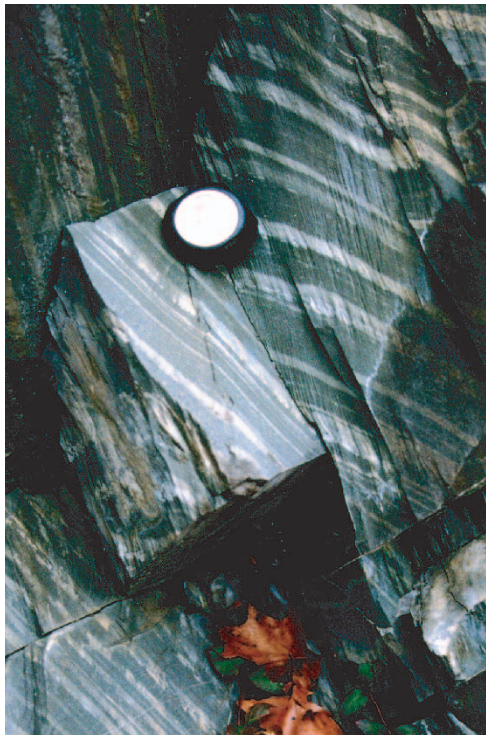

Fig. 8*A* Laminated beds and pervasive cleavage characterize the Pigeon Siltstone. Altimeter for scale.

Fig. 8*B* Some laminated beds show soft-sediment slump folds and microscopic normal faults. Outcrop is 1 ft across. These rocks are located in the Gatlinburg, Tenn., 7.5-minute quadrangle.

Figure 9 Metcalf Phyllite (Zm) was derived from shearing of the Pigeon Siltstone.

Fig. 9*A* Shear-band cleavage characterizes the Metcalf Phyllite along the Little River. An early phyllonitic foliation that is nearly horizontal is transected by later cleavage that dips to the lower left in this photograph. Looking southwest, shear sense indicators are thrust to the northwest (left to right in photo). Brunton compass for scale.

Fig. 9*B* Early laminations, parallel to edge of notebook, are vertical beds that strike north-south into the faults along the Little River. These rocks are located in the Wear Cove, Tenn., 7.5-minute quadrangle.

Fig. 10 Rich Butt Sandstone (Zrb) is transitional above Pigeon Siltstone at the east side of the park, and has characteristic laminated beds. This outcrop is in the Cove Creek Gap, N.C., 7.5-minute quadrangle. Rock hammer for scale.

Fig. 11 Elkmont Sandstone (Ze) is brownish-rusty colored medium grained, thin bedded metasandstone interlayered with dark slaty rocks, as seen in the Gatlinburg, Tenn.-N.C., 7.5-minute quadrangle. Outcrop along Little River Road is 10 ft high.

Figure 12 Thunderhead Sandstone (Zt).

Fig. 12*A* Thick beds of massive Thunderhead Sandstone form cliffs hundreds of feet high in the north-central part of the park. These are unique habitats mostly due to sprays of water. Height of cliff is about 30 ft.

Fig. 12*B* Slabs of dark slate are within metasandstone beds. They are interpreted to be ripped-up lithified shale that was deposited in the quartz and feldspar matrix with little transport. These rocks are exposed in the Mount Le Conte, Tenn.-N.C., 7.5-minute quadrangle.

Figure 13 Thunderhead Sandstone.

Fig. 13*A* Thunderhead Sandstone grades from massive and thick beds at Mount Le Conte (see fig. 12), southwestward into thin beds of sandstone interlayered with dark metasiltstone (Zts).

Fig. 13*B* The thin-bedded turbidite deposits locally have channel deposits of massive coarse sandstone.

Fig. 13*C* Conglomerate with subangular pebbles of vein quartz and leucogranite. These rocks are exposed in the Wear Cove, Tenn., 7.5-minute quadrangle.

Fig. 14 Dark rusty weathered, sulfidic metasiltstones (Zts) similar to rocks of the Anakeesta Formation are within the Thunderhead Sandstone. Some are thick enough to be portrayed on the map, like these rocks along the Appalachian Trail at Shuckstack, in the Fontana Dam, N.C., 7.5-minute quadrangle.

Figure 15 Thunderhead Sandstone locally contains beds of boulders (Ztb) that are interpreted to be submarine debris-flow deposits.

Fig. 15*A* Cobbles and boulders of leucocratic granite and quartzite in a matrix of sandstone are well exposed in the bed of Big Creek.

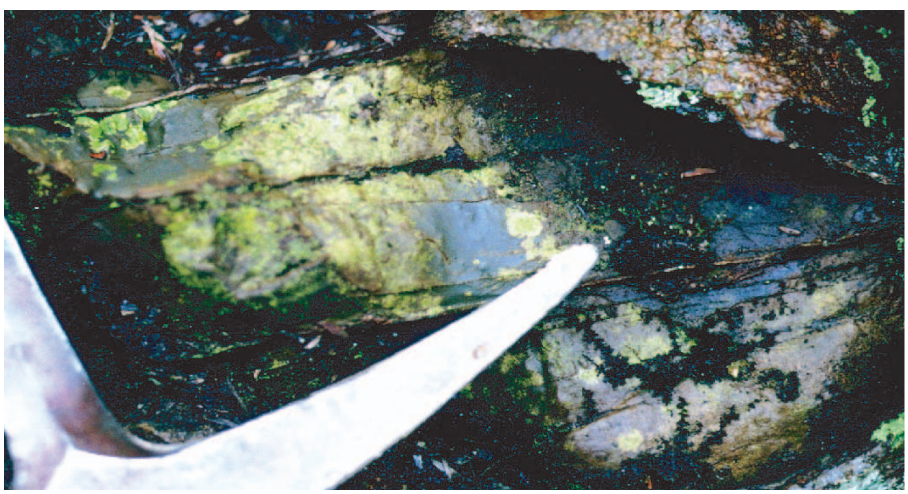

Fig. 15*B* The boulder bed contains carbonate minerals in the sandstone matrix and clasts of sandy dolomite, similar to rocks of the Anakeesta Formation. The boulder bed is exposed in the Luftee Knob, Tenn.-N.C., 7.5-minute quadrangle.

Figure 16 Metasandstone of the Cades Sandstone (Zc).

Fig. 16*A* Beds of medium-grained metasandstone interbedded with metasiltstone characterize the Cades Sandstone. Cleavage is parallel to meter-long stick in center of photo. The rocks are exposed at Abrams Falls, in the Calderwood, Tenn.-N.C., 7.5-minute quadrangle.

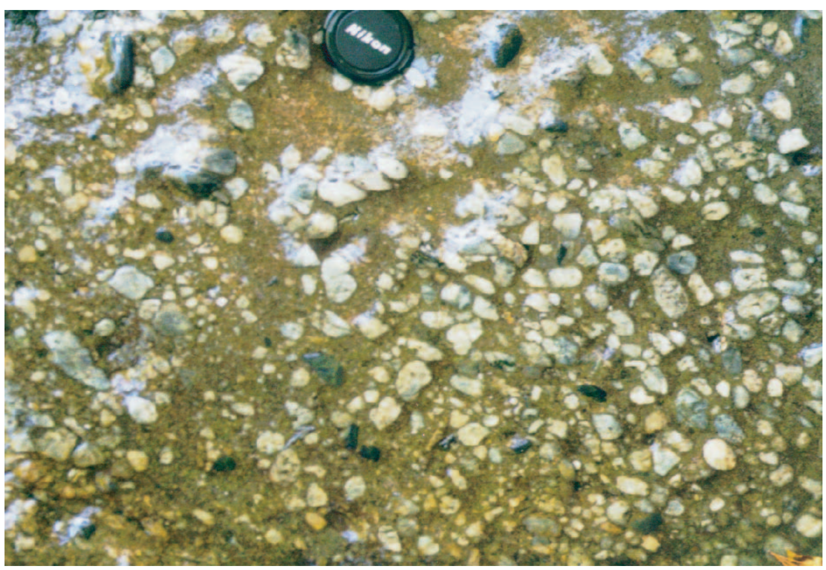

Fig. 16*B* Conglomerate within the Cades Sandstone includes pebbles of quartz and leucocratic granite, and is exposed at Ace Gap in the Kinzel Springs Tenn., 7.5-minute quadrangle. Camera lens cap is for scale.

Figure 17 Dark metasiltstone of the Cades Sandstone (Zcs).

Fig. 17*A* Metasiltstone is interbedded with metasandstone on the trail to Abrams Falls in the Cades Cove, Tenn.-N.C., 7.5-minute quadrangle. Brunton compass is for scale.

Fig. 17*B* Beds of metasandstone interbedded with rusty weathered sulfidic metasiltstone and slate along the Little River are considered to be transitional with rocks of the Thunderhead Sandstone, in the Wear Cove, Tenn., 7.5-minute quadrangle. Road cut is about 10 ft high.

Figure 18 Rusty weathered dark sulfidic slaty rocks of the Anakeesta Formation (Za).

Fig. 18*A* Slate, sandy slate, and metasandstone exposed in a roadcut near Newfound Gap. Roadcut is about 10 ft high.

Fig. 18*B* Metasiltstone exposed at the parking area at Newfound Gap, in the Clingmans Dome, Tenn.-N.C., 7.5-minute quadrangle. Roadcut is about 20 ft high.

Figure 19 Metasandstone interbedded with dark slaty rocks of the upper part of the Anakeesta Formation (Zag).

Fig. 19*A* Southeast-dipping beds at the intersection of Route 441 and the road to Clingmans Dome. Stop sign in lower center for scale.

Fig. 19*B* Interbeds of metagraywacke and metasandstone near the top of the formation. Mile marker 10, Route 411, northeast of Newfound Gap, in the Clingmans Dome, Tenn.-N.C., 7.5-minute quadrangle.

Figure 20 Chloritoid slate of the Anakeesta Formation (Zac).

Fig. 20*A* Modern debris flows near Mount Le Conte expose chloritoid slate (light-colored as opposed to dark graphitic slate).

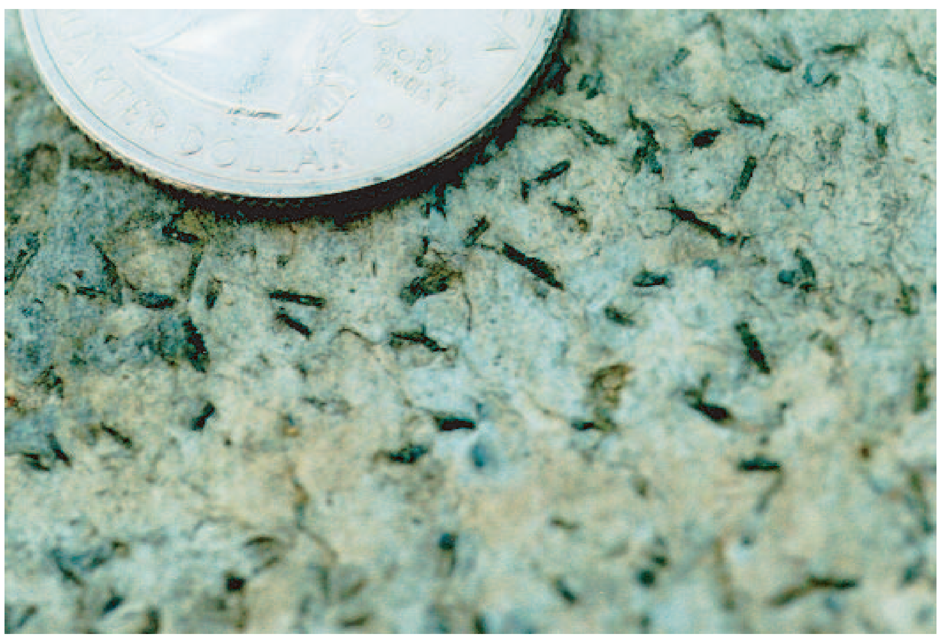

Fig. 20*B* Close-up of chloritoid slate showing dark crystals of chloritoid that are randomly oriented in a matrix of fine quartz. Quarter provides scale. These rocks are exposed in the Mount Le Conte, Tenn.-N.C., 7.5-minute quadrangle.

Fig. 21 At the base of the Anakeesta Formation near Thunderhead Mountain is ankeritic metasandstone (Zas), with voids that were concretions of carbonate Thunderhead Mountain, Tenn.-N.C., 7.5-minute quadrangle. Page-size notebook for scale.

Figure 22 Dolomite of the Anakeesta Formation (Zal).

Fig. 22*A* Thin beds of sandy dolomite within graphitic slate of the Anakeesta Formation have diagnostic dissolution texture of the carbonate rock.

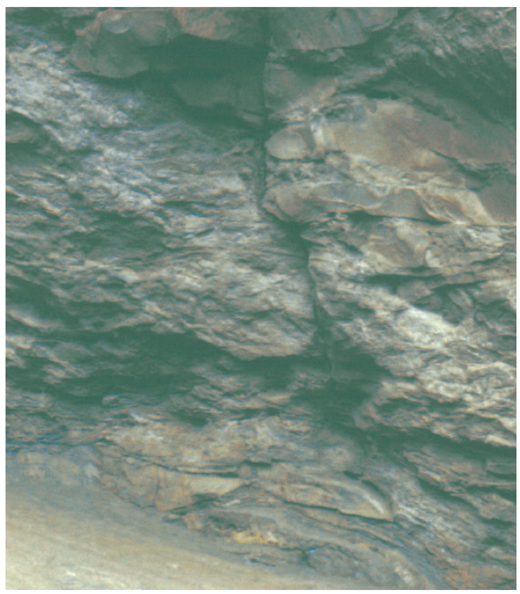

Fig. 22*B* Pods of sandy dolomite occur within the slaty rocks exposed in the bluff at Alum Cave.

Fig. 22*C* Pisolitic dolomite on Mount Le Conte may be algae or inorganic precipitate (Hadley and Goldsmith, 1963). These rocks are exposed in the Mount Le Conte, Tenn.-N.C., 7.5-minute quadrangle.

Figure 23 Turbidite deposits of metagraywacke interbedded with metasiltstone and schist characterize the rocks of the Copperhill Formation (Zch).

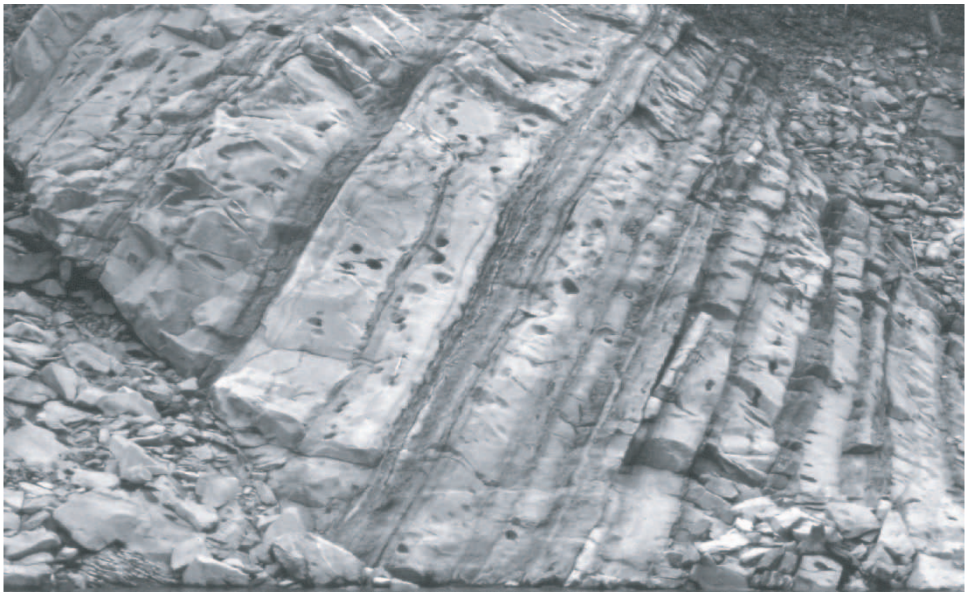

Fig. 23*A* Moderately thick beds of metagraywacke along Fontana Lake. Outcrop is about 12 ft high. Holes in the rock the size of baseballs are weathered calcareous concretions (granofels, pseudodiorite), similar to those in the Thunderhead Formation. These rocks are exposed in the Tuckasegee, N.C., 7.5-minute quadrangle.

Fig. 23*B* Thin metasandstone and metagraywacke beds interbedded with schist in the Copperhill Formation on the northern end of the Bryson City dome, Bryson City, Tenn.-N.C., 7.5-minute quadrangle. Height of outcrop is 3 ft.

Figure 24 Dark slaty metasiltstone of the Copperhill Formation (Zchsl).

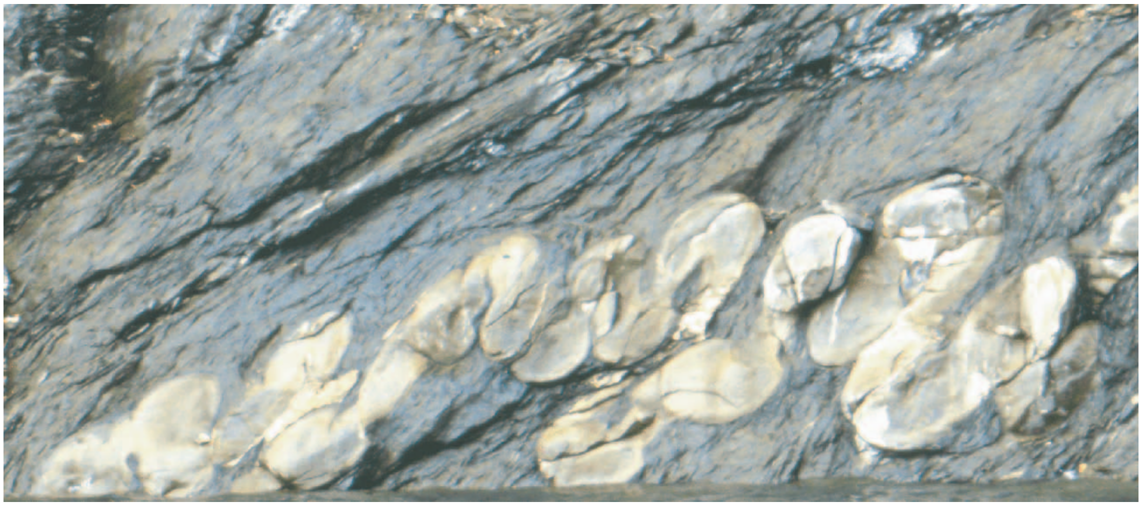

Fig. 24*A* Slaty metasiltstone that resembles rocks of the Anakeesta Formation has metasandstone beds. The 1-ft-thick beds here are folded.

Fig. 24*B* Metasiltstone with soft-sediment slump folds also resembles metasiltstone of the Anakeeesta Formation. This exposure is in the Fontana Dam, Tenn.-N.C., 7.5-minute quadrangle. Rock hammer for scale.

Figure 25 Quartz-muscovite schist of the Copperhill Formation (Zchs).

Fig. 25*A* Typical outcrop is dominated by schistosity. Appalachian Trail, Clingmans Dome, Tenn.-N.C., 7.5-minute quadrangle. Walking stick in center of photo is 3 ft long.

Fig. 25*B* Schistosity dips parallel to the crack in the rock that is about 3 ft long. Note slight color variation, interpreted to be beds, dipping at a lower angle to the lower right.

Fig. 25*C* Compositional layers that are bedding trends from the upper left to lower right of the photo. Cleavage transects from left to right. Tip of compass for scale.

Fig. 25*D* Close-up of schist shows garnets (dark) about 0.5 mm across, with thumbnail for scale. These rocks are exposed in the Tuckasegee, Tenn.-N.C., 7.5-minute quadrangle.

Figure 26 Rocks of the Wehutty Formation (Zwe) in the Murphy synclinorium.

Fig. 26*A* Dark graphitic and sulfidic schist with crystals of kyanite as much as 10 cm long is exposed along Lakeshore Drive. Beds dip to the lower left of photo; cleavage dips to lower right. Brunton compass for scale.

Fig. 26*B* Metasandstone and metaconglomerate beds within the schist dip to the lower right of the photo. Roadcut is about 10 ft high and is located in the Bryson City, Tenn.-N.C., 7.5-minute quadrangle.

Figure 27 Conglomerate of the Shields Formation (Zs).

Fig. 27*A* Quartz-pebble conglomerate is exposed along Abrams Creek, in the Calderwood, Tenn.-N.C., 7.5-minute quadrangle. Altimeter for scale.

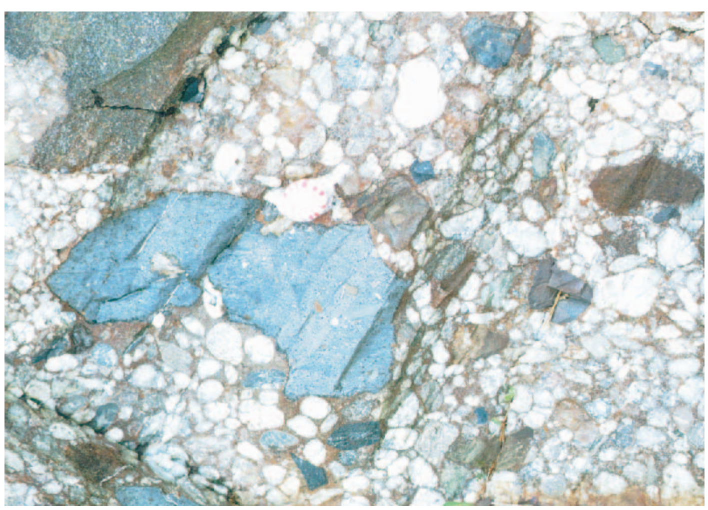

Fig. 27*B* Polymictic conglomerate showing pebbles of white vein quartz, dark quartzite (brown), and gray limestone, along Chilhowee Lake in the Tallassee, Tenn., 7.5-minute quadrangle. Outcrop is about 1 ft across.

Figure 28 Metasiltstone of the Wilhite Formation (Zw).

Fig. 28*A* Folded metasiltstone on the east bank of Abrams Creek along Chilhowee Lake. Rock hammer in right center of photo for scale.

Fig. 28*B* Close-up shows well-developed cleavage transecting folds. Dark layers are rich in ankerite, and light layers are rich in quartz.

Fig. 28*C* Thin beds of metasandstone outline isoclinal folds in the metasiltstone. This outcrop in the Calderwood, Tenn.-N.C., 7.5-minute quadrangle is about 20 ft across.

Figure 29 Limestone of the Wilhite Formation (Zwl) has been interpreted to be blocks deposited in mud.

Fig. 29*A* Large block (100 m by 1 km) of dark carbonaceous thin-bedded limestone exposed along the Foothills Parkway, immediately west of the map area. Rock hammer in right center of photo for scale.

Fig. 29*B* Breccia of limestone clasts within matrix of sandy limestone.

Fig. 29*C* Small block of limestone in shale exposed along the road adjacent to Chilhowee Lake. The limestone is tablet-shaped due to folding within shale. Cleavage trends from upper right to lower left.

Fig. 29*D* Meter-long block of dolomite in shale. These rocks are exposed in the Calderwood, Tenn.-N.C., 7.5-minute quadrangle.

Figure 30 Nebo Quartzite (Cnb).

Fig. 30*A* Cliffs of thin-bedded quartzite beds of the upper part of the Chilhowee Group underlie Buzzard Roost on Stone Mountain in the Hartford, Tenn.-N.C., 7.5-minute quadrangle. Relief of ridge in photo is about 1,000 ft.

Fig. 30*B* Nebo Quartzite has pink lines (perpendicular bedding) and circles on the bedding surface that are trace fossil "worm" burrows called *Skolithos linearis*, on Chilhowee Mountain in the Walden Creek, Tenn., 7.5- minute quadrangle.

Figure 31 Murray Shale (Cm) along roadcut of Foothills Parkway near Look Rock.

Fig. 31*A* Fissile shale dips to the lower right of photo.

Fig. 31*B* Thin beds of sandstone occur within the shale, just as thin beds of shale also occur within the overlying quartzite units. Outcrop is at Chilogatee Gap in the Blockhouse, Tenn., 7.5-minute quadrangle.

Fig. 32 Southeast-dipping beds of Hesse Quartzite (Ch) form the dip slope to the homoclinal ridge of Chilhowee Mountain, where the Foothills Parkway transects it. Pine trees thrive in cracks in the rocks that are well drained and acidic. Rock hammer in lower center of photo for scale.

Fig. 33 Southeast-dipping beds of Shady Dolomite (Cs) on the northwest limb of the syncline at Miller Cove are exposed on the westside of Route 73/321, near the entrance to the Foothills Parkway in the Kinzel Springs, Tenn., 7.5-minute quadrangle. Height of roadcut is about 25 ft.

Figure 34 Hornblende crystals in metadiabase.

Fig. 34*A* Metadiabase dikes (Pzd) intrude the rocks of the Ocoee Supergroup. Boulder of metadiabase used in the foundation of the Hall Cabin, Bone Valley, shows diagnostic knobby texture of coarse dark crystals of hornblende, in the Thunderhead Mountain, Tenn.-N.C., 7.5-minute quadrangle. Block is about 1 ft high.

Fig. 34*B* Equigranular crystals of hornblende and plagioclase distinguish stream-rounded specimens of metadiabase (lower) from conglomeratic rocks of the Thunderhead Sandstone (upper), in the Wear Cove, Tenn., 7.5-minute quadrangle. Thumb for scale.

Figure 35 Altered metadiabase (Pzd).

Fig. 35*A* Foliated greenstone with large body of epidote and quartz (epidosite). Rock hammer for scale.

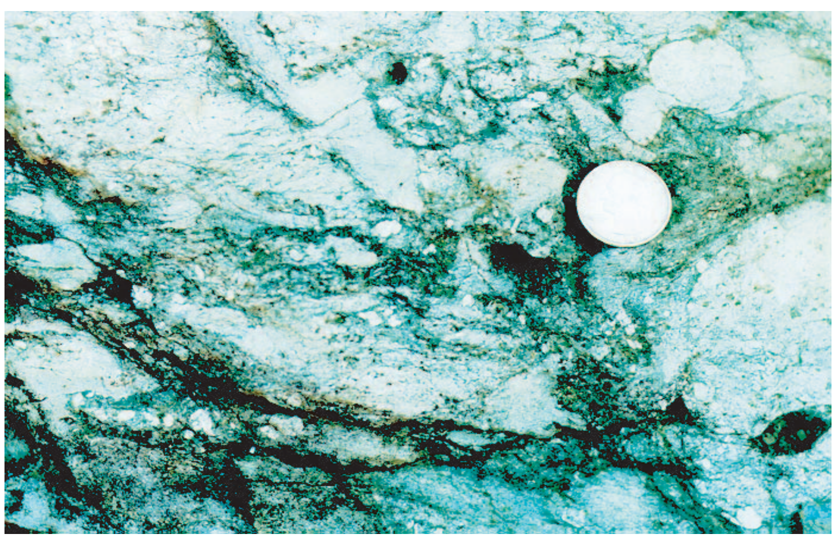

Fig. 35*B* Light-gray fragmental rock along Ecoah Branch, with large feldspar phenocrysts and microbreccia. Fontana Dam, N.C., 7.5-minute quadrangle. Quarter provides scale.

Fig. 36 Pegmatite of quartz, plagioclase, and muscovite (Pzp) intrudes rocks of the Copperhill Formation. Large bodies of pegmatite were mined for feldspar (white), northwest of Bryson City in the Whittier, N.C., 7.5-minute quadrangle. Black biotite crystals at end of hammer head.

Figure 37 Vein quartz intrudes virtually all of the metamorphic rocks.

Fig. 37*A* Southeast-facing view of quartz veins (white lenses) that intrude slate of the Copperhill Formation along Fontana Lake. Outcrop is about 60 ft above lake level, and is located in the Fontana Dam, N.C., 7.5-minute quadrangle.

Fig. 37*B* Vein quartz that intruded a bed of slate within the Thunderhead Sandstone has been folded. Brunton compass provides scale. The rocks are exposed in the Mount Le Conte, Tenn.-N.C., 7.5-minute quadrangle.

Fig. 37*C* Large boulders of white vein quartz are common where fine-grained rocks have been sheared. Boulder left of center is 15 ft in diameter. Photograph is along Little River in the Thunderhead Mountain, Tenn.-N.C., 7.5-minute quadrangle.

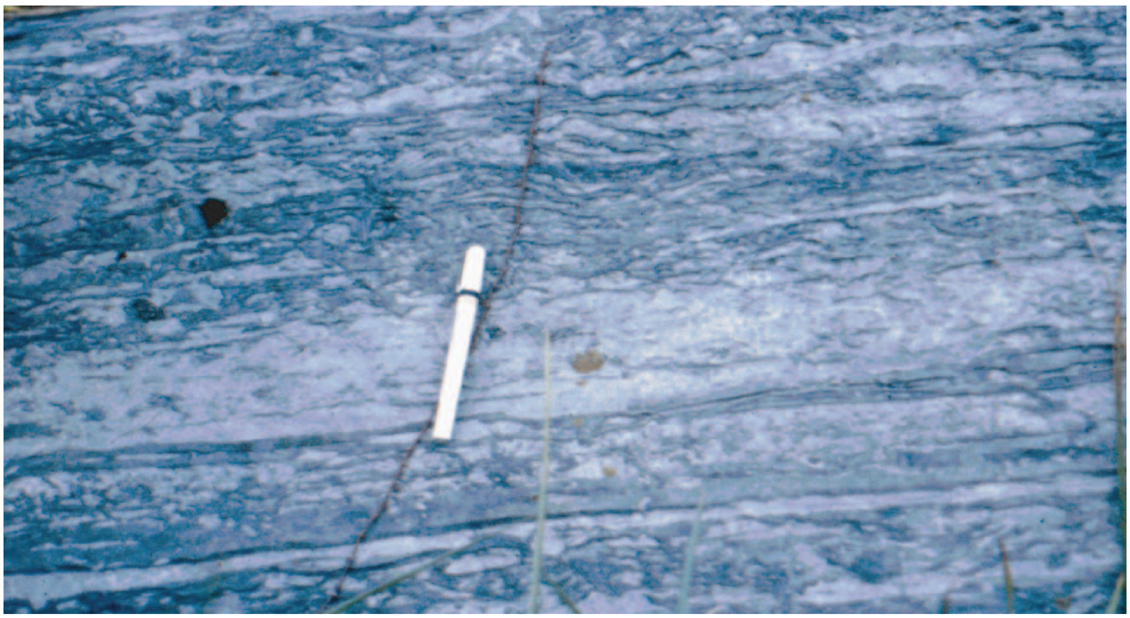

Fig. 38 Laminated and thin-bedded limestone and chert of the Jonesboro Limestone (Oj) exposed on the north side of Cades Cove in the Cades Cove, Tenn.-N.C., 7.5-minute quadrangle. Dark layers are clay and chert horizons within light-gray limestone. Pen is for scale.

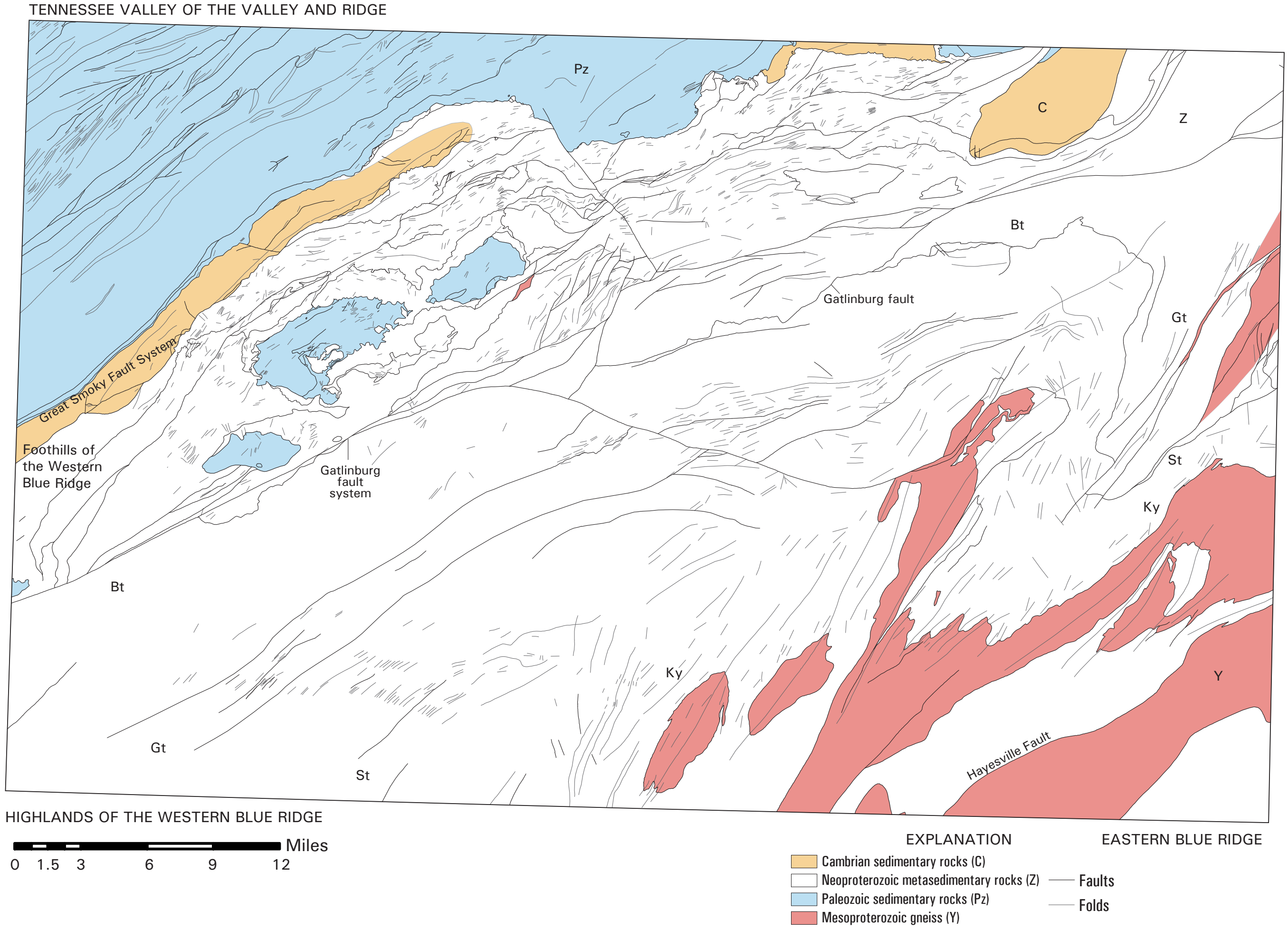

Fig. 39 Summary tectonic map of the study area showing major faults, folds, and metamorphic isograds. Bt, biotite; Gt, garnet; St, staurolite; Ky, kyanite. The biotite isograd is coincident with the Gatlinburg fault system. Rocks north of the Gatlinburg fault system are chlorite grade, if metamorphosed at all.