National Park Service
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Natural Resource Program Center

Great Smoky Mountains National Park

Geologic Resource Evaluation Report

Natural Resource Report NPS/NRPC/GRD/NRR—2008/048

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Geologic Resources Division
Natural Resource Program Center
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COVER: Cades Cove, Great Smoky Mountains NP
INSIDE COVER: Snowy Stream, Great Smoky Mountains NP

NPS Photos, cover photo by Kevin Noon

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Executive Summary

This report accompanies the digital geologic map for Great Smoky Mountains National Park in North Carolina and Tennessee, which the Geologic Resources Division produced in collaboration with its partners. It contains information relevant to resource management and scientific research.

The Great Smoky Mountains are among the oldest mountains in the world and the highest in the Appalachian Mountain chain. These peaks and ridges have been both a daunting obstacle and a source of inspiration since the earliest people set foot in the area. Long before humans arrived, geologic processes, climatic shifts, weather, and fire shaped this environment, producing a dynamic ecosystem.

Great Smoky Mountains National Park reflects the interaction between humans and geology. The experience of the park begins with its geology—processes that established the foundation from which today's environments, history, and scenery arise. Knowledge of the geologic resources is necessary for effective decisions about ecosystem management; research, inventory, and monitoring programs; interpretive needs; and construction and maintenance activities.

Geologic processes give rise to rock formations, mountains and valleys, waterfalls, and lakes. These processes develop a landscape that influences human use patterns. The geology attracted indigenous peoples and European settlers to the Great Smoky Mountains area for hunting, mining, settlement, agriculture, and industry. The geology of the park inspires wonder in visitors (over 9.3 million in 2007). Emphasis on geologic resources should be encouraged to enhance the visitor's experience.

Great Smoky Mountains National Park also serves to preserve a piece of Appalachian history. Buildings, bridges, churches, schools, farms, mills, and fields reflect the rich historical tradition of the area. Some of the principal geologic issues and concerns pertain to protecting these features. Humans have significantly modified the landscape surrounding Great Smoky Mountains, and consequently have modified its geologic system. This system is dynamic and capable of noticeable change within a human life span. Park resource managers face continuing challenges as human-induced change combines with the park's dynamic natural geological processes.

Air and water pollution and the introduction of non-native species have also had a significant impact on the natural resources at Great Smoky Mountains National Park. Park visitors create further impacts that are only beginning to be measured and alleviated. Researchers are striving to better understand these impacts on the park's ecosystem.

The following issues were identified as significant for geologic resource management:

- Erosion and Slope Processes
  A wet climate and steep slopes make the Great Smoky Mountains susceptible to slumping and landslide problems. This is especially true in areas where a lack of stabilizing plant growth combines with substantial seasonal runoff and intense rainstorms. Slope failures can dramatically alter the landscape, creating new hazard areas in the process. Road and trail construction also impacts slope stability.
- Abandoned Mine Lands
  Two copper mines operating in the park produced more than 83 million pounds of copper from 1926 to 1944. Although there is no active mining in the park today the abandoned mine workings pose an environmental and human safety threat.
- Biodiversity and Geology
  The park is famous for its biodiversity, which is a direct result of the geology and climate of the area. During the cooler ice age periods, northern species migrated south; when the climate warmed, they found suitable habitat in the high elevations of the Great Smoky Mountains. Certain geologically influenced environments, such as rockfalls and cliff faces, provide habitats that support specialized micro-ecosystems that include rare and endemic species. Locating and managing these species, as well as understanding the relationships between geology and biology throughout the park, remain key resource management issues.
- Historical Landscapes
  Great Smoky Mountains National Park works to preserve a context through which visitors may gain insight into the rich history of the southern Appalachians. Geology played a significant role in shaping that history. For example, at Cades Cove, the limestone valley floor created fertile soils for agriculture.

  Geologic activity can also compromise human made structures and the preserved historical context. Weathering and erosion are relentlessly changing the landscapes of all historic areas.

Paleontological potential, water quality and quantity, air quality, recreational demands, and a variety of other geologic and ecosystem concerns, were also identified as critical management issues for Great Smoky Mountains National Park. These are described in the *Geologic Issues* section of this report.

Introduction

The following section briefly describes the National Park Service Geologic Resource Evaluation Program and the regional geologic setting of Great Smoky Mountains National Park.

Purpose of the Geologic Resource Evaluation Program

The Geologic Resource Evaluation (GRE) Program is one of 12 inventories funded under the NPS Natural Resource Challenge designed to enhance baseline information available to park managers. The program carries out the geologic component of the inventory effort from the development of digital geologic maps to providing park staff with a geologic report tailored to a park's specific geologic resource issues. The Geologic Resources Division of the Natural Resource Program Center administers this program. The GRE team relies heavily on partnerships with the U.S. Geological Survey, Colorado State University, state surveys, and others in developing GRE products.

The goal of the GRE Program is to increase understanding of the geologic processes at work in parks and provide sound geologic information for use in park decision making. Sound park stewardship relies on understanding natural resources and their role in the ecosystem. Geology is the foundation of park ecosystems. The compilation and use of natural resource information by park managers is called for in section 204 of the National Parks Omnibus Management Act of 1998 and in NPS-75, Natural Resources Inventory and Monitoring Guideline.

To realize this goal, the GRE team is systematically working towards providing each of the identified 270 natural area parks with a geologic scoping meeting, a digital geologic map, and a geologic report. These products support the stewardship of park resources and are designed for non-geoscientists. During scoping meetings the GRE team brings together park staff and geologic experts to review available geologic maps and discuss specific geologic issues, features, and processes.

The GRE mapping team converts the geologic maps identified for park use at the scoping meeting into digital geologic data in accordance with their innovative Geographic Information Systems (GIS) Data Model. These digital data sets bring an exciting interactive dimension to traditional paper maps by providing geologic data for use in park GIS and facilitating the incorporation of geologic considerations into a wide range of resource management applications. The newest maps come complete with interactive help files. As a companion to the digital geologic maps, the GRE team prepares a park-specific geologic report that aids in use of the maps and provides park managers with an overview of park geology and geologic resource management issues.

For additional information regarding the content of this report and up to date GRE contact information please refer to the Geologic Resource Evaluation Web site (http://www.nature.nps.gov/geology/inventory/).

Geologic Setting

Biological diversity is everywhere in Great Smoky Mountains National Park. The park was established on June 15, 1934, to protect and preserve a unique environment for future generations. More than 10,000 species have been documented in the park and additional tens of thousands are thought to exist there. The geologic history of the area, including the interaction of its mountains, glaciers, and climate, is a primary reason for such biodiversity.

In recognition of the unique natural resources at the park, the United Nations designated Great Smoky Mountains National Park as International Biosphere Reserve in 1976. The park was also named as a World Heritage Site on December 6, 1983. These designations complement the mission of the National Park Service to preserve and protect natural areas.

At 521,495 acres, the park is the largest upland landmass under federal protection east of the Mississippi River. The crest of the Great Smoky Mountains forms the boundary between Tennessee and North Carolina. This boundary bisects the park from northeast to southwest in an unbroken mountain chain that rises more than 1,500 m (5,000 ft) for more than 58 km (36 mi).

The elevations in the park range from 267 m (875 ft) to 2,025 m (6,643 ft) at Clingmans Dome. There are sixteen peaks rising more than 1,500 m (5,000 ft). Mount LeConte rises more than 1,615 m (5,300 ft) from its lowest to highest point, making it the tallest single mountain, but not the highest maximum elevation in the eastern United States. The diversity in microclimates and flora and fauna caused by this range in elevation is peculiar to the Smoky Mountains. The change in altitude mimics the latitudinal changes from south to north across the eastern United States.

The Great Smoky Mountains formed approximately 200–300 million years ago (Ma). The Great Smoky Mountains were not extensively glaciated during the last ice age, 10,000 years ago. However, the area of the present-day park became a refuge for many species of plants and animals that were displaced from their northern homes due to the glaciation north of the park.

The Great Smoky Mountains are only a small portion of the southern reaches of the Appalachian Mountains. The Appalachian Mountains, a belt of folded and faulted rocks, extends more than 3,200 km (2,000 mi) from Maine to Georgia. These are among the oldest mountains in the world and once resembled the rugged peaks of the Rocky Mountains in the western United States. For millions of years the erosive forces of wind, rain, and freezing and thawing have whittled away the once craggy peaks.

The Appalachians contain several physiographic provinces including (from east to west) the Piedmont, the Blue Ridge, Valley and Ridge, and the Allegheny Plateau. The Great Smoky Mountains occupy approximately 3,900 square kilometers (1,500 square mi) in the Blue Ridge physiographic province. Within the Blue Ridge, the Great Smoky Mountains are a geologically distinct subdivision that combines several aspects of the Blue Ridge, Piedmont, and Valley and Ridge Provinces described below.

The shared geologic characteristics include exposure of Grenville age (~1.1 billion years old) gneisses such as are found in the Blue Ridge Province; younger sedimentary and metasedimentary rocks ranging up to highly metamorphosed rocks, like those in the Piedmont Province to the east; and folded and faulted rocks, as occur in the Valley and Ridge Province to the west.

Thus, the deformational style of the Great Smoky Mountains is transitional between that of the crystalline Appalachian provinces (Piedmont and Blue Ridge), and the sedimentary Appalachian Valley and Ridge and Cumberland Plateau (far to the west as part of the Allegheny Plateau Province) (DeWindt 1975).

Piedmont Province

The "Fall Line" or "Fall Zone" marks a transitional zone where the softer, less consolidated sedimentary rocks of the Atlantic Coastal Plain to the east intersect the harder, more erosion resistant crystalline metamorphic rocks to the west, forming an area of ridges, waterfalls, and rapids on regional rivers. The Piedmont physiographic province encompasses the Fall Line, westward to the Blue Ridge Mountains (Harris et al. 1997).

The eastward-sloping Piedmont was formed through a combination of folding, faulting, uplift, and erosion. These processes resulted in a landscape of gently rolling hills starting at 60 m (200 ft) in elevation that become gradually steeper toward the western edge of the province at 300 m (1,000 ft) above sea level. Soils in the Piedmont are highly weathered and generally well drained.

Blue Ridge Province

The Blue Ridge Province, located along the eastern edge of the Appalachian Mountains, includes the highest elevations in Great Smoky Mountains National Park. Precambrian and Paleozoic igneous and metamorphic rocks were uplifted during several mountain building events that formed the steep terrain. Resistant Cambrian age quartzites form ridges, whereas Precambrian metamorphic rocks underlie the valleys (Nickelsen 1956).

The Blue Ridge Province is generally characterized by steep terrain covered by thin, shallow soils, resulting in rapid runoff and low ground-water recharge rates.

Valley and Ridge Province

The landscape of the Valley and Ridge physiographic province is characterized by long, parallel ridges generally of resistant sandstone, separated by valleys underlain by more easily eroded shale and carbonate rocks. Areas dominated by carbonate rocks exhibit karst topography. Karst is a term used to describe landscapes dotted by sinkholes, caves, and caverns.

Geologic Issues

A Geologic Resource Evaluation scoping session was held for Great Smoky Mountains National Park on May 8–9, 2000, to discuss geologic resources, address the status of geologic mapping, and assess resource management issues and needs. This section synthesizes the scoping results, in particular those issues that may require attention from resource managers.

Erosion and Slope Processes

Geologic hazards are a concern at Great Smoky Mountains National Park, particularly for landslides and debris flows that could impact park visitors, staff, neighbors, roads, and other infrastructure in the wet, mountainous environment.

Seismic activity in the region is infrequent. However, the area is considered relatively high-risk because of its location east of the New Madrid fault zone in Missouri. The USGS/NEIC Preliminary Determinations of Epicenters (PDE) catalog displays maps of seismic activity in the area. Since 1990, at least seven local earthquakes have been recorded. Despite the slight chance of a large earthquake, the effects of even a moderate seismic event on the steep slopes of the park could be significant. Seismic stations in the area are sparse, so one or more seismometers have been recommended for the park. The University of Kentucky has a website on earthquake activity in the region at: http://tanasi.gg.utk.edu/quakes.html (Accessed August 2008).

The topographic differences in the Great Smoky Mountains National Park can be quite large. The likelihood of landslides increases with precipitation and undercutting of slopes by roads, trails, and other development in addition to natural erosion. Many trails in the park lead visitors through spectacular river, wetland, mountain, and forest scenery. These trails are at risk for rockfall and landslides while less visited areas of the park are also impacted by natural slope processes. Topography, geology, and climate data can be used to model and map the relative potential (risk) for landslide occurrence in the park.

The walls of many river and tributary valleys at the park form steep slopes, rendering them susceptible to rock falls, landslides, slumps, and slope creep. Although slope stability is a particular concern in the weaker rock units such as shales and mudstones, stronger rock units such as sandstones and metamorphic rocks, are often highly fractured in the park, making them a rockfall hazard. Wedge failures may occur because of the intersection of two planes of weakness in the bedrock, producing a wedge-shaped scar (Moore 1988).

Similarly, slumps and other forms of slope failure are common for rock units that are not necessarily associated with cliffs. Unconsolidated alluvial deposits for instance, are especially vulnerable to failure when exposed on a slope. Heavy rainstorms, common in the park, can quickly saturate valley slopes. On slopes, which lack stabilizing vegetation, rock and soil may mobilize and slide downhill resulting in a massive slump or debris flow.

Inventory, Monitoring, and Research Suggestions for Seismicity, Erosion, and Slope Processes

- Work with the GRD Disturbed Lands Restoration team to develop an appropriate monitoring strategy for potential geologic hazard areas and to develop appropriate restoration plans where needed.
- Monitor runoff in flood-susceptible areas; relate to climate and confluence areas.
- Establish working relationships with the North Carolina, Tennessee, and U.S. Geological Surveys to study and monitor the park's watershed, fracture systems, and the hydrology of the area for applications in hydrogeology, landsliding, and other geologic hazards.

Abandoned Mine Lands

The Eagle Creek and Sugar Fork Mines were active copper mines in the park from the 1920s through the 1940s. These substantial mining operations, located in the remote southwestern section of Great Smoky Mountains National Park, produced more than 83 million pounds of copper from 1926 to 1944. Although no active mining takes place in the park today, the abandoned mine workings pose considerable environmental and human safety issues (John Burghardt GRD, personal communication 2008).

Sugar Fork is a first order stream that runs directly through the mine tailings of the Sugar Fork Mine along a 100 meter stretch of the stream with more than 3,000 m2 (0.74 acres) of mine waste visible along the stream. Toxicity effects from these mining operations were informally observed by mining reclamation specialists from GRD in 1992 and 2000. Both inspections noted that the stream displays areas devoid of vegetation and aquatic life close to one kilometer from the source material. The abandoned Eagle Creek Mine is located on an ephemeral feeder stream to Eagle Creek that flows past the mine adits. The Eagle Creek Mine ultimately receives drainage from mine associated seeps. Heavy metal contamination and acid mine drainage are both possible impacts to the local streams that may require remediation to protect vegetation, wildlife, and drinking water supplies (John Burghardt GRD, personal communication 2008).

Both mines are partially fenced off; however, there are large adits and other access points that pose potential health and safety risks to park staff and visitors. The Eagle Creek and Sugar Fork Mines receive considerable but unmeasured visitation as a result of their relative isolation and lack of well defined and maintained access. Park visitors and staff are at risk when visiting or working around the unprotected and inadequately protected mine openings. Safety is increasingly compromised as the rock and mine workings deteriorate through time. Rotten and collapsed timbers, which once supported mine roofs, along with several feet of boulders from roof collapses attest to the deteriorating conditions in the mines (John Burghardt GRD, personal communication 2008).

After inspecting the sites in September 2000, the NPS GRD produced a report with the concurrence of the park, FWS, and North Carolina Wildlife Resources Commission, recommending the instillation of new closures for these mines. The proposed closures include corrosion-resistant, stainless steel bat gates, and heavy-duty, professionally installed fencing at several mine entrances and numerous subsidence areas. Blasting is the recommended closure method at several additional hazardous openings that do not provide bat habitat (John Burghardt GRD, personal communication 2008).

Restoration

Cades Cove

WRD and GRD restoration specialists have identified two opportunities for improving the physical and biological of the Cades Cove valley. One is to reconnect Abrams Creek to the floodplain of the valley floor. This action would stabilize the stream banks and improve the vegetation and habitat structure along the floodplain. Another opportunity is to restore the natural spring-fed and precipitation-generated surface water flow patterns throughout the valley (Kevin Noon WRD and Deanna Greco GRD, personal communication 2008).

Abrams Creek flows through the Cades Cove valley. This creek has a total change in elevation of 49 feet over a total stream length of 6 miles. The creek and its tributaries support an abundance of aquatic life, such as, macroinvertebrates and fish including several endangered species (e.g., the smoky madtom, yellowfin madtom, and spotfin chub). Historicly, settlers and farmers removed woody vegetation from the floodplain in order to maximize agricultural conditions and use. It appears that the stream has been artificially straightened in some reach areas and that it is incised throughout most of its length. There are numerous reaches where the banks are unstable and eroding during high flows(Kevin Noon WRD and Deanna Greco GRD, personal communication 2008).

Restoring large woody debris to the channel, improving culverts, stabilizing banks with vegetation, and planting a wider scrub/shrub and forested buffer along the stream would raise the base- and high-flow water elevations. Such restoration activities would improve the fish and wildlife habitat, provide greater water cleansing opportunities, and reduce the sediment load to downstream areas (Kevin Noon WRD and Deanna Greco GRD, personal communication 2008).

The porous limestone bedrock of Cades Cove supports numerous ground water springs that are scattered throughout the valley. Small intermittent tributaries transfer precipitation runoff from the surrounding hillsides into the valley. Farmers, who once worked this land, developed a network of shallow drainage channels throughout the valley. The ditches collect surface flows and divert them around large farm fields and into Abrams Creek, creating more arable land for agriculture. The diversion of surface flow has artificially changed the hydrology of the open field areas by creating uniform hydrologic conditions (Kevin Noon WRD and Deanna Greco GRD, personal communication 2008).

Filling the network of drainage ditches would allow surface flows to continue down slope through the fields, restoring more natural hydrologic conditions and the associated plant and animal diversity. Additional moisture in natural depressions would encourage the growth of different plant species–the existing large fields of meadow grasses would be divided with plant species that adapt to wetter soils (Kevin Noon WRD and Deanna Greco GRD, personal communication 2008).

Inventory, Monitoring, and Research Suggestions for Restoration

- Identify and inventory disturbed lands throughout the park in coordination with restoration specialists.
- Work with NRPC staff to evaluate potential restoration opportunities.
- Engage multidisciplinary teams including botanists, fisheries biologists, landscape architects, hydrologists, and geomorphologists when initiating watershed scale restoration projects.

Biodiversity and Geology

Great Smoky Mountains National Park is renowned for its incredible biodiversity, which is directly related to its geology and geologic history. During the ice ages, northern species migrated south, along the ridges and valleys of the Appalachians, and have persisted in the high elevations of the Great Smoky Mountains ever since. The high elevations give this area a distinct climate to which these species have adapted.

The All Taxa Biodiversity Inventory (ATBI) is an ongoing program with the goal of inventorying all living species present in Great Smoky Mountains National Park. With 100,000 estimated species to inventory this program relies heavily on geology and its influences on soils and general geochemistry of the park to accomplish its mission. Geology plays a large role in ecosystem management and thus is a major component for understanding species distribution, soils, and general geochemistry as it pertains to the ATBI.

Human activities have disrupted biologic processes in the park, specifically where Anakeesta Formation metasedimentary rocks have been used as road fill or have been exposed by blasting. The Anakeesta Formation (a predominantly shale unit) contains pyrite, which weathers to yield significant quantities of sulfuric acid (Flum and Nodvin 1995). The highly acidic nature of the Anakeesta Formation, where exposed to a water supply and weathered, has indirectly resulted in negative impacts on fish and salamander populations in the Newfound Gap area. Decreases in surface water pH are also attributable to acid rainfall within the park. This is a direct result of air pollution in the surrounding areas.

Geology also controls the development of waterfalls, which can have a profound effect on the fish populations upstream and downstream of the waterfalls. If waterfalls act as boundaries, speciation can result from isolation. Waterfalls may additionally serve as a barrier to invasive species. Recent tectonic uplift and the subsequent effects on drainages are a major control on the development of waterfalls. Cosmogenic isotope dating may be able to shed more information on the history of waterfall formation by accurately defining the timing of unit formation, deformation and uplift, and exposure in relation to the formation of regional drainages.

A variety of wetland types are found within the park and are profoundly influenced by the surrounding geology. These include southern Appalachian bog, high-elevation seeps, swamp-forest bog complex, and bottomland (floodplain) forest. Within the southeastern United States, these increasingly rare wetland types support more species of rare, threatened and endangered species than most other wetlands combined. Understanding the geologic controls on wetland development is key in preserving and protecting these fragile areas.

Inventory, Monitoring, and Research Suggestions for Biodiversity-Geology Connection

- Derive probability maps based on known geological-biological relationships to better predict biologic distributions.
- Support U.S. Geological Survey efforts to conduct regional geologic mapping for a digital geologic database for use with the ATBI.
- Investigate geologic controls related to the floral-faunal break between southern and northern brook trout in the park.

Paleontological Issues

Fossils within Great Smoky Mountains National Park are valuable in determining the ages of various rock units and the living conditions (depositional environment) present during their preservation. Many of the rock units exposed within the park are metamorphosed beyond fossil recognition. However, units of Cambrian age expose fossils such as stromatolites, corals, brachiopods, cephalopods, worm tubes, trilobites, and conodonts. Fossils have proven invaluable in determining the age of the Ocoee Supergroup rocks and by extension have yielded a timing sequence of deposition and mountain building in the area.

Inventory, Monitoring, and Research Suggestions for Paleontological Issues

- Develop resource management plans including inventory and monitoring to identify human and natural threats to paleontological resources.
- Incorporate paleontological findings or suggestions into park general management plans (GMP).
- Train park staff (including interpreters and law enforcement) to recognize and protect paleontological resources.

Air Quality

Air quality is a major resource management concern at Great Smoky Mountains National Park. The geology of the area focuses traffic along narrow mountain roads, trapping air pollution in valleys and on the leeside of higher peaks. Given the high visitation rate in and around the park, traffic contributes significantly to the air quality problem at the park.

The park was named for its naturally occurring blue haze, but according to the National Parks Conservation Association, Great Smoky Mountain National Park rated worst in the nation for acidity of precipitation. The park was second worst nationally for smoggy days and general haze, with visibility on the worst days averaging about 15 miles, much less than the estimate of natural visibility conditions (77 miles) (http://www.nps.gov/grsm/parkmgmt/upload/Brief-Air%20Quality.pdf [Accessed August 2008]).

Nearby industry such as coal-fired power plants, paper mills, and aluminum processing facilities, contribute to the air quality issues at the park. Air Resources Division (ARD) staff review and revise emissions and air quality data for the park and add relevant data on pollution produced by local auto traffic versus pollution from sources outside the park.

Inventory, Monitoring, and Research Suggestions for Air Quality

- Continue work with ARD to monitor air quality in the park.
- Establish a working relationship with appropriate industries, state agencies, and conservation groups to decrease the level of air pollutants in the park.
- Encourage and develop public transportation options to alleviate traffic and reduce air pollution.

Water Issues

At Great Smoky Mountains National Park, the average annual rainfall of approximately 140 cm (55 in) in the valley areas to more than 215 cm (85 in) on many ridges and peaks exceeds any other region of the continental United States outside the Pacific Northwest. During particularly wet years, more than 2 m (6.5 ft) of rain can fall in the high country. The relative humidity in the park during the growing season is very high—about twice that of the Rocky Mountain region in the western United States.

Housing and recreational developments threaten the water quality of the park. Acidic rainwater, created by air pollution, combined with the acidic bedrock in parts of the park threatens the water supply and by extension, the aquatic ecosystems dependent upon it. Borderline environments may deteriorate to inhospitable conditions.

Where agricultural remnants or human waste are stored, nitrogen in the water can reach dangerous levels. Knowledge of the chemicals used in regional agriculture and an understanding of the hydrogeologic system, including ground-water flow patterns are essential to protecting park ecosystems. Runoff from roadways often has high levels of oil and other car emissions that flow to park waterways and seep into the soil.

The movement of nutrients and contaminants through the ecosystem can be modeled by monitoring the composition of system inputs such as rainfall, and outputs such as streamflow. Other input sources include wind, surface runoff, ground-water transport, mine drainage, sewage outfalls, landfills, and fill dirt. Streams in effect integrate the surface runoff and ground-water flow of their watersheds. In doing so, they provide a measure of the status of the watershed's hydrologic system.

Urban development surrounding the park affects the watershed in a variety of ways in addition to water contamination. The hydrogeologic system changes in response to increased surface runoff from development of impervious surfaces such as parking lots, roads, and buildings. Sedimentation also increases due to land-clearing activities for development. Water temperature increases because of the insulating nature of impervious surfaces.

Inventory, Monitoring, and Research Suggestions for Water Issues

- Work with WRD to establish appropriate water monitoring programs.
- Monitor ground- and surface-water quality to determine their impacts on the wetlands of the park and the historic areas (for preservation purposes).
- Map and quantify subterranean water-recharge zones.
- Use sediment coring, tree-ring studies, and historical data to develop chronologies of any past floods and their impacts, and document future frequency and extent of flood impacts, including changes to shoreline morphology and position, nature of the substrate, post-flood changes, and ecosystem recovery. Where possible, data should also be collected during storm and flood events to monitor immediate effects.

Recreational Demands

Millions of visitors come to Great Smoky Mountains National Park every year to enjoy the bounty of recreational opportunities (over 9.3 million in 2007). These visitors are placing increasing demands on the natural resources of the park. Careful management is necessary to alleviate some of the problems overuse creates and to restore damaged areas.

Many roads in the park have a gravel surface. Two-wheel- drive vehicles can navigate these roads; consequently, they receive significant traffic. When the roads cross steep slopes, rockfalls, landslides, and erosion become more likely. Erosion on roadways can create hazardous ruts and gullies that require maintenance. The roads introduce increased traffic into isolated areas of the park, exposing them to exhaust and other emissions from cars.

Key roads in the park include:

- Parsons Branch Road leads from Cades Cove southwest to U.S. Route 129 near Deals Gap. Virgin oak forest lines this historic route. Floods washed away stream crossings in the spring of 1994 causing closures until 1998.
- Heintooga-Roundbottom Road is 24 km (15 mi) long. It leads from Balsam Mountain Road to Big Cove Road. The only access to the area is along the Blue Ridge Parkway. This road descends steeply through the Raven Fork drainage basin.
- Rich Mountain Road heads north from Cades Cove over Rich Mountain to Tuckaleechee Cove and Townsend, Tennessee. The 13 km (8 mi) long road provides beautiful views of Cades Cove and its surrounding area. The road is situated on a dry ridge where an oak-dominated forest lines the roadside. Beyond the boundaries of the park, the road becomes steep and winding.

Many trails, including the Appalachian Trail, wind through unique biological and geological environments in the park. Many of these are especially fragile and off-trail hiking promotes their degradation. Associated with hiking are camping and picnicking. The park attempts to concentrate the impacts of these forms of recreation within designated camp and picnic areas. Camping in nondesignated areas increases the area of impact and places delicate ecosystems at risk for contamination from fires and waste.

Inventory, Monitoring, and Research Suggestions for Recreational Demands

- Design wayside exhibits to encourage responsible use of park resources.
- Restore degraded trails to prevent increased slope erosion.
- Monitor human impacts at camping and climbing areas, official and social trails, and fishing sites.
- Research impacts of paving gravel roads and/or restoring slopes along them.
- Evaluate the impact of existing roads on park resources.

Historical Landscapes

An overarching goal of Great Smoky Mountains National Park is to preserve its historical context.

Continuous natural processes of erosion and weathering and the demands of increasing local population and urban development put this goal under constant pressure. Conflicts may also arise from opposing needs of cultural and natural resource management.

Several areas in the park such as Cades Cove, Cataloochee, Mingus Mill, and the Mountain Farm Museum contain historic structures that require protection from geologic processes and need to coexist harmoniously with the landscape. They must be available for visitation without compromising the natural resources or the historical context.

Inventory, Monitoring, and Research Suggestions for Historical Landscapes

- Map new development and changing land use, including construction, deforestation, and other land-cover changes, and the paving of previously vegetated surfaces in the area.
- Document impacts of land-use change on a variety of natural resource parameters such as runoff, stream morphology, sedimentation, and slope stability.

General Geology and Ecosystem Concerns

Because of the nature of the landscape, several potential geological issues may warrant consideration for land-use planning and visitor use in the park. Along with a detailed geologic map and a road or trail log, a guidebook linking Great Smoky Mountains National Park to the other parks in the southern Appalachian area would enhance visitor appreciation of the geologic history and dynamic processes that created the landscape and impacted the historical events showcased at the park. Strategically placed wayside exhibits can also help explain geology to the visitor.

The geology at Great Smoky Mountain National Park has challenged geologists and nongeologists alike for many years. The heavy vegetation, erratic distribution of exposures, great thickness of lithologically monotonous strata, and a predominance of rocks lacking fossils make the interpretation of the geologic history at Great Smoky Mountains very difficult and intriguing. In addition to these problems, regional metamorphism of the rocks has altered many of the structural features necessary to measure tectonic shortening and determine the deformational history of the park.

Inventory, Monitoring, and Research Suggestions for General Geology

- Create interpretive exhibits that detail geologic features and processes for visitors, and explain the evolution of the landscape. Include geologic influences on human occupation of the area.
- Encourage research that would determine whether the Web Mountain area is a tectonic window.
- Encourage research deciphering area stratigraphy.
- Study geomorphic bedrock-controlled features such as the perched, abandoned valley above the Foothills Parkway.

Geologic Features and Processes

This section describes the most prominent and distinctive geologic features and processes in Great Smoky Mountains National Park as well as the historical landscape of the park.

Clingmans Dome

Clingmans Dome rises 2,025 m (6,643 ft) above the Atlantic coast (fig. 2). It is the highest point in Great Smoky Mountains National Park and Tennessee. Clingmans Dome is also the third highest point in the Appalachian Mountains. The Appalachian Trail reaches its highest elevation between Maine and Georgia where it crosses the dome. Views from the top extend more than 160 km (100 mi) on clear days.

The dome consists primarily of rocks from the Ocoee Supergroup of Precambrian age. Specifically, the resistant Thunderhead Sandstone grades upward into the Anakeesta Formation, which lines the slopes of the dome (Moore 1988). These rocks display bedding tilted at varying high degrees of dip indicative of the regional deformation. At the base of the dome is the Oconaluftee fault, near Indian Gap. This fault underlies the long, linear Oconaluftee Valley.

Newfound Gap and Chimney Tops

Newfound Gap is the lowest road pass through the Great Smoky Mountains National Park (fig. 3), at 1,539 m (5,048 ft) elevation. Because of its low altitude, it attracted historical interest in 1872 when Swiss geographer Arnold Henry surveyed the area. Upon construction, Newfound Gap road pass replaced Indian Gap as the lowest pass through the mountains. It also hosts the Appalachian Trail.

The gap is through the shale-like, brown-to-gray slate and metasiltstone of the Anakeesta Formation. The characteristic rusty color of these rocks results from the oxidation of pyrite (an iron sulfide mineral) present throughout this formation. The rocks are thinly bedded, brittlely deformed and fractured with joints and cleavage (Moore 1988).

Chimney Tops gets its name from the nearly vertical holes or shafts developed through a jutting rock exposure resembling chimneys. The strata composing the chimney walls dip about 50 degrees. These rocks are part of the Anakeesta Formation, jutting 15 m (50 ft) above the surrounding slopes. Erosion along vertical joints in the rock left a backbone ridge (fig. 4) (Moore 1988).

Foothills Parkway Views

Skirting the north side of Great Smoky Mountain National Park is the Foothills Parkway. The parkway offers beautiful views of the landscape. The western section, running southwest from Walland to Chilhowee is 32 km (20 mi) long and provides vistas of Thunderhead Mountain, Happy Valley, and the Great Valley. The eastern section runs for 10 km (6 mi) from Cosby, Tennessee to Interstate Highway 40. This section was built on Green Mountain and provides views of Cosby Valley.

Ocoee Supergroup Rocks

Much of the Great Smoky Mountains are underlain by rocks of the Ocoee Supergroup, a body of terrigenous clastic sedimentary rocks about 9,000 m (30,000 ft) thick (King et al. 1958) The rocks include shale, slate, siltstone, fine- to coarse-grained sandstone, quartz conglomerate and some minor carbonate layers (Hamilton 1961). The Ocoee unconformably overlies Precambrian granitic and gneissic rocks in a series of complexly deformed thrust sheets (King et al. 1958; Knoll and Keller 1979). The Ocoee Supergroup is divisible lithologically, geographically, and in part, tectonically into three distinct groups. These are, in ascending order, the Snowbird, Great Smoky, and Walden Creek Groups (King et al. 1958; Hamilton 1961).

The lowest group, the Snowbird, is more than 3,900 m (13,000 ft) thick. It mostly consists of sandstone, but is interbedded with finer-grained sandstone, siltstone and argillaceous rocks of increasing proportion westward (King et al. 1958). The Snowbird is divided, in ascending order, into the Wading Branch Formation, Longarm Quartzite, Roaring Fork Sandstone, and Pigeon Siltstone. Toward the west, the Metcalf Phyllite composes more of the Snowbird than the other formations (Hamilton 1961).

Sitting atop the Snowbird Group is the Great Smoky Group. This unit is more than 7,600 m (25,000 ft) thick. It is divided into three parts (in ascending order): Elkmont Sandstone, Thunderhead Sandstone, and Anakeesta Formation. The lowest two units consist of fine-grained sandstone, and poorly sorted, coarse feldspathic sandstone in graded beds, respectively. The Anakeesta Formation contains dark, silty and argillaceous rocks that have been metamorphosed to slates, phyllites, and schists (King et al. 1958).

The Great Smoky Group forms much of the crest of the Great Smoky Mountains. In outcrop, the Anakeesta is burnished with a rust color that results from oxidation of pyrite and other iron sulfides in the rock. The slate layers of the Anakeesta, by their fissile nature, have created many of the steep-sided ridges of the mountains as well as unique outcroppings such as Chimney Tops and Charlies Bunion.

The Walden Creek Group forms a varied assemblage of argillaceous and silty rocks mixed with quartz-pebble conglomerate. It is locally about 2,400m (8,000 ft) thick with prominent quartzite, limestone, and dolomite. The Walden Creek Group is divided into the Licklog Formation, Shields Formation, Wilhite Formation, and Sandsuck Formation, in ascending order (King et al. 1958).

The Ocoee Supergroup has been cut and deformed by numerous faults, including the Greenbrier fault, resulting in repeated sections and obscured stratigraphic relationships. This obscurity has posed a challenge to researchers attempting to determine its depositional and deformational history (Costello and Hatcher 1991). The Great Smoky thrust fault separates Ocoee strata from the Paleozoic, unmetamorphosed strata of the Valley and Ridge province (Woodward 1989a).

Determining the age of the Ocoee Supergroup has also proved difficult for researchers. It has largely been assigned a late Precambrian age because of its stratigraphic placement above 1.1 billion year old Grenville basement rocks and well below lowermost Cambrian rocks (Knoll and Keller 1979). Once considered fossil-free, fossils of an acritarch organism led many to believe the entire series was Precambrian in age. Then fossil assemblages of trilobites, ostracodes, bryozoans, agglutinated foraminifers, and microcrinoid fragments were found in the Wilhite Formation of the Walden Creek Group, indicating a Paleozoic age for the upper beds of the Ocoee (Unrug and Unrug 1990).

Tectonic Windows

Several geologic windows are found in Great Smoky Mountain National Park. A window is a term referring to an exposure of younger rocks revealed by localized erosion of overlying rocks. This typically happens when a thrust fault shoves older rock atop younger units and further deformation and deep erosion exposes the rock beneath the thrust sheet (fig. 5).

In the park, the Great Smoky thrust fault system is a relatively continuous feature underlying Ocoee strata and basement rocks. It appears around a number of windows within the Blue Ridge. The famous Mountain City and Grandfather windows are the largest windows through the Blue Ridge thrust sheet. They record at least 50 km (30 mi) of horizontal displacement along the fault. These features are not located within the park, but there are four small windows exposing Valley and Ridge Paleozoic strata (Middle Ordovician and Cambrian and Ordovician rocks) in the park (Woodward 1989a).

Windows in the park where Paleozoic age limestones and shales have been exposed form coves such as Cades, Tuckaleechee, and Wears Coves (Woodward 1989a). These areas are surrounded by older and topographically higher rock strata. Cades Cove is described in detail below. In general, the limestone of the windows developed deep, fertile soils, attractive to farmers. Limestone also dissolves into karst features such as sinkholes (e.g., Whiteoak Sink) and caves. At least four caves are found in the park: Gregorys, Bull, Blowing, and Rainbow Caves (Moore 1988).

Historical Landscape

One of the major goals of the park is to preserve the historical context of the area, including preserving and restoring historic structures and the landscape around them. Maintaining this landscape often means resisting natural geologic changes, which presents several management challenges. Geologic slope processes such as landsliding, slumping, chemical weathering, block sliding, and slope creep are constantly changing the landscape at the park. Runoff erodes sediments from open areas and carries them down streams and gullies. Erosion naturally diminishes higher areas and fills in the lower areas distorting the historical context of the landscape.

Mountain Farm Museum

The Mountain Farm Museum is an assembled collection of farm buildings from locations throughout Great Smoky Mountains National Park. Farm features include a log farmhouse, barn, apple house, springhouse, and a working blacksmith shop, preserving and exhibiting a sense of family life 100 years ago. Most of the structures displayed were built in the late 19th century and were transported in the 1950s.The Davis House offers a rare chance to view a log house built from American Chestnut wood before the chestnut blight decimated the forests during the 1930s and early 1940s.

Mingus Mill

North of the Oconaluftee Visitor Center is Mingus Mill. This historic structure, built in 1886, uses a water-powered working cast-iron turbine instead of a water wheel to power all of the machinery in the building. The water flows down a millrace to the mill. The mill is located at its original site, and its preservation remains of primary concern to park resource management.

Cataloochee

Isolated Cataloochee Valley is nestled in one of the most rugged mountain landscapes in the southeastern United States. Surrounded by 1,800 m (6,000 ft) peaks, this valley was the largest and most prosperous settlement in what is now Great Smoky Mountains National Park. Cataloochee is one of the most picturesque areas of the park and was once known for its orchards and farmsteads. For more information on Cataloochee, visit the following website:
http://www.nps.gov/grsm/planyourvisit/cataloochee.htm

Cades Cove

The Cades Cove district of Great Smoky Mountains National Park is approximately 13 km (8 mi) from Townsend, Tennessee. People come for the abundance of wildlife along Abrams Creek and the collection of historic churches, a gristmill, and cabins in the cove (fig. 6). This 6,800 acre area attracts more than two million visitors every year, causing traffic jams and other use problems.

Cades Cove is profoundly influenced by its landforms and rocks (geomorphology and geology). The area is a window, a good example of older rocks surrounding the valley floor of younger rocks. This juxtaposition arises from the thrusting of older rocks atop younger rocks during mountain building events and the subsequent erosion of the overlying rocks to reveal younger rocks below. At Cades Cove, following a series of faulting and uplift periods, the older Precambrian metamorphic rocks have eroded exposing the younger Ordovician limestones. The erosion created a sheltered valley that set the stage for years of history.

Prior to 1819, Cades Cove was part of the Cherokee Nation. The Cherokee called the cove Tsiyahi, or "place of the river otter." The Cherokee attempted to integrate European technologies and culture with their own, including building log homes and frame houses, attending school, and owning slaves. The 1830 United States census indicated that more than 1,000 slaves were working on Cherokee plantations in the area. However, many white Americans wanted to move all native peoples west of the Mississippi River. Following the discovery of gold on Cherokee lands in Georgia, and Andrew Jackson's rise to the Presidency, an Indian removal plan led to the tragic "Trail of Tears." On this route to Oklahoma in 1838, more than 4,000 people perished.

By 1850, the white American population of Cades Cove reached 685 men, women, and children. Settlers farmed the rich fertile limestone-based soils and built homes, schools, and churches. In 1900, the logging industry brought employment and added income to the people living in the mountains. However, the establishment of the Great Smoky Mountains National Park in 1934 continued the outward migration from the Cove that ended in 1999 when the last resident of Cades Cove, Kermit Caughron, passed away.

Fontana Dam

At 146 m (480 ft), Fontana Dam is the tallest concrete dam east of the Rocky Mountains. The dam impounds the Little Tennessee River forming Fontana Lake and produces hydroelectric power. The reservoir is approximately 11,700 acres in size with a shoreline of about 390 km (240 mi). Fontana Dam is located near Fontana Village, North Carolina and was begun during World War II in 1942.

Major Faults and Timing of Deformation

Faulting accommodates the pile-up of rocks during mountain building orogenies. Four major thrust faults dominate the Great Smoky Mountains region. These are the Greenbrier, Dunn Creek, Miller Cove and Great Smoky thrust faults (fig. 7) (Connelly and Woodward 1992). A later fault, the high-angle Gatlinburg fault, is also a major deformational system in the area (Woodward 1989b). Their spatial relationships reveal the timing of deformation in the Great Smoky Mountains.

The Greenbrier and Dunn Creek thrust sheets were active during the Ordovician Taconic orogeny, prior to extensive metamorphism. Extensive regional metamorphism tends to erase earlier structures. However, in the Great Smoky Mountains foothills, the metamorphism (~460–420 Ma) was lower grade, and many preexisting features are preserved, making the area an ideal location to study Taconic deformation. By removing the overprint of later faults (described below), the Dunn Creek and Greenbrier faults reveal ramp-flat geometries including bedding-parallel faults, ramps, and angular ramp-related folds (Connelly and Woodward 1992).

The Greenbrier fault is a low-angle thrust that separates the Great Smoky Group from the underlying Snowbird Group of Ocoee Supergroup rocks (Woodward 1986; Costello and Hatcher 1986). The Greenbrier thrust is parallel or at low angle to bedding in the footwall along much of its trace. The other premetamorphic, Taconic age fault, the Dunn Creek thrust fault, separates Snowbird Group rocks in the hanging wall from Walden Creek Group rocks in the footwall.

During the Allegheny orogeny, the emplacement of the Great Smoky and Miller Cove thrust faults and the Gatlinburg fault dissected all earlier structures. These faults also cut foliations, lineations, and other metamorphic features, indicating that they postdate regional metamorphism associated with earlier mountain building events. The Great Smoky fault is part of the Blue Ridge-Piedmont fault system with 350–500 km (220–300 mi) of northwestward displacement. The Great Smoky thrust sheet is less than 5–7 km (3–4 mi) thick.

The Miller Cove fault separates metamorphosed Ocoee Supergroup rocks and unmetamorphosed upper Ocoee, Chilhowee Group, and younger strata. Locally, the Miller Cove fault is the frontal Blue Ridge fault, and it may have been active in both the Taconic and Allegheny orogenic events. The younger Gatlinburg fault is high angle with some 2,000 m (6,600 ft) of brittle displacement. It accommodated both strike-slip and dip-slip motion (Connelly and Woodward 1992).

Most of the major faults of the Great Smoky Mountains are part of a connected fault system (Woodward 1986). This system involves cross-cutting relationships, reactivations along preexisting faults, overprinting, and metamorphism. These faults continue to intrigue researchers attempting to decipher the history of the southern Appalachian Mountains.

Alum Cave Bluffs

The 30 m (100 ft) high Alum Cave Bluffs were reportedly a prized source of saltpeter for Civil War gunpowder. Saltpeter is a common name for the mineral potassium nitrate. The bluffs were also the site of a nineteenth century alum mine. Alum is a compound sulfate used in munitions manufacturing, medicines, and setting cloth dyes. The bluffs are on the slopes of Mt. LeConte. They are named for the mineral residues found in the bedrock, in this case, the Anakeesta Formation (Moore 1988).

Figure 2. Clingmans Dome at sunset. Photograph courtesy of The Luminous Landscape (http://www.luminous-landscape.com/).

Figure 3. Newfound Gap. Photograph courtesy of Techimo.com (http://www.techimo.com/).

Figure 4. The Chimney Tops, looking along the backbone ridge of the Anakeesta Formation. Photograph courtesy of Smoky Photos (http://smokyphotos.com/).

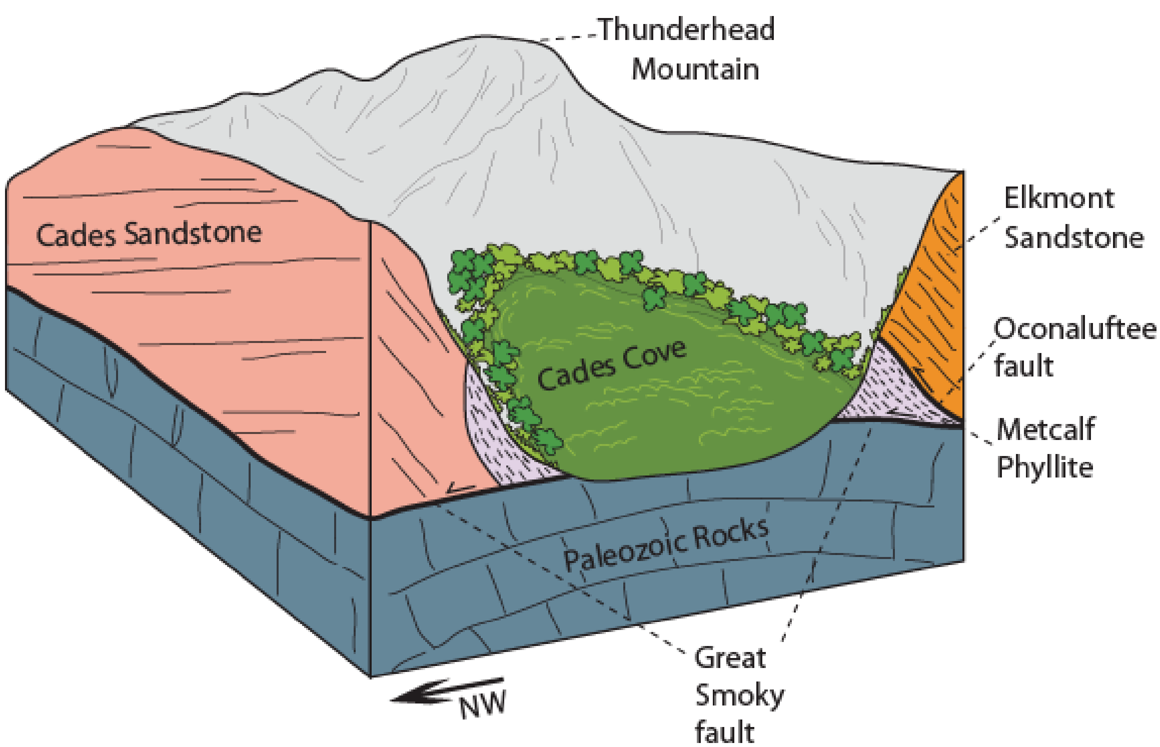

Figure 5. Geologic window at Cades Cove. The cove was formed when erosion penetrated the Great Smoky thrust fault sheet and exposed the underlying Paleozoic limestones and shales. The Great Smoky thrust fault is nearly flat lying. Adapted from Moore (1988).

Figure 6. Gristmill in Cades Cove during the winter months. Photograph courtesy of Jeaneane Payne, © 2004 by Dynamic Web Solutions (http://www.imagesbuilder.com/gsmnp/).

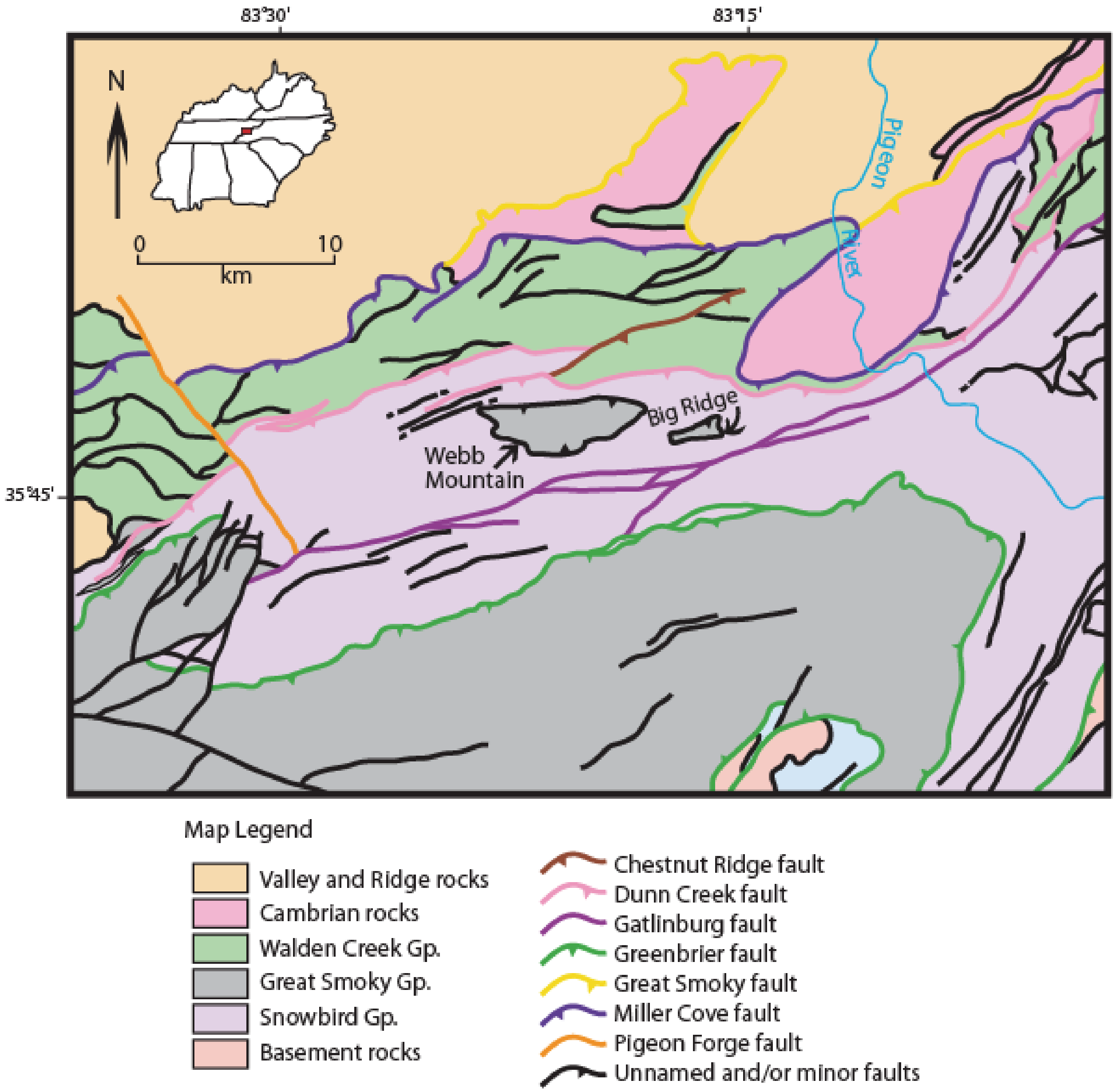

Figure 7. Geologic map of the eastern Great Smoky Mountains showing major faults and rock groups. Note parallel nature of large-scale faults. Also note offset of early faults, i.e., the Greenbrier and Miller Cove faults and later faults. Adapted from Connelly and Woodward (1992).

Map Unit Properties

This section identifies characteristics of map units that appear on the Geologic Resource Evaluation digital geologic map of Great Smoky Mountains National Park. The accompanying table is highly generalized and is provided for background purposes only. Ground-disturbing activities should not be permitted or denied on the basis of information in this table.

Geologic maps facilitate an understanding of Earth, its processes, and the geologic history responsible for its formation. Hence, the geologic map for Great Smoky Mountains National Park informed the "Geologic History," "Geologic Features and Processes," and "Geologic Issues" sections of this report. Geologic maps are essentially two-dimensional representations of complex three-dimensional relationships. The various colors on geologic maps represent rocks and unconsolidated deposits. Bold lines that cross and separate the color patterns mark structural features such as faults and folds. Point symbols indicate features such as dipping strata, sample localities, mine features, wells, and cave openings.

Incorporation of geologic data into a geographic information system (GIS) increases the utility of geologic maps and clarifies spatial relationships to other natural resources and anthropogenic features.

Geologic maps are indicators of water resources because they show which rock units are potential aquifers and are useful for finding seeps and springs. Geologic maps do not show soil types and are not soil maps, but they do show parent material, a key factor in soil formation. Furthermore, resource managers have used geologic maps to make correlations between geology and biology; for instance, geologic maps have served as tools for locating threatened and endangered plant species.

Although geologic maps do not show where future earthquakes will occur, the presence of a fault indicates past movement and possible future seismic activity. Geologic maps will not show where the next landslide, rockfall, or volcanic eruption will occur, but mapped deposits show areas that have been susceptible to such geologic hazards. Geologic maps do not show archaeological or cultural resources, but past peoples may have inhabited or been influenced by various geomorphic features that are shown on geologic maps. For example, alluvial terraces may preserve artifacts, and inhabited alcoves may occur at the contact between two rock units.

The features and properties of the geologic units in the following table correspond to the accompanying digital geologic data. Map units are listed from youngest to oldest. Please refer to the geologic time scale (fig. 8) for the age associated with each time period. This table highlights characteristics of map units such as susceptibility to hazards; the occurrence of fossils, cultural resources, mineral resources, and caves; and the suitability as habitat or for recreational use. The following are source data for the GRE digital geologic map:

Southworth, S., A. Schultz, and D. Denenny, 2005. *Geologic Map of the Great Smoky Mountains National Park Region, Tennessee and North Carolina*. Scale 1:100,000. Open-File Report OF-2005-1225. Reston, VA: U.S. Geological Survey.

Using ESRI ArcGIS software, the Geologic Resource Evaluation team created a digital geologic map from this source. GRE digital geologic-GIS map products include data in ESRI personal geodatabase, shapefile, and coverage GIS formats, layer files with feature symbology, FGDC metadata, a Windows HelpFile that contains all of the ancillary map information and graphics, and an ESRI ArcMap map document file that easily displays the map. GRE digital geologic data are included on the attached CD and are available through the NPS Data Store (http://science.nature.nps.gov/nrdata/).

The Southern Appalachian area contains rocks varying in age from Precambrian gneisses to Quaternary sediments. Because of the regional erosion by large rivers and tributaries, these rocks are on striking display. The rocks exposed at Great Smoky Mountains National Park are divisible into four major groups.

The oldest rocks of the area are Precambrian (about 1.1 billion years old). These are the metamorphosed remnants of volcaniclastic and plutonic rocks mobilized during mountain building. Atop and partially coeval with the crystalline basement are the rock units of the Ocoee Supergroup, of Precambrian to Cambrian age. The Ocoee Supergroup is subdivided into the Snowbird, Great Smoky, and Walden Creek Groups. Above the Ocoee Supergroup is the Lower Cambrian Chilhowee Group, which also contains shallow-shelf sedimentary rocks. The youngest bedrock outcrops at Great Smoky Mountains National Park are of Paleozoic age and are exposed in tectonic windows such as the carbonate Knox Group at Cades Cove. Lining the river valleys and other small basins throughout the park are the unconsolidated sands, silts, and other deposits of Quaternary age. Included in these unconsolidated sediments are vast boulder fields, remnants of frost wedging action during cooler climates.

Geologic History

This section describes the rocks and unconsolidated deposits that appear on the digital geologic map of Great Smoky Mountains National Park, the environment in which those units were deposited, and the timing of geologic events that created the present landscape.

The recorded history of the Great Smoky Mountains National Park landscape, and by extension, the southern Appalachian Mountains, begins in the Proterozoic (figs. 8-9). In the mid-Proterozoic, during the Grenville orogeny (~1.1 billion years ago), a supercontinent had formed that included most of the continental crust in existence at that time, including North America and Africa. The regional sedimentation, deformation, plutonism, and volcanism are manifested in the metamorphic gneisses in the core of the modern Blue Ridge Mountains (Harris et al. 1997).

These rocks were deposited over a period of 100 million years and are more than a billion years old, placing them among the oldest rocks known from this region. They form a basement upon which all other rocks of the Appalachians were deposited (Southworth et al. 2001). Following their uplift, the basement rocks were exposed to erosion before deposition of later rock units (Moore 1988). Fragments of the billion-year-old supercontinent are visible at Blowing Rock in northern North Carolina and Red Top Mountain in northern Georgia (fig. 10) (Clark 2001).

The Late Proterozoic, approximately 1,000–542 Ma, brought a tensional, rifting tectonic setting to the area. The supercontinent broke up and a sea basin formed intermittently that eventually became the Iapetus Ocean (Carter et al. 1993). Locally, the Ocoee basin formed on the margin of the supercontinent in what are now the western Carolinas, eastern Tennessee and northern Georgia. This basin collected many of the mud, silt, and sand sediments worn from the Grenville highlands that would eventually form the rocks of the Appalachian Mountains (Moore 1988). Some of the sediments were deposited as large submarine landslides and turbidity flows, which today preserve the dramatic features of their emplacement. The basin subsided as sediments were deposited making room for further sedimentation in at least two prolonged pulses (Tull and Li 1998). The rocks of the Ocoee Supergroup today display vast thicknesses (~15 km [9 mi]), representative of this depositional setting (Clark 2001). Ocoee Supergroup rocks form the bedrock of the Great Smoky, Unicoi, and Plott Balsam Mountains.

In addition, in this tensional environment at the end of the Proterozoic, flood basalts and other igneous rocks such as diabase and rhyolite added to the North American continent. These igneous rocks were intruded through cracks in the granitic gneisses of the Blue Ridge core and extruded onto the land surface during the break-up of the continental land mass (Southworth et al. 2001). The volcanism was concentrated in areas of present-day Virginia, the Carolinas, and Georgia. This igneous activity is largely responsible for the economic deposits of copper, zinc, iron, and sulfur in the eastern United States formed when hot, metal-bearing fluids vented onto the floor of the Ocoee basin (Clark 2001).

Associated with the shallow marine setting along the eastern continental margin of the Iapetus Ocean were large deposits of sands, silts, and muds in nearshore, deltaic, barrier–island, and tidal-flat areas. Some of these are present as the Antietam Formation in central Virginia, north of Great Smoky Mountains National Park (Schwab 1970; Kauffman and Frey 1979; Simpson 1991). The Chilhowee Group, composed of shale, siltstone, and sandstone is representative of the Cambrian System in the park area (Moore 1988). In addition, huge masses of carbonate rocks represent a grand platform, thickening to the east, that persisted during the Cambrian and Ordovician Periods (545–480 Ma).

The Valley and Ridge Province rocks found just west of the park, formed in a vast, shallow, inland sea—an ideal setting for the accumulation of thick limestone deposits (Clark 2001). Somewhat later, ~540, 470, and 360 Ma, amphibolite, granodiorite and pegmatite, and lamprophyre, respectively, intruded the sedimentary rocks.

Several episodes of mountain building and continental collision responsible for the Appalachian Mountains contributed to the heat and pressure that deformed and metamorphosed the collected sediments, intrusives, and basalts into schists, gneisses, marbles, slates, and migmatites (Southworth et al. 2000). Migmatites and gneisses are exposed in many places along the Blue Ridge Parkway.

Many of the rocks of the Ocoee basin were subjected to relatively low grades of metamorphism and retain their original sedimentary features (Clark 2001). Rocks between the Chilhowee Group and Quaternary sediments are largely missing from the park, however examples from nearby locations are included to better understand the regional geologic history.

Following mountain building, the rocks were extensively folded and faulted. This faulting may have happened during regional rifting that occurred about 200 Ma. Given the available fault conduits, hot fluids moved upward, depositing quartz veins containing small amounts of gold. This was the source of the mining interest in the mid-Appalachians area intermittently from 1867 until 1941 (Reed et al. 1980).

Some of the larger faults can be identified throughout the southern Appalachian Mountains. Among these are the Dunn Creek, Greenbrier, and Miller Cove fault systems (Connelly and Woodward 1990). Near Linville Falls, North Carolina, huge masses of rocks moved along a fault for a distance of 100 km (60 mi) or more. The rocks that make up the mountains above Linville Falls are older than the resistant ledges that form them. The fault is traceable as a zone of intense deformation below the falls in Linville Gorge. In Cades Cove at Great Smoky Mountains National Park, the limestone floor of the cove is younger than the surrounding rocks, a testament to the effects of faulting in the area (Clark 2001).

From Early Cambrian through Early Ordovician time, mountain building (orogenic) activity along the eastern margin of the continent began again. This involved the closing of the ocean, subduction of oceanic crust, the creation of volcanic arcs, and the uplift of continental crust. In response to the overriding plate thrusting westward onto the continental margin of North America, the crust bowed downward creating a deep basin that filled with mud and sand eroded from the highlands to the east (Harris et al. 1997). This so-called Appalachian basin was centered on what is now West Virginia. These infilling sediments covered the grand carbonate platform and are today represented by the shale of the Middle and Upper Ordovician (472–444 Ma) Martinsburg Formation (Southworth et al. 2001).

During the Late Ordovician, the oceanic sediments of the shrinking Iapetus Ocean were thrust westward onto other deepwater sediments of the western Piedmont. This occurred along the Greenbrier fault and others like the Pleasant Grove fault, found further north. Sandstones, shales, siltstones, quartzites, and limestones were then deposited in the shallow marine to deltaic environment of the Appalachian basin. These rocks, now metamorphosed, currently underlie the Valley and Ridge Province. The Piedmont metasedimentary rocks record the transition from nonorogenic, passive margin sedimentation to extensive, synorogenic clastic sedimentation from the southeast during Ordovician time (Fisher 1976).

Shallow marine to fluvial sedimentation continued for about 200 million years during the Ordovician, Silurian, Devonian, Mississippian, Pennsylvanian, and Permian Periods, resulting in thick piles of sediments. These sediments came from highlands that were rising to the east during the Taconic orogeny (Ordovician), and the Acadian orogeny (Devonian).

The Taconian orogeny involved a volcanic arc–continent convergence. Oceanic crust and the volcanic arc were thrust onto the eastern edge of the North American continent along large-scale thrust faults such as the Greenbrier (Moore 1988; Connelly and Woodward 1990). The Acadian orogeny continued the mountain building of the Taconian orogeny as the African continent approached North America (Harris et al. 1997). This orogeny was focused to the north of the Great Smoky Mountains.

Following the Acadian orogenic event, the proto-Atlantic Iapetus Ocean was completely destroyed during the late Paleozoic as the North American and African continents collided. This mountain building episode, the Allegheny orogeny, is the last major orogeny of the Appalachian evolution. The rocks were deformed and folded by faults to produce the Sugarloaf Mountain anticlinorium and the Frederick Valley synclinorium in the western Piedmont, the Blue Ridge-South Mountain anticlinorium, and the numerous folds of the Valley and Ridge Province (Southworth et al. 2001). The deformation associated with the Allegheny orogeny overprints many previous structures in the southern Appalachians. Preexisting faults such as the Miller Cove and other Paleozoic faults were reactivated as planes of weakness by the Great Smoky thrust fault. Renewed faulting combined with extremely large strains and lack of strain markers makes restoration of any pre-Allegheny deformation difficult (Connelly 1990; Connelly and Woodward 1992).

During the Allegheny orogeny, rocks of the Great Valley, Blue Ridge, and Piedmont Provinces were transported westward onto younger rocks of the Valley and Ridge Province along the North Mountain fault. Estimates range from 20–50 percent shortening or about 125–350 km (75–125 mi) of translation (Harris et al. 1997). Deformed rocks in the eastern Piedmont were also folded and faulted and existing thrust faults were reactivated as both strike-slip and thrust faults during the Allegheny orogenic events (Southworth et al. 2001). The high angle Gatlinburg fault was emplaced near the end of Paleozoic time as the Allegheny orogeny was ending (Moore 1988).

Following the Allegheny orogeny, during the Late Triassic, a period of rifting began as the deformed rocks of the joined continents began to break apart from about 230–200 Ma. The supercontinent Pangaea was segmented into roughly the continents that persist today. This episode of rifting or crustal fracturing initiated the formation of the current Atlantic Ocean and caused many block-fault basins to develop with accompanying volcanism (Harris et al. 1997; Southworth et al. 2001).

Large alluvial fans and streams carried debris shed from the uplifted Blue Ridge and Piedmont Provinces. These were deposited as nonmarine shales and sandstones in fault-created troughs such as the Culpeper Basin in the western Piedmont. Erosion removed most of the younger rocks during the Mesozoic, leaving only the older, core rocks exposed (Moore 1988).

The large faults, which formed the western boundaries of the basins, provided an escarpment that was quickly covered with eroded debris. Igneous rocks were intruded into the new strata as plutons, subhorizontal sheets, or sills, and near-vertical dikes that extend beyond the basins into adjacent rocks. Plutons occur across the southern Appalachians and are now exposed in places such as Looking Glass Rock, North Carolina (Clark 2001).

After these igneous rocks were emplaced at approximately 200 Ma, the region underwent a period of slow uplift and erosion. The uplift was in response to isostatic adjustments within the crust that forced the continental crust upward and exposed it to erosion.

Thick deposits of unconsolidated gravel, sand, and silt were shed from the eroded mountains and were deposited at the base of the mountains as alluvial fans, which spread eastward to be part of the Atlantic Coastal Plain (Duffy and Whittecar 1991; Whittecar and Duffy 2000; Southworth et al. 2001).

The amount of eroded material inferred from the now-exposed metamorphic rocks is immense. Many of the rocks exposed at the surface must have been at least 20 km (~10 mi) below the surface prior to regional uplift and erosion.

The erosion continues today along regional drainage patterns developed during the early part of the Cenozoic Era. The large rivers and tributaries are stripping the Coastal Plain sediments, lowering the mountains, and depositing alluvial terraces—processes that are creating the present landscape (Moore 1988).

Since the breakup of Pangaea and the uplift of the Appalachian Mountains, the North American plate has continued to drift toward the west. The isostatic adjustments that uplifted the continent after the Allegheny orogeny continued at a subdued rate throughout the Cenozoic Era (Harris et al. 1997).

During the late Cenozoic, the primary geologic processes at work in the Appalachians were erosion and weathering. Rain, frost, rivers, rooted plants, streams, dissolution, mass wasting, and landslides wore down the once craggy peaks. Layers of resistant rocks such as sandstones, toped ridges and created ledges commonly associated with waterfalls at Great Smoky Mountains National Park and the Blue Ridge Parkway (Schultz and Seal 1997), and within limestone coves and windows, numerous solution caves were formed.

Though glaciers never reached the southern Appalachians, the colder climates of the ice ages (~1.6 Ma–11 thousand years ago) played a role in the mountains' geomorphology. The landforms and deposits are probably late Tertiary to Quaternary in age when a wetter climate, sparse vegetation, and frozen ground caused increased precipitation to run into ancestral rivers enhancing downcutting and erosion (Schultz and Seal 1997; Zen 1997a and 1997b). Many of the concentrations of boulders, block fields, and fine-textured colluvium on the forested mountainsides of the southern Appalachians record the process of frost-wedging.

The unique flora and fauna of Great Smoky Mountains National Park and the Blue Ridge Parkway are a result of ancient species migrating south ahead of the advancing glacial front (Clark 2001). Species such as the saw-whet owl, common to northern climates, are established in the southern Appalachians.

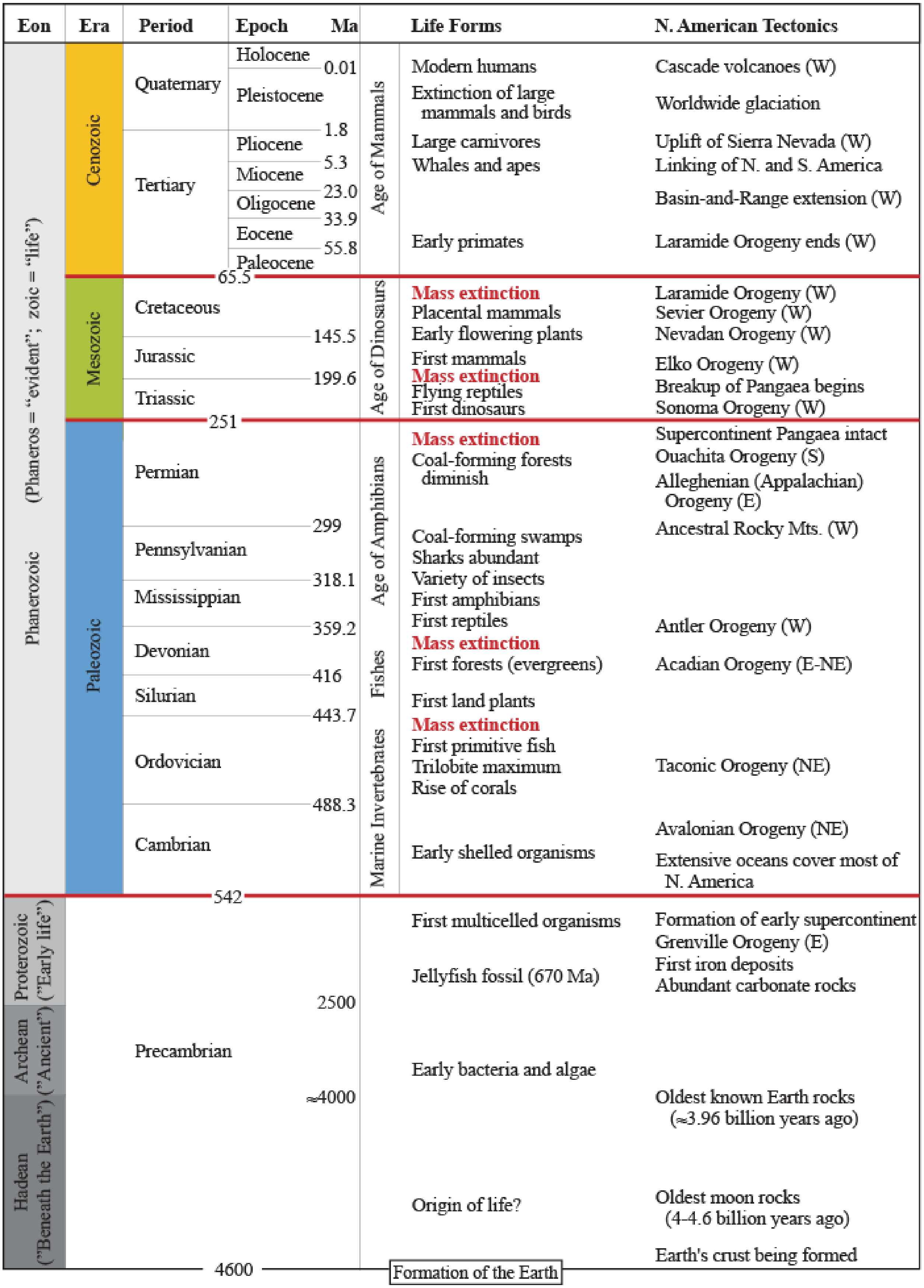

Figure 8. Geologic time scale; adapted from the U.S. Geological Survey. Red lines indicate major unconformities between eras. Included are major events in life history and tectonic events occurring on the North American continent. Absolute ages shown are in millions of years.

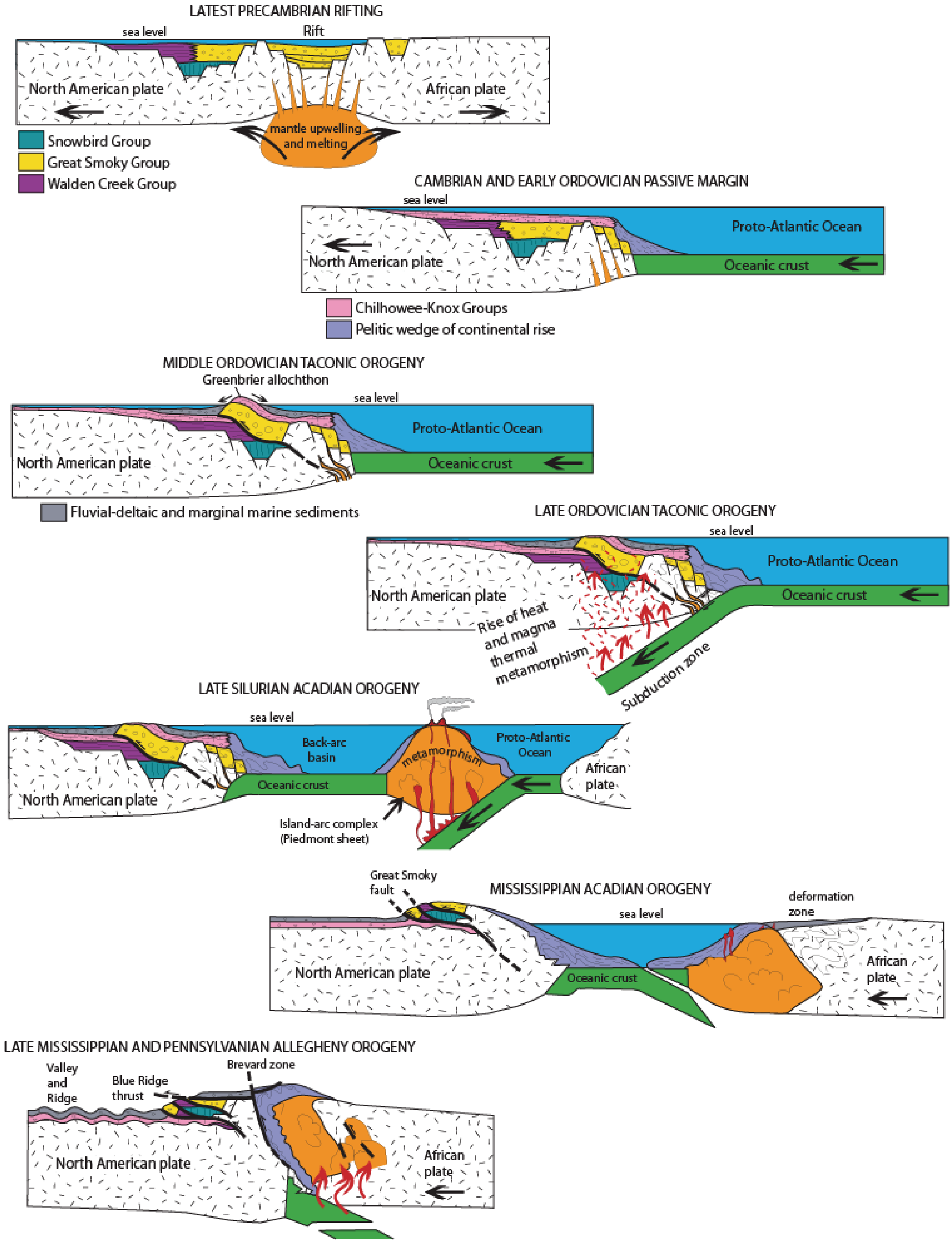

Figure 9. Cross-sectional view of the evolution of the Southern Appalachian Mountains from the Precambrian to Pennsylvanian. Following Precambrian rifting and passive margin deposition, the Taconian orogeny created the Greenbrier allochthon and fault as well as regional metamorphism. The Acadian orogeny involved collision with an island arc that continued into the Allegheny orogeny with the collision of the African continental plate and the development of the Blue Ridge and Valley and Ridge deformation. Adapted from DeWindt (1975).

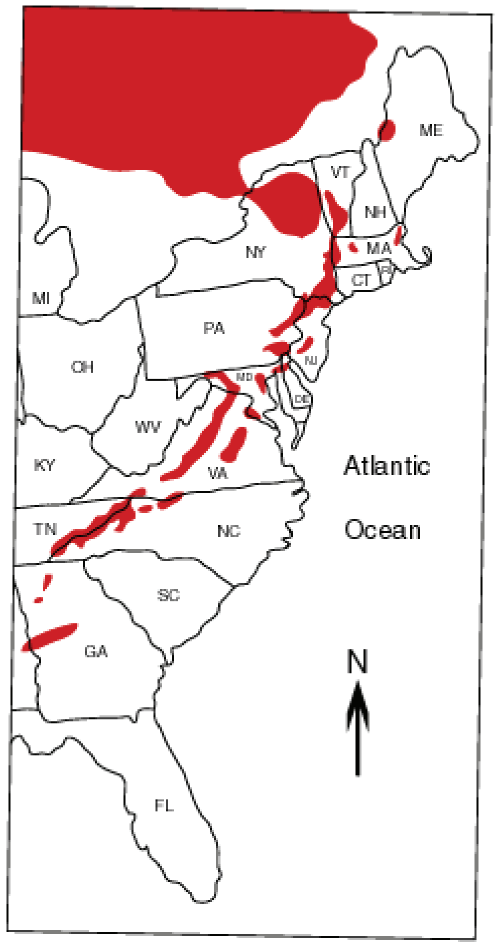

Figure 10. Map showing the location of rocks older than 1.1 billion years (red areas) in southeastern Canada and the eastern United States. The red areas indicate remnants of the ancient supercontinent. Adapted from Clark (2001).

Glossary

This glossary contains brief definitions of technical geologic terms used in this report. Not all geologic terms used are referenced. For more detailed definitions or to find terms not listed here please visit: http://wrgis.wr.usgs.gov/docs/parks/misc/glossarya.html.

active margin. A continental margin where significant volcanic and earthquake activity occurs; commonly a convergent plate margin.

acritarch. A unicellular, or apparently unicellular, resistant walled microscopic organic body of uncertain biologic relationship.

alluvial fan. A fan-shaped deposit of sediment that accumulates where a high-gradient stream flows out of a mountain front into an area of lesser gradient, such as a valley.

alluvium. Stream-deposited sediment that is generally rounded, sorted, and stratified.

angular unconformity. An unconformity where the strata above and below are oriented differently; generally caused by structural deformation and erosion prior to deposition of the upper bed.

anticlinorium. A composite anticlinal structure of regional extent composed of lesser folds.

aquifer. Rock or sediment that are sufficiently porous, permeable, and saturated to be useful as a source of water.

argillaceous. Pertaining to, composed of, or largely composed of clay minerals.

ash (volcanic). Fine pyroclastic material ejected from a volcano (also see "tuff").

asthenosphere. Weak layer in the upper mantle below the lithosphere where seismic waves are attenuated.

basement. The undifferentiated rocks, commonly igneous and metamorphic, that underlie the rocks of interest.

basin (structural). A doubly-plunging syncline in which rocks dip inward from all sides (also see "dome").

basin (sedimentary). Any depression, from continental to local scales, into which sediments are deposited.

bed. The smallest sedimentary strata unit, commonly ranging in thickness from one centimeter to a meter or two and distinguishable from beds above.

bedding. Depositional layering or stratification of sediments.

bedrock geology. The geology of underlying solid rock as it would appear with the sediment, soil, and vegetative cover stripped away.

block (fault). A crustal unit bounded by faults, either completely or in part.

braided stream. A stream, clogged with sediment that forms multiple channels that divide and rejoin.

calcareous. A rock or sediment containing calcium carbonate.

carbonaceous. A rock or sediment with considerable carbon, especially organics, hydrocarbons, or coal.

cementation. Chemical precipitation of material into pores between grains that bind the grains into rock.

chemical sediment. A sediment precipitated directly from solution (also called "nonclastic").

chemical weathering. The dissolution or chemical breakdown of minerals at Earth's surface via reaction with water, air, or dissolved substances.

clastic. Rock or sediment made of fragments or pre-existing rocks.

clay. Clay minerals or sedimentary fragments the size of clay minerals (>1/256 mm).

cleavage (rock). The tendency of rock to break along parallel planes that correspond to the alignment of platy minerals.

concordant. Strata with contacts parallel to the attitude of adjacent strata.

conglomerate. A coarse-grained sedimentary rock with clasts larger than 2 mm in a fine-grained matrix.

continental crust. The type of crustal rocks underlying the continents and continental shelves; having a thickness of 25–60 km (16–37 mi) and a density of approximately 2.7 grams per cubic centimeter.

continental drift. The concept that continents have shifted in position over Earth (see and use "plate tectonics").

continental rise. Gently sloping region from the foot of the continental slope to the abyssal plain.

continental shelf. The shallowly submerged part of a continental margin extending from the shoreline to the continental slope with water depths of less than 200 m (656 ft).

continental shield. A continental block of Earth's crust that has remained relatively stable over a long period of time and has undergone only gentle warping compared to the intense deformation of bordering crust

continental slope. The relatively steep slope from the outer edge of the continental shelf down to the more gently sloping ocean depths of the continental rise or abyssal plain.

convergent boundary. A plate boundary where two tectonic plates are moving together (i.e., a zone of subduction or obduction).

craton. The relatively old and geologically stable interior of a continent (also see "continental shield").

cross-bedding. Uniform to highly varied sets of inclined sedimentary beds deposited by wind or water that indicate distinctive flow conditions.

cross section. A graphical interpretation of geology, structure, and/or stratigraphy in the third (vertical) dimension based on mapped and measured geological extents and attitudes depicted in an oriented vertical plane.

crust. The outermost compositional shell of Earth, 10–40 km (6–25 mi) thick, consisting predominantly of relatively low-density silicate minerals (also see "oceanic crust" and "continental crust").

crystalline. Describes the structure of a regular, orderly, repeating geometric arrangement of atoms

debris flow. A rapid and often sudden flow or slide of rock and soil material involving a wide range of types and sizes.

deformation. A general term for the process of faulting, folding, shearing, extension, or compression of rocks as a result of various Earth forces.

delta. A sediment wedge deposited at a stream's mouth where it flows into a lake or sea.

dike. A tabular, discordant igneous intrusion.

dip. The angle between a structural surface and a horizontal reference plane measured normal to their line of intersection.

dip-slip fault. A fault with measurable offset where the relative movement is vertical. These include normal and reverse faults.

disconformity. An unconformity at which the bedding of the strata above and below are parallel.

discordant. Having contacts that cut across or are set an angle to the orientation of adjacent rocks.

divergent boundary. A tectonic plate boundary where the plates are moving apart (e.g., a spreading ridge or continental rift zone).

drainage basin. The total area from which a stream system receives or drains precipitation runoff.

eustatic. Relates to simultaneous worldwide rise or fall of sea level in Earth's oceans.

evaporite. Chemically precipitated mineral(s) formed by the evaporation of solute-rich water under restricted conditions.

exfoliation. The breakup, spalling, peeling, flaking, etc., of layers or concentric sheets from an exposed rock mass due to differential stresses resulting from thermal changes or pressure unloading.

extrusion. The emission of relatively viscous lava onto the Earth's surface; also, the rock so formed.

extrusive. Of or pertaining to the eruption of igneous material onto the surface of Earth.

facies (metamorphic). The pressure-temperature regime that results in a particular, distinctive metamorphic mineralogy (i.e., a suite of index minerals).

facies (sedimentary). The depositional or environmental conditions reflected in the sedimentary structures, textures, mineralogy, fossils, etc. of a sedimentary rock.

fault. A subplanar break in rock along which relative movement occurs between the two sides.

foliation. A general term for a planar arrangement of textural or structural features in any type of rock.

foot-wall. The underlying side of a fault. Where a fault plane slopes the foot-wall is below the hanging-wall.

formation. Fundamental rock-stratigraphic unit that is mappable and lithologically distinct from adjoining strata and has definable upper and lower contacts.

fracture. Irregular breakage of a mineral; also any break in a rock (e.g., crack, joint, fault)

frost wedging. The breakup of rock due to the expansion of water freezing in fractures.

geology. The study of Earth including its origin, history, physical processes, components, and morphology.

gneiss. A foliated rock formed by regional metamorphisim.

hanging-wall. The overlying side of a fault. Where a fault plane slopes the hanging wall is above the footwall.

igneous. Refers to a rock or mineral that originated from molten material; one of the three main classes or rocks—igneous, metamorphic, and sedimentary.

intrusion. A body of igneous rock that invades older rock. The invading rock may be a plastic solid or magma that pushes its way into the older rock.

island arc. A line or arc of volcanic islands formed over and parallel to a subduction zone.

isostasy. The process by which the crust "floats" at an elevation compatible with the density and thickness of the crustal rocks relative to underlying mantle.

isostatic adjustment. The shift of the lithosphere of the Earth to maintain equilibrium among units of varying mass and density; excess mass above is balanced by a deficit of density below, and vice versa.

joint. A semi-planar break in rock without relative movement of rocks on either side of the fracture surface.

karst topography. Topography characterized by abundant sinkholes and caverns formed by the dissolution of calcareous rocks.

lacustrine. Pertaining to, produced by, or inhabiting a lake or lakes.

lamination. The finest stratification or bedding as seen in shale and siltstone (syn: lamina or laminae) or the formation of laminae.

landslide. Any process or landform resulting from rapid mass movement under relatively dry conditions.

lava. Magma that has been extruded out onto Earth's surface, both molten and solidified.

levees. Raised ridges lining the banks of a stream; may be natural or artificial.

limbs. The two sides of a structural fold on either side of its hingeline.

lineament. Any relatively straight surface feature that can be identified via observation, mapping, or remote sensing, commonly representing tectonic features.

lithification. The conversion of sediment into solid rock.

lithology. The description of a rock or rock unit, especially the texture, composition, and structure of sedimentary rocks.

lithosphere. The relatively rigid outmost shell of Earth's structure, 50–100 km (31–62 mi) thick, that encompasses the crust and uppermost mantle.

loess. Silt-sized sediment deposited by wind, generally of glacial origin.

mafic. A rock, magma, or mineral rich in magnesium and iron.

magma. Molten rock generated within the Earth that is the parent of igneous rocks.

mantle. The zone of Earth's interior between crust and core.

matrix. The fine-grained interstitial material between coarse grains in porphyritic igneous rocks and poorly sorted clastic sediments or rocks.

meanders. Sinuous lateral curves or bends in a stream channel.

mechanical weathering. The physical breakup of rocks without change in composition (syn: physical weathering).

member. A lithostratigraphic unit with definable contacts that subdivides a formation.

metamorphic. Pertaining to the process of metamorphism or to its results.

metamorphism. Literally, "change in form." Metamorphism occurs in rocks through mineral alteration, genesis, and/or recrystallization from increased heat and pressure.

mid-ocean ridge. The continuous, generally submarine, seismic, median mountain range that marks the divergent tectonic margin(s) in the world's oceans.

mineral. A naturally occurring, inorganic crystalline solid with a definite chemical composition or compositional range.

mud cracks. Cracks formed in clay, silt, or mud by shrinkage during subaerial dehydration.

nonconformity. An erosional surface preserved in strata in which crystalline igneous or metamorphic rocks underlie sedimentary rocks.

normal fault. A dip-slip fault in which the hanging wall moves down relative to the footwall.

obduction. The process by which the crust is thickened by thrust faulting at a convergent margin.

oceanic crust. Earth's crust formed at spreading ridges that underlies the ocean basins. Oceanic crust is 6–7 km (3–mi) thick and generally of basaltic composition.

orogeny. A mountain-building event, particularly a well-recognized event in the geological past (e.g., the Laramide orogeny).

outcrop. Any part of a rock mass or formation that is exposed or "crops out" at Earth's surface.

overbank deposits. Alluvium deposited outside a stream channel during flooding.

paleogeography. The study, description, and reconstruction of the physical geography from past geologic periods.

paleontology. The study of the life and chronology of Earth's geologic past based on the phylogeny of fossil organisms.

Pangaea. A theoretical, single supercontinent that existed during the Permian and Triassic Periods (also see "Laurasia" and "Gondwana").

parent (rock). The original rock from which a metamorphic rock or soil was formed.

passive margin. A tectonically quiet continental margin indicated by little volcanic or seismic activity.

pebble. Generally, small, rounded rock particles from 4 to 64 mm in diameter.

permeability. A measure of the ease or rate that fluids move through rocks or sediments.

plateau. A broad, flat-topped topographic high of great extent and elevation above the surrounding plains, canyons, or valleys (both land and marine landforms).

plate tectonics. The theory that the lithosphere is broken up into a series of rigid plates that move over Earth's surface above a more fluid aesthenosphere.

pluton. A body of intrusive igneous rock.

plutonic. Describes igneous rock intruded and crystallized at some depth in the Earth.

porosity. The proportion of void space (cracks, interstices) in a volume of a rock or sediment.

progradation. The seaward building of land area due to sedimentary deposition.

provenance. A place of origin. The area from which the constituent materials of a sedimentary rock were derived.

radioactivity. The spontaneous decay or breakdown of unstable atomic nuclei.

radiometric age. An age in years determined from radioisotopes and their decay products.

recharge. Infiltration processes that replenish ground water.

red beds. Sedimentary strata composed largely of sandstone, siltstone, and shale that are predominantly red due to the presence of ferric oxide (hematite) coating individual grains.

regression. A long-term seaward retreat of the shoreline or relative fall of sea level.

relative dating. Determining the chronological placement of rocks, events, fossils, etc. from geological evidence.

reverse fault. A contractional, high-angle (>45°), dip-slip fault in which the hanging wall moves up relative to the footwall (also see "thrust fault").

rift valley. A depression formed by grabens along the crest of an oceanic spreading ridge or in a continental rift zone.

ripple marks. The undulating, subparallel, usually small-scale ridge pattern formed on sediment by the flow of wind or water.

rock. A solid, cohesive aggregate of one or more minerals or mineraloids.

roundness. The relative amount of curvature of the "corners" of a sediment grain, especially with respect to the maximum radius of curvature of the particle.

sandstone. Clastic sedimentary rock of predominantly sand-sized grains.

scarp. A steep cliff or topographic step resulting from vertical displacement on a fault or by mass movement.

seafloor spreading. The process by which tectonic plates diverge and new lithosphere is created at oceanic ridges.

sediment. An eroded and deposited, unconsolidated accumulation of lithic and mineral fragments.

sedimentary rock. A consolidated and lithified rock consisting of detrital and/or chemical sediment(s).

sequence. A major informal rock-stratigraphic unit that is traceable over large areas and defined by a major sea level transgression-regression sediment package.

shale. A clastic sedimentary rock made of clay-sized particles that exhibit parallel splitting properties.

silt. Clastic sedimentary material intermediate in size between fine-grained sand and coarse clay (1/256–1/16 mm).

siltstone. A variably lithified sedimentary rock composed of silt-sized grains.

slickenside. A smoothly polished and commonly striated surface representing deformation of a fault plane.

slope. The inclined surface of any geomorphic feature or rational measurement thereof (syn: gradient).

slump. A generally large, coherent mass movement with a concave-up failure surface and subsequent backward rotation relative to the slope.

soil. Surface accumulation of weathered rock and organic matter capable of supporting plant growth and commonly overlying the parent rock from which it formed.

spring. A site where water flows out at the surface due to the water table intersecting the ground surface.

strata. Tabular or sheetlike masses or distinct layers (e.g., of rock).

stratigraphy. The geologic study of the origin, occurrence, distribution, classification, correlation, age, etc. of rock layers, especially sedimentary rocks.

stream. Any body of water moving under gravity flow and confined within a channel.

strike. The compass direction of the line of intersection that an inclined surface makes with a horizontal plane.

strike-slip fault. A fault with measurable offset where the relative movement is parallel to the strike of the fault.

subduction zone. A convergent plate boundary where oceanic lithosphere descends beneath a continental or oceanic plate and is carried down into the mantle.

subsidence. The gradual sinking or depression of part of Earth's surface.

suture. The linear zone where two continental landmasses become joined due to obduction.

syncline. A fold of which the core contains the stratigraphically younger rocks; it is generally concave upward.

synclinorium. A composite synclinal structure of regional extent composed of lesser folds.

tectonic. Relating to large-scale movement and deformation of Earth's crust.

tectonics. The geological study of the broad structural architecture and deformational processes of the lithosphere and aesthenosphere (also see "structural geology").

terraces (stream). Step-like benches surrounding the present floodplain of a stream due to dissection of previous flood plain(s), stream bed(s), and/or valley floor(s).

terrane. A region or group of rocks with similar geology, age, or structural style.

terrestrial. Relating to Earth or Earth's dry land.

theory. A hypothesis that has been rigorously tested against further observations or experiments to become a generally accepted tenet of science.

thrust fault. A contractional, dip-slip fault with a shallowly dipping fault surface ($<45^o$) where the hanging wall moves up and over relative to the footwall.

topography. The general morphology of Earth's surface including relief and location of natural and anthropogenic features.

trace (fault). The exposed intersection of a fault with Earth's surface.

trace fossils. Sedimentary structures, such as tracks, trails, burrows, etc., that preserve evidence of organisms' life activities, rather than the organisms themselves.

transgression. Landward migration of the sea due to a relative rise in sea level.

trend. The direction or azimuth of elongation of a linear geological feature.

type locality. The geographic location where a stratigraphic unit is well displayed, is formally defined as a typical section, and derives its name.

unconformity. A surface within sedimentary strata that marks a prolonged period of nondeposition or erosion.

uplift. A structurally high area in the crust, produced by movement that raises the rocks.

volcanic. Related to volcanoes; describes igneous rock crystallized at or near Earth's surface (e.g., lava).

water table. The upper surface of the saturated (phreatic) zone.

weathering. The set of physical, chemical, and biological processes by which rock is broken down in place.

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Appendix A: Geologic Map Graphic

The following page is a snapshot of the geologic map for Great Smoky Mountains National Park. For a poster-size PDF of this map or for digital geologic map data, please see the included CD or visit the Geologic Resource Evaluation publications Web page (http://www.nature.nps.gov/geology/inventory/gre_publications).

Appendix B: Scoping Summary

The following excerpts are from the GRE scoping summary for Great Smoky Mountains National Park. The scoping meeting was held on May 8-9, 2000; therefore, the contact information and Web addresses referred to in this appendix may be outdated. Please contact the Geologic Resources Division for current information.

Executive Summary

An inventory workshop was held for Great Smoky Mountain National Park (GRSM) on May 8-9, 2000 to view and discuss the park's geologic resources, to address the status of geologic mapping by the United States Geological Survey (USGS), various academics, the North Carolina Geological Survey (NCGS), and the Tennessee Geological Survey (TNGS) for compiling both paper and digital maps, and to assess resource management issues and needs. Cooperators from the NPS Geologic Resources Division (GRD), Natural Resources Information Division (NRID), NPS Great Smoky Mountain NP, USGS, NCGS, TNGS, University of Tennessee at Knoxville (UTK) and the Tennessee Department of Transportation (TDOT) were present for the two-day workshop.

Day one involved a field trip throughout Great Smoky Mountain NP led by USGS Geologist Scott Southworth.

Day two involved a daylong scoping session to present overviews of the NPS Inventory and Monitoring (I&M) program, the Geologic Resources Division, and the ongoing Geologic Resources Evaluation (GRE) for North Carolina.

Round table discussions involving geologic issues for Great Smoky Mountain NP included interpretation, paleontologic resources, the status of cooperative geologic mapping efforts, sources of available data, geologic hazards, and action items generated from this meeting. Brief summaries follow.

Geologic Mapping

Existing Geologic Maps

After the bibliographies were assembled, a separate search was made for any existing surficial and bedrock geologic maps for Great Smokies. The bounding coordinates for each map were noted and entered into a GIS to assemble an index geologic map. Separate coverages were developed based on scales (*1:24,000, 1:100,000*, etc.) available for the specific park.

Numerous geologic maps at varying scales and vintages cover the Great Smokies area. In addition, the USGS is currently involved in a comprehensive project to refine the mapping of GRSM, led by Scott Southworth.

Developing Geologic Products

GRSM Perspective

Some of the main geologic issues that GRSM staff is interested in are:

- Geologic hazards (landslides, debris flows, earthquakes);
- Complete geologic map coverage for all of GRSM at 1:24,000 scale;
- Interpretation of geologic features and processes for the visiting public to explain how landscapes have changed and why people have come to this region over the years.
- geology as it relates to the All Taxa Biodiversity Inventory (ATBI); and man's effects on natural processes

Geologic hazards are a common theme at GRSM because of landslides and debris flows that can affect the visiting public (estimated at 10 million per year) and destroy park roads. Earthquakes are also of interest to park staff. Seismic stations in the area are sparse. It was suggested to have one in the park, as this is one of the higher earthquake activity areas east of the New Madrid Fault zone. Unfortunately, earthquakes usually only receive attention after they have occurred. Bob Hatcher mentioned that UTK has a website on earthquake activity in the region at: http://tanasi.gg.utk.edu/quakes.html

Keith Langdon (GRSM) gave the group some background on why the park thinks geology is important to understanding the other natural resources of GRSM. The ATBI currently underway relies heavily on geology and its influences on soils and general geochemistry of the park.

GRSM does not have a staff geologist, so in 1992 they requested assistance from the USGS for help in geologic mapping, mining issues and general understanding of geomorphic/geologic features and processes.

Geology plays a large role in ecosystem management and is thus a major component for understanding species distribution, soils and general geochemistry as it pertains to the ATBI. GRSM would like to derive "probability" maps based upon these associations to better predict biologic distributions, which should be possible with sufficient geologic data.

Chuck Parker (USGS-Biologist stationed at GRSM) talked of how man's activities have disrupted biologic processes in the park, specifically where Anakeesta metasediments have been used as road fill. The highly acidic nature of the Anakeesta Formation has indirectly affected fish and salamander populations in the Newfound Gap area negatively.

Chuck is also interested in the timing for waterfall development in the park, especially at Black Creek Falls

(?). Fish populations above the waterfalls are important to the biologic story and he hopes that geologic data will give him some controls on when these features developed. Bob Hatcher talked of recent uplift and the subsequent effects on drainages being the major control on these features. The evolving science of cosmogenic isotope dating may be able to shed more information on this subject; dates of ~172,000-year exposure were mentioned for the area.

Chuck would like to know if there are geologic controls related to the floral-faunal break between southern and northern brook trout.

USGS Perspective

Scott Southworth updated the group on the existing USGS project to conduct regional geologic mapping and produce digital geologic databases for GRSM to support the ATBI.

Some of the more interesting things about GRSM geology for Scott are:

- Sulfitic rocks,
- Large areas with debris flows underlain by Anakeesta and Chilhowee rock types,
- Karst areas,
- Limestones in Foothills block of Walden Creek Group and Cosby,
- Mapping the geology correctly and producing a usable geologic database,
- Evidence east of Gatlinburg lending support to neotectonics in park (fission track data suggest post Cretaceous uplift along faults there),
- fans in Cosby area where bedrock geology is Greenbrier, Dunn Creek and Great Smoky and all converge at one site in the foothills,
- abandoned meanders of Little River,
- White Oak Sink,
- Big Spring Cove area has a window based on geomorphology,
- Cades Cove,
- well developed elevated colluvial terraces of Tuckasegee River near Bryson City, and
- Foothills Parkway has geomorphic bedrock controlled features (perched, abandoned valley sitting up high).

He distributed “USGS Project: Geology of the Great Smoky Mountains NP”, which summarized USGS activities at GRSM. The joint NPS-USGS project was initiated in October 1992 by the NPS Southeast Region and an interagency agreement was developed.

Its initial goals were to:

- produce geologic maps for unmapped 1:24,000 quadrangles,
- upgrade existing 1:62,500 scale mapping to 1:24,000 scale,
- conduct detailed surficial mapping of the entire park, and
- develop digital geologic map coverage for use in a park-wide GIS.

As a result, the following quadrangles have been mapped and published:

- Fontana Dam and Tuskeegee (Southworth 1995; OF 95-264)
- Mount LeConte (Schultz 1998; OF 98-32)
- Cades Cove (Southworth et al. 1999; OF 99-175; http://geology.er.usgs.gov/eespteam/smoky/cades_cove/Cades_Cove_WP/introduction.htm)
- Mount Guyot, Luftee Knob and Cove Creek (Schultz 1999; OF 99-536)

Additionally, other miscellaneous products to date include:

- Report on Sulfidic rocks of Lakeshore Drive “Road to Nowhere” (?? correct terminology) for Senator Helms inquiry, Interpretation workshop with Gene Cox, and report on secondary minerals from weathering of Anakeesta Formation at Alum Cave (Flohr et al. 1995; OF 95-477)
- Report on water chemistry related to Fontana Mine and sulfidic rocks (Seal et al. 1998; OF 98-476 and Seal et al. 1999; OF 99-375)
- Report on Paleozoic fossils (Repetski 1999; NPS-GRD Technical Report 98-1
- Various abstracts on fission track analysis for uplift rates (Naesers)
- Folio on Geologic map (which Scott considers as only preliminary at this time) and geologic history of Great Smoky Mountains NP; a visitors guide (Great Smoky Mountains Natural History Association in cooperation with USGS, 2000)

Anticipated products in the near future are:

- Digital Mount LeConte quadrangle (Schultz) (now completed as USGS Open-File Report 00-261) and website (Southworth)
- *1:100,000* scale geologic compilation map for GRSM
- geochemistry of black sulfidic shales (Foley)
- lithogeochemistry of bedrock units (Robinson)
- Remote sensing (Rowan)
- Fission track for timing of uplift (Naesers)
- Be10 dating of erosion surfaces and surficial deposits
- [Also completed is the geologic map of Cades Cove and Calderwood quadrangles, USGS Open-File Report 99-175]

More details on these projects can be found at: http://geology.er.usgs.gov/eespteam/smoky/smoky.html

Scott hopes to work closely with Natural Resource Conservation Service (NRCS) personnel who are currently mapping the soils, to integrate with USGS work and make sure that it can all be incorporated into a master geologic database.

Scott displayed a new plot of vegetation classes (*1:125,000 scale*) derived from LANDSAT data from spectral satellites, sometimes called HIMAP technology. This makes for a good mineralogical and vegetation mapping tool as it uses some 260 channels of spectral data at 0.01 micron wavelength and 2 meter resolution. This particular map covered only the western edge of the park, and it is hoped that the entire park will be flown in the near future.

As of May 2000, the USGS project is only funded through December 2001 by the USGS. The NPS is very supportive of USGS efforts at GRSM and is willing to lend any support to ensuring the continuance of this project until completion.

Scott has requested a letter from the acting GRSM superintendent as a show of support for continuing this project to give to his managers at the USGS. To date, it is unknown if such a letter has been sent by the park. GRE staff will follow up on this matter with GRSM staff.

Scott also mentioned that the existing topographic base map coverage leaves much to be desired and often hinders the geologic mapping process. Currently, base cartographic data are only available as DRGs (digital raster graphics). Joe Gregson thought that DLGs (digital line graphs) would be produced later this year that would be more useful in geologic analysis.

Scott is very interested in having a separate meeting with USGS, GRE and GRSM staff to further discuss the database he is developing, and how it can fulfill the desired GRE goals. GRE staff intends to work closely and cooperatively to meet this goal.

USGS Professional Paper 349 is devoted to the geology of GRSM.

TNGS Perspective

Pete Lemiszki (TNGS) says that his group is not actively working in GRSM, but would like to have a better working relationship with the USGS, NCGS and NPS as it pertains to the geologic issues regarding GRSM. Specifically, Pete would be interested in further studying fracture systems and the hydrology for applications in hydrogeology, landslides, and geologic hazards.

Pete located the original 1948 geologic mapping park plan by Philip B. King in their archives; these documents may be of historical significance and GRD would like to obtain copies if possible for our “History of Geologic Exploration” section for our report.

Pete mentioned that TNGS has an agreement in place with USGS to digitize all existing quadrangles in Tennessee, and they are awaiting deliverables from the USGS. The format for the deliverables was unknown at the time of the meeting.

NCGS Perspective

Carl Merschat (NCGS) told the group that the NCGS was involved in a cooperative mapping project with the Tennessee Valley Authority (TVA), but most of their efforts have been concentrated along the Blue Ridge Parkway.

However, NCGS has published the Noland Creek quadrangle that was mapped as part of a graduate thesis. Also, the western half of the Asheville 1:100,000 sheet is slated for completion by 2006 and the eastern half by 2003. This sheet consists of 32 1:24,000 quadrangles. Scott Southworth expressed interest in further discussing this mapping project with NCGS staff for stratigraphic correlations and identification of similar map units.

Academic Perspective

Bob Hatcher (UTK) has had numerous students mapping in and around GRSM for many years, including NCGS Geologist Mark Carter (now with the Virginia Division of Mineral Resources). Some of the mapping was done at 1:12,000 and compiled at 1:24,000 scale. The Dellwood and Bunches Bald quadrangles were specifically mentioned.

Bob mentioned a few things of interest to him regarding GRSM geology:
Is the Cades Sandstone actually the Thunderhead?
The Web Mountain area appears to be a “window”
Phil King (USGS mapper in 1940s) may have miscorrelated some units
The NPS bibliography is missing numerous articles of relevance to GRSM that he knows of; he has since supplied those references to add to our bibliography
He is very interested in seeing a geologic database for GRSM and hopes it will be an excellent resource for the geologic community for many years to come.
He spoke of research to core in caves to determine the rates of earthquake occurrence in the region and use deformed flood plain sediments to deduce earthquake timing; use “teetering” rocks to know when earthquakes have occurred.

Issues

Interpretation

One goal of GRD is to promote geologic resource interpretation within the National Park Service. GRD has staff and technology to assist in preparation of useful materials including developing site specific bulletins, websites, and resource management proposal (RMP) statements appropriate to promoting geology. Jim Wood (GRD) and others have worked with several other NPS units in developing web-based geology interpretation themes, and should be considered as a source of assistance should the park desire. GRD has also received much positive recognition for the “Park Geology Tour of National Parks” and subsequent “Geology Field Notes” at http://www2.nature.nps.gov/grd/tour/index.htm. GRD posted these sites based on available park brochures, but they are always in need of fresh material. Park staff may wish to review these and suggest improvements to GRD.

Paleontology

GRD provides support on policy and Government Performance and Results Act (GPRA) goals related to paleontological resources in parks.
At the present time, Paleontology is *not* one of the main baseline natural resource inventories, but it has been included within the GRE.

GRD staff has led refresher-training courses for NPS rangers at multiple parks to raise awareness for the protection of paleontological resources. Often a first step is for parks to determine whether they have paleontological resources, and then to have a baseline inventory completed.

Many parks have become interested in having Paleontological Surveys conducted. Surveys are already completed or in progress for Big Bend, Zion, Yellowstone and Death Valley. Vince Santucci (Vince_Santucci@nps.gov; NPS Paleontologist) is willing to discuss such matters with park staff, if they are interested. Often, these surveys have shed valuable new information on previously unrecognized resources. These surveys involve a literature review and subsequent bibliography, as well as recognition of type specimens, species lists, and maps (which are unpublished to protect locality information), and also make park specific recommendations for protecting and preserving the resources.

Samples of existing paleontological surveys are available online at:
http://www2.nature.nps.gov/grd/geology/paleo/surveys/surveys.htm

If a paleontological survey were conducted and yielded significant findings, the following might be derivative steps:

- Develop resource management plans including inventory and monitoring to identify human and natural threats to these resources;
- Incorporate findings or suggestions into park general management plans (GMP);
- train park staff (including interpreters and law enforcement) in resource protection; the fossil trade "black market" has become quite lucrative for sellers and often results in illegal collecting from federal lands;
- Collections taken from the area residing in outside repositories could be tracked down for inventory purposes;

Fossils offer many interpretive themes and combine a geology/biology link and should be utilized as much as possible in interpretive programs.

List of Scoping Meeting attendees with contact information

NAME	AFFILIATION	PHONE	E-MAIL
Joe Gregson	NPS, Inventory & Monitoring Program	(970) 225-3559	Joe_Gregson@nps.gov
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Bob Hatcher	Univ. of Tennessee	(423) 974-6565	Bobmap@utk.edu
Carl Merschat	North Carolina Geologic Survey	(828) 251-6208	Carl.Merschat@ncmail.net
Peter Lemiszki	Tennessee Geologic Survey	(865) 594-5596	plemiszki@mail.state.tn.us
Keith Langdon	NPS, GRSM	(423) 436-1705	Keith_Langdon@nps.gov
Mark Carter	Virginia Division of Mineral Resources	828-251-6208	mark.carter@dmme.virginia.gov
Chuck Parker	USGS	865-436-1704	Chuck_Parker@usgs.gov
Harry Moore	TN DOT	865-594-9436 865-594-9373	Hmoore@mail.state.tn.us
Richard Schulz	GRSM, GIS	865-430-4745	Richard_Schulz@nps.gov
Lindsay McClelland	NPS, Geologic Resources Division	202-513-7185	Lindsay_mcclelland@nps.gov
Michael Kunze	NPS, GRSM	865-436-1703	Michael_Kunze@nps.gov

Existing Geologic Maps for GRSM

Quadrangle	Scale	Author	Year	Digital	Acceptable for database	Pub #
Blockhouse	1:24,000	R.B. Neuman & R.L. Wilson	1960			GQ 131
Bryson City						
Bunches Bald						
Cades Cove	1:24,000	Scott Southworth et al.	2000	Yes		OF 99-0175
Calderwood	1:24,000	Scott Southworth et al.	2000	yes		OF 99-0175
Clingmans Dome						
Cove Creek Gap	1:24,000	Art Schultz	1999			OF 99-0536
Dellwood						
Fontana Dam	1:24,000	Scott Southworth	1995			OF 95-0264
Gatlinburg	1:24,000	P.B. King	1964			PP-349 C
Hartford						
Jones Cove	1:24,000	Warren Hamilton	1961			PP-349 A
Kinzel Springs	1:24,000	R.B. Neuman & W.H. Nelson	1965			PP-349 D[1]
Luftee Knob	1:24,000	Art Schultz	1999			OF 99-0536
Mount Guyot	1:24,000	Art Schultz	1999			OF 99-0536
Mount Le Conte	1:24,000	Art Schultz et al.	2000	yes		OF 00-261
Noland Creek	1:24,000	David Moh	1975			NCGS
Pigeon Forge	1:24,000	P.B. King	1964			PP-349 C
Richardson Cove	1:24,000	Warren Hamilton	1961			PP-349 A
Silers Bald	1:24,000	P.B. King	1964			PP-349 C
Smokemont						
Tapoco						
Thunderhead Mountain	1:24,000	P.B. King	1964			PP-349 C
Tuskeegee	1:24,000	Scott Southworth	1995			OF 95-0264
Walden Creek	1:24,000	P.B. King	1964			PP-349 C
Waterville						
Wear Cove	1:24,000	P.B. King	1964			PP-349 C[2]
Whittier						

[1] Portions of the Wildwood, Kinzel Springs, Blockhouse, Tallassee, Calderwood, and Cades cove quadrangles are compiled at 1;62,500 in USGS PP 349- D

[2] portions of the Walden Creek, Pigeon Forge, Wear Cove, Gatlinburg, Thunderhead Mountain, and Silers Bald quadrangles are compiled at 1:62,500 scale in USGS PP 349- B

Maps associated with USGS Professional Paper 349

Folio and Title	Quadrangles covered	Scale	Author	Year
A Geology of the Richardson Cove and Jones Cove Quadrangles	Richardson Cove Jones Cove	1:24,000	Warren Hamilton	1961
B Geology of the eastern Great Smoky Mountains, North Carolina and Tennessee	??	1:62,500	Hadley, J.B.; Goldsmith, R.,	1963
C Geology of the Central Great Smoky Mountains Tennessee	Walden Creek Pigeon Forge Wear Cove Gatlinburg Thunderhead Mountain Silers Bald	1:24,000	Philip B. King	1964
	All above compiled as "Central" map	1:62,500		
D Geology of the Western Great Smoky Mountains Tennessee	Kinzel Springs	1:24,000	Robert B. Neuman; Willis H. Nelson	1965
	Portions of : Wildwood Kinzel Springs Blockhouse Tallassee Calderwood Cades Cove	1:62,500		

Great Smoky Mountains National Park

Geologic Resource Evaluation Report

Natural Resource Report NPS/NRPC/GRD/NRR—2008/048
NPS D-626, September 2008

National Park Service

Director • Mary A. Bomar

Natural Resource Stewardship and Science

Associate Director • Bert Frost

Natural Resource Program Center

The Natural Resource Program Center (NRPC) is the core of the NPS Natural Resource Stewardship and Science Directorate. The Center Director is located in Fort Collins, with staff located principally in Lakewood and Fort Collins, Colorado and in Washington, D.C. The NRPC has five divisions: Air Resources Division, Biological Resource Management Division, Environmental Quality Division, Geologic Resources Division, and Water Resources Division. NRPC also includes three offices: The Office of Education and Outreach, the Office of Inventory, Monitoring and Evaluation, and the Office of Natural Resource Information Systems. In addition, Natural Resource Web Management and Partnership Coordination are cross-cutting disciplines under the Center Director. The multidisciplinary staff of NRPC is dedicated to resolving park resource management challenges originating in and outside units of the national park system.

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