



Surficial Geologic Map of the Great Smoky Mountains National Park Region, Tennessee and North Carolina

By Scott Southworth, Art Schultz, Danielle Denenny, and James Triplett

U.S. Geological Survey Open-File Report 03-381

Any use of trade, product, or firm names in this publication is for descriptive purposes only and does not imply endorsement by the U.S. Government.

U.S. Department of the Interior
U.S. Geological Survey

Surficial Geologic Map of the Great Smoky Mountains National Park Region, Tennessee and North Carolina

By Scott Southworth, Art Schultz, Danielle Denenny, and James Triplett

Introduction

The geology of the Great Smoky Mountain National Park region of Tennessee and North Carolina was studied from 1993 to 2003 as part of a cooperative investigation with the National Park Service (NPS). This 1:100,000-scale map is compiled from detailed mapping at 1:24,000 scale.

This preliminary surficial geologic data and map supports cooperative investigations with NPS, the U.S. Natural Resource Conservation Service, and the All Taxa Biodiversity Inventory (<http://www.dlia.org/>) (Southworth, 2001). Although the focus of our work was within the Park, the geology of the surrounding area is provided for regional context. Surficial deposits document the most recent part of the geologic history of this part of the western Blue Ridge and eastern Tennessee Valley of the Valley and Ridge Province of the Southern Appalachians. Additionally, there is great variety of surficial materials, which directly affect the different types of soil and associated flora and fauna. The surficial deposits accumulated over millions of years under varied climatic conditions during the Cenozoic era and resulted from a composite of geologic processes.

Previous Investigations

Studies of the surficial geology by Hamilton (1961), Hadley and Goldsmith (1963), King (1964), and Neuman and Nelson (1965), were incidental to the detailed investigations of the bedrock, although prominent surficial geologists (J. Gilluly, C.S. Denny, G.M. Richmond, J. Hack, and H.E. Malde) observed them in the field and provided insight for their reports. These workers recognized that the three dominant types of surficial deposits of the region are residuum, colluvium, and alluvium, and that many units were deposited during climatic conditions very different than those of today. Although a previous small-scale map of the park, at 1:125,000-scale (King and others, 1968), did not include surficial units, individual geologic maps of scales of 1:62,500 and 1:24,000 did include these three general types. Rozanski (1943), King and Stupka (1950), King (1964), Clark (1968), Michalek (1968), Richter (1973), Reheis (1972), Torbett and Clark (1985), and Clark and Ciolkosz (1988) interpreted polygonal ground, block streams, fan deposits, and other features in the Great Smoky Mountains as periglacial in origin.

Modern debris flows that occur in the highlands underlain by slate of the Anakeesta Formation have been described by Bogucki (1970; 1976), Koch (1974), Moore (1986), and Clark (1987).

Older fan deposits near Dellwood (Hadley and Goldsmith, 1963), have been studied more recently by Mills (1982; 1986), Kochel (1990), and Mills and Allison (1994; 1995a,b) also mapped and studied similar young, intermediate, and old fan deposits in the Hazelwood, NC, area.

Methodology

Surficial geologic units mapped in the field were compiled on 1:24,000-scale topographic base maps that mostly have 40-foot contour intervals. In general, topographic features on the surface of the deposits are not resolved by the 40-foot contour, since much of the micro-topography of the landscape and deposits have less than 40 feet of relief. These features include swales, ridges, terraces, bedrock pinnacles, and ephemeral streams.

Surficial deposits were mapped along selected field traverses, and by interpretation of aerial photographs and expression on topographic maps. The surficial units have distinctive geomorphic characteristics with mappable contacts, distinctly different from the surrounding units. For example, debris fans consist of diamicton of metasandstone that is distinctly different than the bedrock or residuum that underlie them, and from the colluvium derived from the local bedrock. These fans have distinct morphology with clear mappable boundaries. Conceptual models were generated from strategic field traverses that allow interpretation of landforms and recognition of surficial units away from the field observations. These traverses comprise several thousands of miles of trails and roads that cross the area. Outcrops include natural exposures provided by landslides, stream cut banks, as well as roadcuts, and rare excavations. Surficial units were revised from published 1:24,000-scale geologic maps of

Hadley and Goldsmith (1963), King (1964), Neuman and Nelson (1965), Southworth (1995), Southworth and others, 1999), Schultz (1998; 1999), and Schultz and others (2000). These published maps cover about 31 percent of the map area.

Surficial geologic map units were inked on mylar registered to latitude/longitude coordinates of 7.5-minute quadrangles (fig. 1), then digitally scanned and edited. The 7.5-minute quadrangles were then mosaicked for presentation at 1:100,000-scale. The base maps used are the 50-m contour interval 1:100,000-scale mosaic of the Knoxville, TN, and northern half of the Fontana Dam, NC, 30- by 60- minute quadrangles, and the 30-m digital elevation model (DEM) of the National Elevation Dataset (NED). Since the 30- by 60-minute metric maps were derived from the 7.5-minute maps, the 1:24,000-scale unit polygons may not correspond directly with the generalized topographic contours on the 1:100,000-scale base map.

The surficial units are defined primarily by materials with some reference to known or interpreted origin and age. For example, debris fans derived from granitic gneiss are mapped separately from debris fans of conglomeratic rock deposited on limestone. Both of these debris fans may be deposits of prehistoric debris flows, but the unit name relates to the landform and materials without reference to an interpreted origin.

General Geologic Setting and Physiography

The study area is centered on the Great Smoky Mountains National Park, situated in the western Blue Ridge Province (fig.2). The map area contains a small area of the eastern Blue Ridge Province of North Carolina (in the southeast), and part of the

Tennessee Valley section (Great Valley) of the Valley and Ridge Province (in the northwest). The regional drainage is westward to the Tennessee River and the Gulf of Mexico. The distribution and types of surficial deposits closely correspond to the physiographic provinces and bedrock (Schultz and Southworth, 2000) (fig.3).

The mountains of the region rise more than 4600 ft (1500 m) above adjacent valley floors with significant local relief of slopes in places reaching 18 to 28 degrees. Mean annual rainfall ranges from 65 to 98 inches (165 to 250 cm), making the area a temperate rainforest. Slopes are mostly covered with soil and residuum as much as 6 to 32 ft (2 to 10 m) deep; the heavy vegetation cover makes the slopes rather stable. The lowlands and coves were clear cut to support agriculture during early settlement of the 1800's.

Western Blue Ridge Province

Highlands Section

The western Blue Ridge Province consists of 2 sections, the highlands and the foothills. The highlands section is predominantly underlain by coarse metasedimentary rocks of the Neoproterozoic Great Smoky Group, followed by Mesoproterozoic gneiss, and lesser metasedimentary rocks of the Neoproterozoic Snowbird Group (King and others, 1968). The area has steep topography with relief ranging from about 1000 ft along the Little Tennessee River, to about 6643 ft on Clingmans Dome (305 to 2025 m). It is characterized by coarse slope material deposited as fans and coarse alluvium in upper drainages.

Foothills Section

The foothills section is northwest of the highlands and is characterized by rolling

hills with relief ranging from about 800 ft along the Little Tennessee River to about 3069 ft on Chilhowee Mountain and 4077 ft on Cove Mountain (244 to 1243 m). In part, faults form the boundary between the highlands and foothills sections, and coves, developed in the tectonic windows of the Great Smoky thrust fault, occur near the boundary. The bedrock of the foothills is predominantly fine- to coarse-grained metasedimentary rocks of the Neoproterozoic Walden Creek Group, fine-grained metasedimentary rocks of the Neoproterozoic Snowbird Group, lower Cambrian sandstone of the Chilhowee Group, Ordovician Jonesboro Limestone, and minor metasandstone of the Great Smoky Group. The coarse-grained and quartzose rocks hold up the high knobs, such as Webb Mountain, Shields Mountain, Green Mountain, and Chilhowee Mountain, whereas the carbonates and siltstones underlie the valleys and coves. Surficial deposits include debris deposits in the coves underlain by carbonate rock, and fan deposits along the northwest-facing outcrop slope of Chilhowee Mountain. Alluvium and terraces are better developed than in the highlands and there are few bouldery debris deposits. Karst features such as sinkholes, caves, and residuum occur in the coves and valleys underlain by limestone.

Eastern Blue Ridge Province

The southeastern part of the study area is in the western part of the eastern Blue Ridge Province. It is underlain by gneiss and schist, and has rugged topography like the adjacent western Blue Ridge province. The dominant surficial deposits are debris fans concentrated in hollows along the lower slope.

Tennessee Valley of the Valley and Ridge Province

The eastern part of the Tennessee Valley of the Valley and Ridge is underlain by

Ordovician limestone and thin siliciclastic rocks interbedded with limestone. The sandy and shaly beds underlie linear hills with relief ranging from about 900 ft to 1400 ft (274 to 427 m) on Bays Mountain. The dominant surficial deposits are broad alluvial flood plains, fluvial terraces, and local areas of residuum. Sinkholes also are common.

Surficial Deposits

Introduction

The surficial geology in the Great Smoky Mountains National Park region of Tennessee and North Carolina consist of three main types (Hadley and Goldsmith, 1963; King, 1964; Neuman and Nelson, 1965):

- 1) Alluvium (fine and coarse) and elevated terrace deposits of fluvial (rivers and creeks) origin,
- 2) Residual deposits due to chemical and physical weathering of limestone associated with karst landforms such as caves and sinkholes, and
- 3) Slope deposits including a) debris flows, b) colluvium, including block streams and block fields, and c) prehistoric debris fans.

In general, colluvium, debris fans, coarse alluvium, and terrace deposits, are a continuum but are distinguished from one another by slope and distance of transport by gravity and water. Abundant examples of this continuum are seen throughout the Park region, such as (from east to west), Cosby Creek, Rocky Grove, along the valley of the Little Pigeon River from Greenbriar Cove, the valley of Le Conte Creek, the valley of Sugarland, and the valley of Little River near Elkmont. Along the valley of Le Conte Creek from Mount Le Conte north to Gatlinburg (fig. 4), colluvium (Qc) occurs high on

the slope with modern talus (fig. 5) and older talus (fig. 6), boulder fields, and boulder streams (fig. 7) derived from weathering of the Thunderhead Sandstone. On lower slopes the material is transported to the lower slope by floods, creep, and solifluction, where it forms debris fans (Qd). For example, Cherokee Orchard was developed on a large debris fan (fig. 8). Twin Creeks has incised the debris from that fan, and removed fine material leaving coarse alluvium (Qac)(fig. 9). Downstream, Mynatt Park is a remnant of the same debris fan with incised coarse alluvium. Airport Road was developed on a terrace (QTt) developed on this fan. Exposures next to a parking lot expose the deposit on weathered metasilstone of the Elkmont Sandstone (fig. 10). These fluvial terraces have been incised by modern streams that flow through coarse alluvium and, locally, bedrock (fig.11).

Fluvial deposits and landforms

Fluvial deposits and landforms include alluvium (Qa and Qac) underlying valleys and modern flood plains, bedrock terraces or strath terraces with or without associated alluvial deposits (Qt), and upper level strath terraces with, or without, alluvial deposits (QTt) (fig.12).

Alluvium

Alluvium (Qa) consists of unconsolidated deposits of stratified silt, sand, gravel, and cobbles as much as 20 feet (6 m) thick that has been transported and deposited by running water. Alluvium is typically exposed along the banks where incised by creeks and rivers (fig.13) and in road cuts. The large valleys in areas like Cades Cove, Tuckaleechee Cove, and Wear Cove (west central part of the map), are broad alluvial plains that are not inundated by modern floods. Larger drainages like the Little River,

West Prong of the Little Pigeon River, Oconaluftee River, Tuckasegee River, and Jonathon Creek have narrow flood plains that are subject to high-water floods and deposition of alluvium. Most rivers at lower elevation occupy broad valleys. Extensive alluvium was deposited here in the past, but modern streams incise the alluvium and expose bedrock. The particle size of alluvium is a function of the parent bedrock and how far the material has been transported. Erosion-resistant, silica-rich bedrock produce abundant boulders and cobbles (fig. 14), whereas finer-grained bedrock units produce mostly silt and clay. Although alluvium (Qa) is ubiquitous on the map, its volume is not great.

One of the most characteristic features of the Great Smoky Mountains National Park region are creeks, streams, and rivers containing very coarse alluvium (fig.15 A-D). Coarse alluvium (Qac) occurs along drainages within the Blue Ridge highlands and consists of boulders of metasandstone and metaconglomerate as much as 33 ft (10 m) across. Boulders as much as 5 ft (16 m) across are actively transported during modern storms (Moneymaker, 1939; King, 1964). The size and abundance of boulders is a function of the local bedrock source. The predominant type of boulder is derived from massive, thick bedded, coarse metasandstone of the Thunderhead Sandstone, and they are blocky. Well-foliated biotite gneiss forms rectangular slabs of coarse alluvium in “The Gorge” of Raven Fork , above Big Cove, NC.

Previous workers referred to these deposits as alluvium or coarse bouldery alluvium (King, 1964). Much of the coarse alluvium is a lag deposit of pre-existing material in a debris fan from which the fines have been removed as modern drainages incise into it. They are the product of modern erosion of a relict deposit. Coarse

alluvium occurs in the upper reaches of Hazel Creek, Little River, Little Pigeon River, Big Creek, Oconaluftee River, Cataloochee Creek, and Straight Fork. Some areas of coarse alluvium have broad flood plains with fine alluvium preserved on top, as is the case at Rough Fork of Cataloochee Creek (fig. 16) and at the Pioneer Village at the Oconaluftee Visitor Center.

Terraces

Terraces (Qt) are underlain by benches, called straths, that are cut by rivers into bedrock and are comprised of unconsolidated sand, gravel, and cobbles (fig. 18). Terraces range from 10 to 120 ft (3 to 36 m) above modern water levels in the study area (fig. 17). The majority of clasts consist of resistant quartz-rich rocks that are in a fine-grained matrix of silt and clay. Terrace deposits are well developed along the Tuckasegee River in North Carolina, and along the Little River, West Prong Little Pigeon River, Little Pigeon River, Dunn Creek, and Cosby Creek (fig.19), in Tennessee. Terraces that are abandoned fluvial meanders occur at “The Sinks” along Little River (between Metacalf Bottoms and the Townsend “Y”) and along Camp Prong, about 2.5 mi (4 km) north-northwest of Clingmans Dome (fig.20). The meander at “The Sinks” is about 80 ft (24 m) above current water level and the Camp Prong meander is more than 200 ft (61 m) above current water level. Airport Road in Gatlinburg is on a terrace developed on the lower part of a boulder debris fan about 80 ft (24 m) above modern drainage.

Terraces near Glade (fig. 21) and Emerts Cove near Pittman Center (see fig.17) suggest an interesting history related to hardness of bedrock and subsequent stream capture. Terraces at the lower reach of Greenbrier are well developed on Pigeon Siltstone but not on Roaring Fork Sandstone. To the west, remnants of terrace gravel deposits are

preserved in “The Glades”, where no modern drainage exists. The earlier north-flowing drainage was captured by Dunn Creek, which flows west to Gatlinburg, leaving “the Glades” as an abandoned “dry” valley. On terraces near Pigeon Forge, TN, cobbles and pebbles of coarse metasandstone derived from the highlands were transported a distance of more than 7 miles (12 km).

Upper level terraces (QTt) are cut into bedrock as much as 200 ft (61 m) above current stream levels. Much of the unconsolidated deposits once lying on the bedrock have been eroded away, leaving a few remnant boulders and cobbles on the flat area. Upper level terraces occur along the Tuckasegee River between Ela and Bryson City, NC, along Little River in Tuckaleechee Cove, and along West Prong of the Little Pigeon River and Little Pigeon River, between Pigeon Forge and Sevierville, TN.

Landforms and deposits of physiochemical weathering

Introduction

The physical and chemical weathering of rocks and minerals contributed greatly to the landscape evolution of the Great Smoky Mountains region, over several tens of millions of years under different climatic regimes. All rocks of the region are chemically weathered and saprolite and (or) residuum that is highly oxidized (red) and leached (yellow) is common. With the exception of isolated outcrops of bedrock, the majority of the landscape is underlain by saprolite, residuum, and(or) surficial deposits that commonly contains recycled residuum. Residuum mantles much of the area, but only a few deposits are shown on the map because it is difficult to recognize. Hamilton (1961) and King (1964) noted extensive residuum and saprolite as much as 100 ft (30 m) thick

in the foothills, and Hadley and Goldsmith (1963) described residuum of highly variable thickness as much as 100 ft (30 m) thick on the mountain, which became exposed during construction of the Blue Ridge Parkway.

Where contacts are exposed, residuum is found unconformably overlain by colluvium, debris, and alluvium. This residuum may form in situ beneath the overlying deposit or it may have developed during a climate different from today. Hadley and Goldsmith (1963) noted that residuum on upper slopes was unconformably overlain by debris, whereas close to base level streams in the valleys debris was unconformably above fresh bedrock. They suggested that the matrix of debris was recycled residuum. This suggests that the earlier landscape of the Great Smoky Mountains was dominated by the production of residuum and saprolite during climate that was a warmer and more humid than now. The saprolite and residuum was eroded and recycled into a variety of surficial deposits. Currently these deposits are eroding to form the present landscape.

Karst

The carbonate rocks exposed in Tennessee are soluble in groundwater, forming caverns and sinkholes ([fig.22](#)). Minerals resistant to solution in the limestone and dolomite, such as quartz and chert, remain as lag deposits in the clay-rich residual matrix ([fig. 23](#)). The carbonate rocks and associated residuum are restricted to the tectonic windows (from west to east in the west central part of the map area) at Calderwood, Cades Cove, Big Spring Cove, Tuckaleechee Cove, and Wear Cove, as well as near Cosby, Walland, and northwest of Chilhowee Mountain in the Valley and Ridge province.

Caverns

Tuckaleechee Caverns, south of Townsend, TN, is the only commercial cave in the study area. Within the park, but closed to the public, are Bull Cave and unnamed caves in White Oak Sink (both in the southern part of Tuckaleechee Cove), and Gregory Cave on the north side of Cades Cove. Bull Cave is unique in that it is located near the crest of Rich Mountain at about 1900 ft (579 m) in elevation (fig.24). The depression that leads to the opening is about 140 ft (43 m) deep and the cave shaft is over 500 ft (152 m) deep. A stream flows into a cave at White Oak Sink at about 1700 ft (518 m) elevation (fig.25), that is thought to emerge about 3 mi (5 km) to the northwest at Dunn Spring, about 640 ft (195 m) lower in elevation. There are numerous smaller caverns and cavities in the limestone rocks that demonstrate that the process is active at all scales (fig. 26).

Sinkholes

In the western Blue Ridge province, sinkholes (QTs) are locally common within parts of Cades Cove (fig. 27), Tuckaleechee Cove and White Oak Sink, and Big Spring Cove, where they range from several meters in diameter to as much as 1000 ft (305 m) wide at “Big Sink”, south of Townsend, TN. Recently collapsed sinkholes are in the northern part of White Oak Sink near the cliffs of limestone. In Big Spring Cove, mounds of boulders and intervening pits and depressions are in debris of metasandstone. The depressions often contain water and are interpreted as collapse sinkholes. In Cades Cove, “Lake in the Woods” and two small ponds northeast of Carter Shields Place are also interpreted to be water-filled sinkholes (fig. 28). Sinkholes are very abundant in

Tuckaleechee Cove, but few are recognized in Wear Cove. Sinkholes also are found within areas of Cambrian Shady Dolomite in Miller Cove near Walland, and in the valley between Cosby and Wilton Springs. Numerous valleys in the western foothills, such as (west to east) Happy Valley, Walden Creek valley north of “Sinkhole Mountain”, and near Jones Cove, are underlain by limestone of the Walden Creek Group, and sinkholes occur there as well.

Sinkholes are most abundant in the Tennessee Valley of the Valley and Ridge province. Although sinkholes presently are forming, material deposited within them suggests that they have formed over an extended period of time. About 75 mi (40 km) northeast of the study area near Gray, TN, Miocene vertebrate fossils that could be 5 to 23 Million years old may have been trapped in a sink (Kohl, 2000; <http://www.state.tn.us/environment/tdg/gray/>).

Residuum

Accumulations of subrounded to angular cobbles and boulders of quartz and chert that was originally in veins or beds of limestone or dolomite is mapped as residuum (QTr). These silica minerals are very resistant to erosion and remain as a lag deposit in clay-rich terra rosa as the carbonate rock chemically disintegrates. Small deposits with small quartz and chert clasts are locally preserved in road cuts in Tuckaleechee Cove (see [fig. 23](#)), and on the tops of small knobs in fields near Cosby. In Tuckaleechee Cove north of Townsend at elev. 1200 ft (366 m), residuum contains limonite concretions. Similar residuum with concretions of iron and manganese oxides were prospected in Cades Cove (Southworth and others, 1999), Tuckaleechee and Wear Coves (King, 1964),

and in the foothills underlain by limestone of the Walden Creek Group (Hamilton, 1961).

Accumulations of cobbles and boulders of jasper are mapped as residuum locally in the Cambrian Shady Dolomite in the valleys near Walland (fig. 29). Neuman and Nelson (1965) suggests that the jasper is a residual precipitate from the percolation of water derived from the overlying silica-rich slope material. If this interpretation is correct, the jasper residuum is a very old deposit from a climate that favored the development of laterites. Similar laterite deposits of bauxite, kaolinite, and lignite in the Appalachians may be Late Cretaceous in age (Pierce, 1965; Hack, 1979).

Areally extensive gravel deposits as much as 40 ft (12 m) thick at elevation 1420 ft (433 m) asl near Sixmile in the Tennessee Valley are mapped as residuum. Neuman and Wilson (1960) suggested that the gravel was an areally extensive “sheet” deposit of Tertiary alluvium that was warped, modified by dissolution of the underlying carbonate bedrock, and locally mixed with residual gravel.

Residuum of rocks of the Great Smoky Group must have been extensive, as the abundant debris deposits have a clay-rich matrix that may have been recycled and derived from it. The only fresh rock seen is along streams, in some roadcuts, and the scarce outcrops on slopes and ridges. Extensive residuum of Pigeon Siltstone is exposed along Rt. 73 (fig. 30), and there are broad areas of residuum of biotite granite gneiss (fig. 31) south of Cherokee along Rt. 441.

Slope Deposits

Introduction

The surficial deposits in the Great Smoky Mountains National Park

region are three general types of slope deposits (fig. 32), listed by increasing abundance:

- 1) historical and recent debris flows in parts of the upper highlands, that result from intense rain storms,
- 2) colluvium in hollows on slopes below bedrock escarpments, on side slopes above valley bottoms, and depressions on the upper slopes of the highlands, and
- 3) coarse boulder debris that forms broad, gently-sloping fans on the lower slopes.

Although some debris flows and colluvium form today, debris fans are relict deposits of a former time and climate.

Debris Flows

Debris flows (Qdf) are a type of landslide that are common in the highlands north of Newfound Gap, along the Boulevard Trail, and along the Appalachian Trail from Charlies Bunion to Laurel Top. Debris flows consist of bedrock, soil, and vegetation that fails catastrophically and moves rapidly down slope, usually incorporating more material as they move. The debris flows occur on steep mountain slopes (35 to 44 degrees; Bogucki, 1970; 1972) underlain by soil and regolith that generally is less than a meter thick developed in slate of the Anakeesta Formation. Bogucki (1970, 1976) suggests a strong relationship between many chute-facing directions and compositional layering in the Anakeesta Formation. The head of some debris flow scars have very narrow “V”-shaped ravines that are called wedge-failures (Moore, 1986). The “V”-shape forms at the intersection of cleavage and joints or cleavage and beds. Elsewhere, the flows originate on very steep slopes as small slips on the cleavage or bedding plane. Debris flows in the study area have occurred as a result of prolonged rainfall events in 1938 (Moneymaker,

1939; Koch, 1974), 1940 (USGS, 1949), and 1942, 1943, 1951, 1956, 1967, 1971, 1975, 1984, and 1993 (Bogucki, 1970, 1972, and 1976; Clark, 1987; Schultz and others, 2000). Water-logged soil and regolith usually fails when large trees topple and begin moving down very steep slopes. Initially, a very small amount of material breaks free. These slope failures are a major geomorphic agent that form the steep craggy summits in the central part of the park (fig. 33). The map mostly shows scars of historical debris flows (fig.34) that are slow to revegetate due to the lack of soil (fig. 35). Local concentrations of debris flows formed during isolated cloudbursts. Charlies Bunion, for example, located west of Newfound gap along the Appalachian Trail, is the site of an isolated debris flow event. A forest fire burned the vegetation cover and later, a rainstorm resulted in debris flows that stripped the burned trees to expose bedrock (fig. 36). Debris flow deposits of trees and rock can be seen north of Arch Rock where the Alum Cave Trail crosses Styx Branch (fig. 37), and along the tributaries along the upper part of Newfound Gap Road in Tennessee.

Rock slides, slumps, and smaller landslides are common along road embankments that have been cut into inclined bedrock and(or) unconsolidated soil and debris. These landslides and rock falls are very common along the Foothills Parkway where sandstone and quartzite beds dip into the road, along steep roadcuts around Gatlinburg, and elsewhere in the map area (fig.38). These features are not depicted on the map.

Colluvium

Colluvium (Qc) includes talus, boulder streams, boulder fields, and transported boulder regolith, consisting of cobbles and boulders derived from weathering of bedrock on the upper slopes and hollows of the highlands Talus continues to form today below

steep bedrock escarpments (see [fig. 5](#)). Boulders are typically 3 to 10 ft (1 to 3 m) long, but can be as much as 50 ft (15 m) long (King, 1964). On the surface of the colluvial deposits, large boulders abut one another and are oriented randomly. Many boulder streams and boulder fields probably formed in periglacial environments during the Pleistocene (Delcourt and Delcourt, 1985). However, recent boulder talus merges down slope with older deposits ([fig. 39](#)). In boulder streams and boulder fields, gravity, solifluction, freeze-thaw, ice-wedging, and ice rafting probably contributed to downslope movement (Clark and Ciolkosz, 1988). Boulder deposits contain little or no soil, sand, or clay matrix, thus they do not support much vegetation. In some cases, they are free from any vegetation (see [fig. 5](#)). They have internal, underground drainage, but intermittent streams periodically flow on and through them and modify the existing deposit ([fig. 40](#)). Individual boulders may be covered with moss and (or) lichen ([fig. 41](#)), which suggests that they are relatively stable. There is no direct evidence of recent movement in these deposits, only minor bent trees ([fig. 42](#)), but movement may be so little and so slow that instrumentation is required to measure it. Although colluvium and talus is being produced today, the majority of the mapped deposits are relicts of an earlier (Pleistocene) cold, periglacial climate. Areas of bedrock cliffs near waterfalls, like Rainbow Falls, Grottoe Falls, and Buckeye Cove ([fig. 43](#)), have blocks of metasandstone that have detached along bedding planes and joints from the cliff. Below and downslope of the escarpments are fresh piles of jumbled blocks of metasandstone. In other areas the production and local transport of colluvium may be more dynamic. Moneymaker (1939) and Hamilton (1961) describe a cloud burst in 1938 on Webb Mountain, TN, that caused debris flows that stripped colluvium from the upper slopes to expose bedrock. When

Hamilton visited the site in 1952, the upper slopes were filled again with colluvium of sandstone derived from the higher slope.

Some colluvium seems unrelated to modern topography. It fills swales on ridges (King, 1964) and noses of slopes. These suggest processes similar to those described by Mills (1981). Road excavations reveal steep angular unconformities of colluvium on bedrock residuum that are perpendicular to modern slopes (fig. 44). This suggests that colluvium has been produced through time in a variety of settings, much like residuum and debris fans.

Colluvium was mapped mostly in the upland hollows where it predominantly consists of coarse metasandstone of the Great Smoky Group. Many of the Beech Gaps exposed along the road to Clingmans Dome contain colluvium although it is largely vegetated (see fig. 6). Colluvium occurs on all hard rock units including the clastic rocks of the foothills, especially on Chilhowee Mountain (fig. 45) and Green Mountain, as well as on quartzose gneiss in the eastern highlands. However, these deposits are not as large nor are they as extensive as the ones developed in the Great Smoky Group rocks in the highlands.

Debris fans

Both fan-shaped and irregular sheet-like accumulations of debris constitute the dominant and most prominent Cenozoic deposit on the middle and lower elevations in the unglaciated highlands of the Appalachians (Mills, 2000a; 2000b), and they characterize a significant portion of the landscape of the Great Smoky Mountains and Blue Ridge Province. The debris fans are very poorly sorted deposits of mostly matrix-supported diamicton, consisting of boulders and cobbles in a fine-grained matrix of sand, silt, and

clay. Debris fan deposits are classified according to the dominant lithology, size of the clasts, and the matrix material. These units will be referred to herein by modifiers, such as gneiss debris fans rather than debris of gneiss that forms fan-shaped deposits.

Additionally, the size, shape, and topographic setting of the debris fans are distinctive. Examples include fans of gneiss debris near Dellwood and Hazelwood, NC (Mills and Allison, 1994), fans of metasandstone boulder debris near Gatlinburg, TN (Schultz, 1998), fans of fine metasandstone above carbonate rocks (Southworth and others, 1999), and fans of cobbly sandstone debris on Chilhowee Mountain, TN. The abundance of large and durable boulders contribute to the size of the fans by armoring their surface from weathering and erosion. Many of the fans occur in coves and hollows away from erosive rivers are well preserved. The debris fans are complex assemblages reflecting a long history of deposition and modification. Today, these debris fans are relict deposits that are now undergoing chemical weathering and stream incision. The oldest deposits are residuum with few clasts and clay rich matrix. Fan material is reworked into coarse alluvium with removal of fine matrix leaving a bouldery surface as a lag concentrate. Early settlers modified the deposits as land was cleared for pasture; evidence includes piles, terraces, and fence lines of boulders (see [fig. 19](#)). Lateral migration of streams, and stream capture, are the dominant secondary processes that contribute to the present patchwork assemblage of deposits on any given fan. The many hardwood cove forests of the area are established on this unit due to rich soil and abundant moisture.

Debris fans are thought to have formed through several different processes.

Earlier workers called the deposits colluvium (Hamilton, 1961; Hadley and Goldsmith, 1963; Neuman and Nelson, 1965), bouldery alluvial deposits (Hadley and Goldsmith,

1963), and coarse bouldery alluvium in Piedmont coves (King, 1964). Today, deposits dominated by debris-flow processes are often called debris fans, and those deposits dominated by fluvial processes are called alluvial fans (Mills, 2000b). It is probable that a combination of processes created the fans in the Great Smoky Mountains. Debris flows were common during Pleistocene glacial/interglacial transitions as warm and cold cycles fluctuated and storms were common. A build-up of debris and colluvium on the upper slopes during cold periods was transported down slope as debris flows during warm periods of increased precipitation (Mills, 2000b). Many fans are in hollows and valleys, suggesting a pre-existing depression. Fluvial erosion must have formed a basin, cove, hollow, or valley, by incision, then fill with debris, and subsequently get modified.

Metasandstone debris fans

Metasandstone debris fans (Qd) are mostly derived from rocks of the Cades Sandstone, Walden Creek Group, and Chilhowee Group in the foothills section of the western Blue Ridge. These are small deposits in isolated hollows where there is a source of coarse-grained quartz-rich bedrock. Relative to the highlands, there are not many deposits in the foothills due to the dominance of fine-grained bedrock.

Boulder debris fans

Boulder debris fans (Qdb) are the dominant slope deposit in the Blue Ridge highlands where the bedrock is thick-bedded, massive, coarse-grained metasandstone of the Great Smoky Group (see [fig. 2](#)). Thunderhead Sandstone is the dominant source, but metasandstone of the Elkmont Sandstone, Anakeesta Formation, and Copperhill Formation also form this unit. Locally, Longarm Quartzite of the Snowbird Group also

forms boulder debris. These deposits make extensive, broad, convex-upward fans and aerially extensive sheets which have been modified by erosion. Boulder debris is especially abundant where the Thunderhead Sandstone is massive, thick bedded, and coarse-grained, and forms large outcrop cliffs that face north-northwest. Individual cliffs are as much as 250 ft (76 m) tall, but they range over 4000 ft (1220 m) in total relief. These massive escarpments of outcrop extend approximately from Blanket Mountain near Elkmont, TN, east to Cosby, TN. The north-facing aspect, abundant source material, and orographic setting for storms has provided a favorable setting for the formation of these deposits ever since the bedrock was exposed. The amount and size of boulder debris deposits is directly related to the eastward thickening wedge of Thunderhead Sandstone (King and others, 1958).

These deposits are mostly matrix-supported diamicton with locally stratified silt and clay supporting sub-rounded boulders of metasandstone (fig. 46). Hadley and Goldsmith (1963) report a block of metasandstone and metaconglomerate 40 ft (12 m) long at Cherokee Orchard (fig. 47), and another block 20 ft (6 m) high, 25 ft (7.6 m) wide, and 45 ft (14 m) long that was 1.3 mi (2 km) from the outcrop source at Greenbriar Pinnacle. Stream incision on some debris fans is in excess of 70 ft (21 m) without bedrock being exposed. Thickness of material is highly variable, as some fans appear to fill concave-up depressions with 20 ft (6 m) of debris at the head and toe and more than 70 ft (21 m) in between.

Noteworthy areas of boulder debris fans are in Tennessee (from west to east), at the Cades Cove Campground (fig. 48), Big Spring Cove, Sugarland Valley, Cherokee Orchard, Roaring Fork Valley, Greenbriar Cove, Albright Cove, and the Cosby

campground (fig.49). Good exposures of the diamicton (fig. 50) are in road cuts along the trail south of Elkmont along Little River, in small landslides on Albright Grove and the head of Cosby Creek, along Route 19 north of Soco Gap at the head of Maggie Valley, and along Big Creek. Deposits of boulder debris are also found outside of the region of massive Thunderhead Sandstone, such as near the Oconoluftee Valley of North Carolina (fig. 51), and along the tributaries that drain Fontana Lake (fig. 52).

Some of the largest ancient debris fans in the Appalachian highlands occur near Cosby, TN (fig. 53). Small knobs of bedrock surrounded by boulder debris are as much as 200 ft (61 m) above the valley, suggesting a long and complex history of erosion and deposition. Exposures of the lower parts of these fans show deeply weathered and oxidized matrix (fig. 54). The fan to the west at Albright Grove supports an old growth forest more than 500 years old. This fan forms the drainage divide of two tributaries for 2 mi (3.2 km) (fig. 55), then they diverge at the base of the fan and enter the French Broad River 25 mi (40 km) apart. This suggests a complex history. The boulder debris was deposited in a valley that today is topographically inverted by gully gravure (Mills, 1981) to form a convex upland. There are abundant smaller versions of this type of topographic inversion in other debris deposits throughout the region, with as much as 60 ft (18 m) of relief. Near Cosby, boulders more than 5 ft (1.5 m) across have been transported more than 6 mi (9.7 km) from a bedrock source (Hamilton, 1961). Debris from Greenbriar Pinnacle was transported northward to rest today in the valley of Webb Creek (fig. 56), where fluvial erosion has locally modified the fans to form as terraces.

Perhaps one of the oldest landforms and deposits in the region is the upper level

fan of boulder debris (Qdbu) near Cosby (fig. 57). These deposits occupy a transitional area between debris fans and alluvial terraces, and they are about 160 ft (49 m) above the modern drainage of Cosby Creek. As described in the section on Old Landforms, there are possibly even higher terraces and fans here and elsewhere in the region that suggests a very old landscape.

Boulder debris fans above carbonate rock (Qdbl) is mapped at the southeast end of Cades Cove (fig. 58) and to the east at Big Spring Cove. These types of deposits may include residuum of carbonate rock in the matrix at depth, as the landforms have been modified by sinkholes. King (1964) described a hole drilled in Big Spring Cove that penetrated 45 feet (14 m) of debris before hitting limestone bedrock.

Metasandstone debris fans above carbonate rock

Metasandstone debris fans above carbonate rock (Qdl) is mapped in Cades Cove, Tuckaleechee Cove, and Wear Cove. Here, fine-grained, thin-bedded metasandstone of the Cades Sandstone is the source of material that forms diamicton above the carbonate bedrock. Excavated pits in Cades Cove have stratified to non-stratified, rounded to subrounded fine-grained metasandstone in fine-grained matrix, suggesting significant alluvial transport (fig. 59). Sinkholes have modified the fans. Some of the fans in Cades Cove have been incised to expose bedrock along the margins, so the deposits there are as little as a meter thick (Southworth and others, 1999). However, the underlying karst in the central coves may allow a significant amount of material to accumulate, as is seen in similar settings in central Virginia near Elkton (King, 1950).

In White Oak Sink, metasandstone boulders are less than a meter across. In

Tuckaleechee Cove, metasandstone boulders as much as 8 ft (2.4 m) long are concentrated in incised drainages more than a mile (2 km) from the source on Rich Mountain. Exposures in Wear Cove show several feet of mature soil overlying as much as 10 ft (3 m) of metasandstone debris on limestone residuum (Neuman and Nelson, 1965). The distal, lower elevation parts and toes of the debris fans in Wear Cove and Cades Cove are terraced and have been modified by water. The same process (debris fans modified by alluvial processes) probably affected the fans along the Little River in Tuckaleechee Cove, although they are portrayed as alluvial terraces on this map.

Upper level fans of metasandstone debris above carbonate rock (Qdlu) are mapped in the Dry Valley and White Oak Sink parts of Tuckaleechee Cove ([fig. 60](#)). The fans are the remains of the oldest preserved fill in the cove. The upper level fan in White Oak Sink is about 100 ft (30 m) above the present bottom of the sink. Red residual soil underlies the upper level fan, and gray, cobbly soil characterizes the lower and younger fan deposit (Neuman and Nelson, 1965). The upper level fans are elongate as they have been incised by streams to depths as much as 50 ft (15 m), to expose bedrock along the margins.

Sandstone debris fans

Sandstone debris fans (Qdc) of the Lower Cambrian Chilhowee Group comprise an extensive series of fans on the northwest outcrop slope of Chilhowee Mountain. The angular to sub-rounded cobble-size clasts of fine-grained, sugary-textured sandstone ([fig. 61](#)) of the Cochran Sandstone, Nebo Sandstone, and some Hesse Quartzite that litter the surface have weathering rinds and often are friable. Excavations reveal a

clay-rich ruby red matrix that is highly oxidized (fig. 62). These fans are incised by modern streams to form terraces. The majority of fans here are mapped as upper level fans (Qdcu). These fans are as much as 80 ft (24 m) above the lower fans and along their incised margin are 100 ft (30 m) above the modern drainages. The angular cobbles of sandstone grade down-slope to sub-angular to well-rounded cobbles that average about 6 inches across, with the largest boulder about 2 ft in diameter. These cobbles and boulders are deposited on mostly shale of the underlying Ordovician Tellico Formation. The gentle slope and rounding of the cobbles suggests a large alluvial component of either primary deposition or secondary modification. These landforms and deposits are best seen in road cuts between Camp Montvale and Foothills Parkway, west of Look Rock. As noted by Mills and Whisner (2000), these old weathered deposits are unique to the Blue Ridge province.

Cobbles of sandstone and quartzite of rocks of the Chilhowee Group on Green Mountain were deposited as fans above carbonate rock northeast of Cosby. The cobbles of sandstone here are mixed with residuum of the Shady Dolomite. The thickness of these apron-like fans is unknown as dissolution of dolomite may lead to a thick accumulation as seen elsewhere in the Appalachians (King, 1950; Hack, 1979; Whittecar and Duffy, 2000).

Gneiss debris fans

Gneiss debris fans (Qds) form extensive deposits in North Carolina, from west to east, at the north end of the Ela dome, at the head of Big Cove, Maggie Valley, Dellwood, and Saunook. Boulders of gneiss are elongated slabs that have broken along foliation planes. Feldspar has decomposed to clay, so the clasts are highly friable, have

thick weathering rinds, and the surrounding clay-rich matrix is oxidized and red. Mills and Allison (1995a) determined the relative age of fans using 1) percent clay, 2) Munsell hue, or degree of redness, and 3) percent of weathered clasts. In the Dellwood and Saunook area south of Hazelwood, Mills and Allison (1995a and b) differentiated a few old and intermediate fans amongst mostly young fans, but they are too small to portray on this map. Impressive fans of gneiss debris in the Park are located at the head of Big Cove where Raven Fork has incised into them in “The Gorge”. Good exposures of the gneiss debris are seen in excavations in Maggie Valley, Dellwood, and Saunook.

Periglacial Deposits and Landforms

Periglacial deposits and landforms are in Great Smoky Mountains National Park but they are not portrayed as such on the map. King and Stupka (1950) first suggested that during cold phases of the Pleistocene, ridge crests in the Great Smoky Mountains may have been above the forest limit, in an active periglacial frost-climate environment. As an example, King (1964) described 10 to 15 feet of “mantle” on bedrock exposed during construction on the Clingmans Dome Road. Rozanski (1943), Clark (1968), Michalek (1968), Richter (1973), Reheis (1972), and Torbett and Clark (1985), Clark and Ciolkosz (1988), and Clark and others (1989) also have interpreted polygonal ground, block streams, block fields, fan deposits, and other features in the Great Smoky Mountains as periglacial in origin. Block fields and block streams are types of colluvial deposits that have long been considered to be periglacial deposits. Block fields are large sheet-like accumulations of blocks that commonly mantle upland surfaces. Block streams typically extend farther downslope than along slope contour, which suggests significant

transport. Differences between valley forms developed on north- and south-facing slopes in the Great Smoky Mountains, as noted by Richter (1973), probably have a periglacial origin as well. Coarse boulder deposits in the north-facing drainage basins, like Le Conte Creek (see [fig. 4](#)), probably formed under Pleistocene periglacial environments. Erosion over-steepened bedrock highwalls of a south-dipping homocline of thick, massive Thunderhead Sandstone and solifluction moved the rock debris down valley.

Erosion Rates

Recent analyses of cosmogenic isotopes in rocks and sediment shows that rates of erosion are temporally and spatially uniform in the Great Smoky Mountains (Matmon and others, 2003a,b). Be^{10} measured in fluvial sediments from 8 drainages in the park suggests spatially homogeneous generation of sediment at $73 \pm 11 / \text{km}^2$, equivalent to 27 ± 4 m/my of bedrock erosion. This is consistent with rates derived from fission-track analysis of zircon and apatite in bedrock (Naeser and others, 2001), long-term sediment budget of streams and rivers, and sediment yield data. The highlands of the Great Smoky Mountains have eroded at rates of about 30 m per 1,000,000 years for over 200,000,000 years since the Mesozoic (Matmon and others, 2003a,b). Unroofing rates during the Paleozoic orogenesis were higher (>100 m/my) but erosion decreased after crustal faulting about 280 My ago (Naeser and others, 2001). This enabled the highlands to survive as an isostatically maintained feature in the present landscape some 300 My later. Were the mountains as high as the present Rocky Mountains? Probably not—the present overall relief of about 5000 to 4500 ft (1524 to 1372 m) has probably remained the same, much like the roughly 8000 ft (2438 m) of relief from the foothills to the 14,000 ft (4,267 m) peaks of the Rocky Mountains of Colorado.

Age of Deposits and Landforms

Absolute Ages

Debris fans

There are a few radiocarbon dates of organic material recovered from debris deposits and terraces in this area. Davidson (1983) found 6,600 year before present (ybp) charcoal in “Lake of the Woods” in Cades Cove (see [fig.27 A](#)). “Lake of the Woods” is a water-filled depression on a terrace developed on a debris fan (Southworth and others, 1999). Near Dellwood, NC, Kochel (1990) obtained ten ¹⁴C samples from 5 fans that had ages ranging from 1,000 to 25,000 years, with 16,000 to 18,000 years being the most consistent age. He suggested that the summer polar front retracted several thousand years earlier in North Carolina, so that post-glacial debris flows and fan deposition began around 16,000 years ago. To the north around Shenandoah National Park, VA, about 39 ¹⁴C samples from fans, slope, and fluvial deposits show a range of ages from more than 51,000 to 2000 years before present (Eaton and others, 2003a). Although some may be recycled, the range of ages suggests debris flow activity over at least 25,000 years has recurred, on average, at least every 2500 years since the onset of the Wisconsin glacial maximum. Whittecar and Duffy (2000) and Eaton and others (2003b) suggest that debris fans around Shenandoah National Park, VA, formed during the late Pleistocene and have since been eroded by Holocene incision.

Some fans in the western Blue Ridge highlands may be hundreds of thousands of years old, and paleomagnetic reversal of iron oxides suggests that a minimum age of 1,000,000 years is likely (Mills and Allison, 1995a and b). Mills and Granger (2002) also

analyzed cosmogenic ^{10}Be and ^{26}Al in quartz, to derive a 1.45 ± 0.17 Ma age for a debris fan on Rich Mountain, in Watauga County, NC, approximately 78 mi (125 km) northeast of this area. This cosmogenic age corresponds with a 1.5 ± 0.3 Ma cosmogenic age obtained from the southern advance of the ice sheet at the Ohio River (Mills and Granger, 2002). Therefore, debris fans are composite landforms that have been forming intermittently throughout the Pleistocene, at least.

Terraces

The study of the Little Tennessee River by Delcourt (1980) identified nine discontinuous terraces as much as 100 feet (30 m) above river level. Consistent ^{14}C ages from organic remains from the lowest terrace were 15,000 to 7,000 ybp and an average of about 31,000 ybp was obtained from the next highest terrace level. He suggested that these terraces record deposition of destabilized upland surfaces during the transition from cold-phase maxima to interglacial or interstadial conditions. Frost-bound debris provided large sediment loads, remnants of which are preserved in the terraces.

Relative ages of landforms

Landforms that have been incised by modern streams and rivers can be used to calculate a minimum relative age of the landforms by using modern erosion rates of 28 meters per million year (My), that was determined from cosmogenic exposure ages (Matmon and others, 2003a,b). Possibly the oldest features are the abandoned meander at Camp Prong, a few upper level terraces, and the bedrock knoll within the boulder debris fan near Cosby campground. These elevated landforms suggest incision for about 2.18 My (late Pliocene). Boulder debris fan deposits have been incised for 750,000 years. The debris fans on Chilhowee Mountain were incised about 214,000 years ago, while

the upper level fans have been incised for about 857,000 years. Terraces along the major rivers have been incised for about 1.29 Ma, while the terraces along modern floodplains have been incised for about 429,000 years.

Cenozoic History

Erosion rates of 28 m/My (Matmon and others, 2003a,b) suggest that material removed since the 280 My Alleghanian orogeny has lowered the elevation more than 8.3 km (27,000 ft). A comparatively low volume of sediment deposited in the Gulf of Mexico and Atlantic Ocean 66 to 15 My ago (Poag and Sevon, 1989; Pazzaglia and Brandon, 1996), suggests that the mountains in the Blue Ridge province were not providing sediment; so they must not have had high relief. In the last 15 My (post-Middle Miocene), a more than 20-fold increase in offshore sedimentation suggests that the mountains were of high relief and actively eroding (Mills, 2000c). A drop in temperature due to climate change, associated buildup of ice, and increased precipitation contributed to an increase in sediment deposition, but rejuvenation of topographic relief likely was involved.

Therefore, the landscape of the Great Smoky Mountains National Park region could be as old as 15 My, with the deposits and landforms related to former climatic regimes and uplift. The current climate and processes are modifying ancient deposits by down-cutting and removal and transport of material downslope into streams. The oldest deposits are probably residuum, or chemically eroded bedrock and secondary mineral precipitates. The residuum formed during a warm and humid climate, perhaps as laterites during the Tertiary. Manganese, limonite, and jasper precipitated during chemical erosion

of bedrock. Residuum formed in place with little transport and locally is over 100 ft (30 m) thick. Much of the residuum formed during a warm and humid climate, possibly from the Cretaceous to Oligocene (140 to 24 My). Large valleys were eroded during this time. The valleys and hollows were then filled with coarse debris. Extensive colluvium and debris deposits unconformably overlie the residuum and the matrix of the debris is likely derived from similar residuum. Locally, residuum, colluvium, and debris has little relationship to current topography, suggesting that the current landscape is developed on a pre-existing one. The production of colluvium and debris may have begun as early as Oligocene time and culminated in the Pleistocene. Slope material was most likely generated during the cold glacial episodes, and erosion and deposition was during the many interglacial stages of warmer and wetter regimes. The minimum relative ages of some landforms and deposits range from 2.18 My (late Pliocene), to 214,000 years. A debris fan outside of the study area in North Carolina yielded a cosmogenic age of 1.45 My (Mills and Granger, 2002) that corresponds to the length of incision on terraces here. At the end of glaciation about 18,000 to 12,000 years ago, a new and warmer weathering regime began. Sparsely covered slopes were covered by deciduous vegetation, which increased the slope stability (Delcourt and Delcourt, 1985; 1988). Increased temperatures and precipitation resulted in fluvial incision and transport of sediment. Increased discharge of water resulted in the creation of terraces, broad alluvial valleys, and flood plains. Debris fans and lower terraces yield ^{14}C ages of 16,000-18,000 and 6,600 to 15,000, respectively, with 31,000 ybp from a higher terrace.

Currently, alluvial flood plains are being incised by rivers and creeks that are eroding into bedrock. In the headwaters, the same drainages are cut into debris fans as

much as 70 ft (21 m) deep. Coarse alluvial boulders in drainages are being exposed by modern incision into old, inactive debris deposits. In the Great Smoky Mountains National Park area, boulder debris was largely deposited during the Pleistocene but possibly before it. The old deposits were eroded and recycled throughout the Pleistocene and Holocene. Periodic and local storms of high rainfall result in landslides and debris flows of soil, rock, and vegetation, specifically in the highlands underlain by slate of the Anakeesta Formation. But these small debris flows are generally confined to steep bedrock chutes and do not form fan-shaped deposits that extend to modern flood plains. Today, the production of colluvium and (or) debris, is much more limited than in the geologic past.

References Cited

- Bogucki, D.J., 1970, Debris slides and related flood damage associated with the September 1, 1951, cloudburst in the Mt. Le Conte-Sugarland Mountain area, Great Smoky Mountains National Park: Knoxville, University of Tennessee, Unpublished Ph.D dissertation.
- Bogucki, D.J., 1972, Intense rainfall in the Great Smoky Mountains National Park: *Journal of Tennessee Academy of Science*, v. 47, p. 93-97.
- Bogucki., D.J., 1976, Debris slides in the Mt. Le Conte area, Great Smoky Mountains National Park, U.S.A.; *Geografiska Annaler*, v.58A, p. 179-191.
- Clark, G.M., 1968, Sorted patterned ground: New Appalachian localities south of the glacial border: *Science*, v. 161, p. 355-356.
- Clark, G.M., 1987, Debris slide and debris flow historical events in the Appalachians south of the glacial border *in*: *Geological Society of America Reviews in Engineering Geology*, v.VII, p. 125-138.
- Clark, G.M., and Ciolkosz, E.J., 1988, Periglacial geomorphology of the Appalachian Highlands and Interior Highlands south of the glacial border—a review: *Geomorphology*, v.1, p.191-220.

Clark, G.M., Ciolkosz, E.J., Kite, J.S., and Lietzke, D.A., 1989, Central and southern Appalachian geomorphology-Tennessee, Virginia, and West Virginia: 28th International Geological Congress Field trip Guidebook T150. American Geophysical Union, Washington, D.C., 105p.

Davidson, J.L., 1983, Paleoecological analysis of Holocene vegetation, Lake in the Woods, Cades Cove, Great Smoky Mountains National Park [M.S. thesis]: University of Tennessee, Knoxville, 100p.

Delcourt, P.A., 1980, Quaternary alluvial terraces of Little Tennessee River valley, east Tennessee: University of Tennessee Department of Anthropology Report of Investigations, v.29, p.110-121 and 175-212.

Delcourt, P.A., and Delcourt, H.R., 1985, Dynamic Quaternary landscapes of East Tennessee: an integration of paleoecology, geomorphology, and archaeology, Field trip 7, *in* Field trips of the Southern Appalachians, SEGSA 1985: University of Tennessee, Department of Geologic Sciences, Studies in Geology 9, p. 191-220.

Delcourt, P.A., and Delcourt, H.R., 1988, Quaternary landscape ecology: relevant scales in space and time: *Landscape Ecology*, v.2, no.1, p. 23-44.

Eaton, L.S., Morgan, B.A., Kochel, R.C., and Howard, A.D., 2003a, Role of debris flows in long-term landscape denudation in the central Appalachians of Virginia: *Geology*, v. 31, no.4, p. 339-342.

Eaton, L.S., Morgan, B.A., Kochel, R.C. and Howard, A.D., 2003b, Quaternary deposits and landscape evolution of the central Blue Ridge of Virginia: *Geomorphology*, v. 1351, p. 1-16.

Hack, J.T., 1979, Rock control and tectonism—Their importance in shaping the Appalachian highlands: U.S. Geological Survey Professional Paper 1126-B, 17p.

Hadley, J.B., and Goldsmith, Richard, 1963, Geology of the eastern Great Smoky Mountains, North Carolina and Tennessee: U.S. Geological Survey Professional Paper 349-B, 118p., map scale 1:62,500.

Hamilton, W., 1961, Geology of the Richardson Cove and Jones Cove Quadrangles, Tennessee: U.S. Geological Survey Professional Paper 349-A, p. A1-A55.

King, P.B., 1950, Geology of the Elkton area, Virginia: U.S. Geological Survey Professional Paper 239, 82 p.

King, P.B., 1964, Geology of the central Great Smoky Mountains, Tennessee: U.S. Geological Survey Professional Paper 349-C, 148 p.

- King, P.B., and Stupka, A., 1950, The Great Smoky Mountains—their geology and natural history. Science Monogram, v. 71, p. 31-43.
- King, P.B., Hadley, J.B., Neuman, R.B., and Hamilton, W.B., 1958, Stratigraphy of the Ocoee series, Great Smoky Mountains, Tennessee and North Carolina: Geological Society of America Bulletin, v. 69, p. 947-966.
- King, P.B., Newman, R.B., and Hadley, J.B., 1968, Geology of the Great Smoky Mountains National Park, Tennessee and North Carolina: U.S. Geological Survey Professional Paper 587, 23p., map scale 1:125,000.
- Koch, C.A., 1974, Debris slides and related flood effects in the 4-5 August 1938 Webb Mountain cloudburst; Some past and present environmental geomorphic implications [M.S. thesis]: Knoxville, University of Tennessee, 112p.
- Kochel, R.C., 1990, Humid fans of the Appalachian Mountains, in Rachocki, A.H., and Church, M., eds., Alluvial fans: a field approach: New York, Wiley, p. 109-129.
- Kohl, M., 2000, Welcome to the Gray Site: Tennessee Geological Survey, <http://www.state.tn.us/environment/tdg/gray/>
- Matmon, A., Bierman, P.R., Larsen, J., Southworth, S., Pavich, M., and Caffee, M., 2003a, Temporally and Spatially Uniform Rates of Erosion in the Southern Appalachian Great Smoky Mountains: *Geology*, v. 31, no. 2, p.155-158.
- Matmon, A., Bierman, P.R., Larsen, J., Southworth, S., Pavich, M., Finkel, R., Caffee, M., 2003b, Erosion of an ancient Mountain Range, The Great Smoky Mountains, North Carolina and Tennessee: *American Journal of Science*, v. 303, p. 817-855.
- Michalek, D.D., 1968, Fanlike features and related periglacial phenomena of the southern Blue Ridge [PhD. Thesis]: Chapel Hill, University of North Carolina, 198 p.
- Mills, H.H., 1981, Boulder deposits and the retreat of mountain slopes, or, “Gully Gravure” revisited: *Journal of Geology*, v.89, p. 649-660.
- Mills, H.H., 1982, Piedmont-cove deposits of the Dellwood Quadrangle, Great Smoky Mountains, U.S.A.: *Morphometry: Zeitschrift fur Geomorphologie*, v.26, p. 163-178.
- Mills, H.H., 1986, Piedmont-cove deposits of the Dellwood quadrangle, Great Smoky Mountains, North Carolina, U.S.A.: Some aspects of sedimentology and weathering: *Biuletyn Peryglacjalny*, v.30, p. 91-109.
- Mills, H.H., 2000a, The relationship of slope angle to regolith clast size: A study based on surficial mapping in the southern Blue Ridge province, western North Carolina: *Southeastern Geology*, v. 39, nos. 3 and 4, p. 243-258

Mills, H.H., 2000b, Controls on the form, process, and sedimentology of alluvial fans in the central and southern Appalachians, Southeastern U.S.A. *Southeastern Geology*, v. 39, nos. 3 and 4, p. 281-313.

Mills, H.H., 2000c, Apparent increasing rates of stream incision in the eastern United States during the late Cenozoic: *Geology*, v.28, no.10, p. 955- 957.

Mills, H.H., and Allison, J.B., 1994, Controls on the variation of fan-surface age in the Blue Ridge Mountains of Haywood County, North Carolina: *Physical Geography*, v.15, no.5, p. 465-480.

Mills, H.H., and Allison, J.B., 1995a, Weathering and soil development on fan surfaces as a function of height above modern drainage ways, Roan Mountain, North Carolina: *Geomorphology*, v. 14, no.1, p. 1-17.

Mills, H.H., and Allison, J.B., 1995b, Weathering rinds and the evolution of Piedmont Slopes in the southern Blue Ridge Mountains: *The Journal of Geology*, v. 103, p. 379-394.

Mills, H.H., and Whisner, S.C., 2000, Old fan deposits on the northwestern flanks of Chilhowee Mountain, southeastern Tennessee: Indicators of an inactive landscape: AMQUA Program and Abstracts of the 16th Biennial Meeting, 2000, Fayetteville, Arkansas, p. 84.

Mills, H.H., and Granger, D.E., 2002, Cosmogenic isotope burial dating reveals 1.5 million-year-old fan deposit in Blue Ridge Mountains of North Carolina. *Geological Society of America Abstracts with Programs*, v.34, no.2, p. A-32.

Money maker, B.C., 1939, Erosional effects of the Webb Mountain (Tennessee) cloudburst of August 5, 1938: *Journal of Tennessee Academy of Science*, v.14, p.190-196.

Moore, H. L., 1986, Wedge failures along Tennessee highways in the Appalachian region: their occurrence and correction: *Bulletin Association of Engineering Geologists*, v. 23, no. 4, p. 441-460.

Naeser, C.W., Naeser, N.D., Kunk, M.J., Morgan, B.A., III, Schultz, A.P., Southworth, C.S., and Weems, R.E., 2001, Paleozoic through Cenozoic uplift, erosion, stream capture, and deposition history in the Valley and Ridge, Blue Ridge, Piedmont, and Coastal Plain provinces of Tennessee, North Carolina, Virginia, Maryland, and District of Columbia [abs.]: *Geological Society of America Abstracts with Programs*, v. 33, no. 6, p. A312.

Neuman, R.B., and Wilson, R.L., 1960, *Geology of the Blockhouse Quadrangle, Tennessee*: U.S. Geological Survey Geologic Quadrangle Map GQ-131, scale 1:24,000.

Neuman, R.B., and Nelson, W.H., 1965, Geology of the western Great Smoky Mountains, Tennessee. U.S. Geological Survey Professional Paper 349-D, 81p., map scale 1:62,500.

Pazzaglia, F.J., and Brandon, M.T., 1996, Macrogeomorphic evolution of the post-Triassic Appalachian Mountains determined by deconvolution of the offshore basin sedimentary record: *Basin Research*, v.8, p. 255-278.

Pierce, K.L., 1965, Geomorphologic significance of a Cretaceous deposit in the Great valley of southern Pennsylvania, *in*, *Geological Survey Research 1965*: U.S. Geological Survey Professional Paper 525-C, p. C152-C156.

Poag, C.W., and Sevon, W.D., 1989, A record of Appalachian denudation in postrift Mesozoic and Cenozoic sedimentary deposits of the U. S. Middle Atlantic continental margin: *Geomorphology*, v.2, p. 119-157.

Reheis, M.J., 1972, Periglacial features in the Southern Appalachian Mountains. [B.S. Thesis]: University of Georgia, Athens, Ga., 26p.

Richter, D.M., 1973, Periglacial features in the Central Great Smoky Mountains. [Ph.D. thesis]: University of Georgia, Athens, Ga., 156 p.

Rozanski, G., 1943, Stone-centered polygons: *Journal of Geology*, v.51, p. 330- 341.

Schultz, Art, 1998, Geologic map of the Mount LeConte 7.5 min. quadrangle, Great Smoky Mountains National Park, Tennessee and North Carolina: U.S. Geological Survey Open-File Report 98-32, 10p., map scale 1:24,000.

Schultz, Art, 1999, Geologic maps of the Mount Guyot, Luftee knob, and Cove Creek Gap 7.5-minute quadrangles, Great Smoky Mountains National Park, Tennessee and North Carolina: U.S. Geological Survey Open-File Report 99-536, 8p., and 4 1:24,000-scale maps.

Schultz, A.P., and Southworth, C.S., 2000, Geologic history and geologic map of Great Smoky Mountains National Park: Special Publication of the Great Smoky Mountains Natural History Association, map scale 1:200,000
<http://www.smokiesstore.org/browse.cfm/4,58.htm>

Schultz, Art, Southworth, Scott, Fingeret, Carrie, and Weik, Tom, 2000, Digital Geologic Map and Web site of the Mount LeConte 7.5-minute quadrangle, Great Smoky Mountains National Park, Tennessee and North Carolina, U.S. Geological Survey Open File Report 00-261 <http://geology.er.usgs.gov/eespteam/Mtleconte/>

Southworth, Scott, 1995, Preliminary geologic map of the Great Smoky Mountains National Park within the Fontana Dam and Tuskegee quadrangles, Swain County, North

Carolina: U.S. Geological Survey Open-File Report 95-264, 33 p. and map scale 1:24,000. <http://geology.er.usgs.gov/eespteam/smoky/>

Southworth, Scott, 2001, The link between Geology, GIS, and ATBI plots, ATBI Quarterly Spring Newsletter, Discover Life In America, Gatlinburg, TN, p. 6-7.

Southworth, Scott, Chirico, Peter, and Putbrese, Trevor, 1999, Geologic story and map of parts of the Cades Cove and Calderwood quadrangles, Tennessee and North Carolina, Great Smoky Mountains National Park: U.S. Geological Survey Open-File Report 99-175, map scale 1:24,000, http://geology.er.usgs.gov/eespteam/smoky/cades_cove/Cades_Cove_WP/introduction.htm

Torbett, C.A., III, and Clark, G.M., 1985, Morphology, pedology, and origin of selected sorted patterned ground, Great Smoky Mountains National Park, Tennessee/North Carolina (abs.): Geological Society of America Abstracts with Programs, v. 17, no. 2, p. 139.

U.S. Geological Survey, 1949, Floods of August 1940 in the southeastern states: U.S. Geological Survey Water Supply Paper 1066, 554p.

Whittecar, G.R., and Duffy, D.B., 2000, Geomorphology and stratigraphy of late Cenozoic alluvial fans, Augusta County, Virginia, U.S.A. Southeastern Geology, v. 39, no.2 and 3, p. 259-279.

Figure Captions

Fig. 1- Index to 7.5-minute topographic quadrangle maps within the GSMNP region.

Fig. 2- A) Physiographic provinces of the Appalachian region. Fig.2- B) Physiographic provinces of the study area.

Fig. 3- Generalized geologic map of the study area, modified after Schultz and Southworth, 2000.

Fig. 4- Isometric view of digital elevation model data, looking south to Mount Le Conte, showing the morphology of surficial deposits near Le Conte Creek drainage and locations of figs. 5-11.

Fig. 5- Modern talus of Thunderhead Sandstone accumulates below the cliffs at Rainbow Falls. Daypack and 4 ft stick in foreground for scale (elev = 4320 ft, Mount Le Conte quadrangle).

Fig. 6- Ancient talus of Thunderhead Sandstone is moss covered and forms boulder fields high on the slopes (elev = 5400 ft, Mount Le Conte quadrangle).

Fig. 7- Boulder fields of moss-covered colluvium of Thunderhead Sandstone underlie the slopes near Rainbow Falls, where they transition to boulder debris. Daypack and 4 ft stick in foreground for scale (elev = 4200 ft, Mount Le Conte quadrangle).

Fig. 8- Cultivated debris fans on the lower slopes (elev = 2400-2800 ft) of Cherokee Orchard (view is to the southwest, ca. 1950) (Hadley and Goldsmith, 1963). See Hadley and Goldsmith (1963, fig. 45B, p. B109) for a photograph showing an excavation of the same boulder debris deposit (diamicton of large metasandstone boulders supported in a fine matrix) in the town of Gatlinburg.

Fig. 9- Incision by modern drainage of Twin Creeks produces vertical topographic relief in excess of 40 feet within the fans, and exposes large boulders of coarse alluvium in the channels.

Fig. 10- Fluvial terraces have incised the boulder debris fan along Le Conte Creek on the lower part of the fan (elevation = 1400 ft). This excavation of a parking lot shows rounded cobbles of Thunderhead Sandstone deposited unconformably above weathered Roaring Fork Sandstone. The fence and house are approximately 100 ft above Le Conte Creek. This view is to the south, up the fan.

Fig. 11- At the lower end of drainages, coarse alluvium unconformably overlies bedrock, (arrow) along the West Prong Little Pigeon River, Gatlinburg quadrangle. Subsequent incision by streams exposes bedrock in the channel. Exposure is 2 m high (elev = 1370 ft).

Fig. 12- Distribution of alluvium, coarse alluvium, and terraces within the study area are shown on a digital elevation model hillshade.

Fig. 13- Looking southeast at a tributary of Cove Creek in Wear Cove (above), at fining-upward alluvium of the flood plain about 1-meter thick. Close-up (below) shows fine silt and sand above sub-rounded cobbles of fine meta-sandstone (elev = 1400 ft, Wear Cove quadrangle). Knife in foreground for scale.

Fig. 14- Northeast view up Eagle Creek at Fontana Lake showing boulder bed of coarse alluvium of Thunderhead Sandstone overlain by silt and sand (elev = 1720 ft, Fontana Dam quadrangle).

Fig. 15- Coarse alluvium consists of boulders of metasandstone that remain as a lag deposit as water removes fine material and reworks older boulder debris deposits. Examples are shown below.

A) Rowans Creek (elev = 2400 ft, Cades Cove quadrangle).

B) Fish Camp Prong (elev = 3140 ft, Silers Bald quadrangle).

C) West Prong of the Little Pigeon River (elev = 3040 ft, Mt. Le Conte quadrangle).

D) Road Prong (elev = 3480 ft, Mt. Le Conte quadrangle).

Fig. 16- Alluvial plain of the Rough Fork of Cataloochee Creek has fine-grained alluvium overlying coarse alluvium (elev = 2840 ft, Dellwood quadrangle).

Fig. 17- Terraces of the Little Pigeon River that drain Greenbriar Cove underlie the flatlands in the foreground. Looking south from Emerts Cove near Pittman Center to Greenbriar Pinnacle (elev = 1300 ft, Richardson Cove quadrangle). (Photo by Warren Hamilton, USGS, May 1954).

Fig. 18- A) Roadcut in terrace between Greenbriar Creek and Cosby Creek.

Fig. 18- B) Close-up of the roadcut, which consists mainly of cobbles of metasandstone that unconformably overly residuum of Pigeon Siltstone (elev = 1600 ft, Hartford quadrangle).

Fig. 19- Terrace of Ogle Spring Branch is developed on the lower reach of boulder debris fan of Dunn Creek. View is looking south to Mount Guyot. The source of the material is about 10 km away. Right of center are fences constructed of piled boulders of metasandstone cleared from the terrace (elev = 1640 ft, Jones Cove quadrangle).

Fig. 20- Isometric perspectives of a digital elevation model of the abandoned meanders.

Fig. 20- A) Abandoned meanders of "the Sinks" of Little River (elev = 1550 ft, Wear Cove quadrangle).

Fig. 20- B) Abandoned meanders of Fish Camp Prong (elev = 2900 ft, Silers Bald quadrangle).

Fig. 21- View looking south into "The Glades", an area of abandoned terraces (elev = 1600 ft, Mount Le Conte quadrangle).

Fig. 22- Distribution of carbonate rocks and associated sinkholes (QTs, red) and residuum (QTr, blue) in the study area, shown on a digital elevation model hillshade.

Fig. 23- Road cut, about 2 m high, in Wear Cove showing sub-rounded pebbles and cobbles of quartz in a red clay residuum derived from the weathering of Ordovician Limestone (elev = 1450 ft, Wear Cove quadrangle).

Fig. 24- Bull Cave on Rich Mountain is developed in Jonesboro Limestone (elev = 1900 ft, Kinzel Springs quadrangle).

Fig. 25- A) At the east end of White Oak Sink, an unnamed creek flows into a sinkhole and cave, shown in B (below) (approximate elev = 1750 ft, Wear Cove quadrangle).

Fig. 26- Small caverns commonly form within limestone bedrock by dissolution; meter stick for scale (elev = 1720 ft, Cades Cove quadrangle).

Fig. 27- Sinkholes develop where dissolved limestone creates underground voids, with subsequent collapse of overlying materials. These sinkholes are about 3 m deep and occur on the north side of Cades Cove (elev = 2000 ft, Cades Cove quadrangle).

Fig. 28- Ponds in Cades Cove are interpreted to be water-filled sinkholes. A) "Lake of the Woods" at elev = 1760 ft and B) pond at 1900 ft elevation.

Fig. 29- Sub-angular boulders of light gray jasper, approximately 1 m diameter, litter the surface of areas underlain by Shady Dolomite on the south side of Chilhowee Mountain (elev = 1100 ft, Kinzel Springs quadrangle).

Fig. 30- Excavation, about 4m deep, showing residuum of Pigeon Siltstone overlain by colluvium of fine chips of siltstone, near Gatlinburg (elev = 1600 ft, Mt. Le Conte quadrangle).

Fig. 31- A) Road cut, about 3m deep, showing residuum of biotite gneiss near Qualla, NC. Fig. 31- B) Close-up showing residuum of sub-angular quartz gravel and oxidized soil derived from biotite gneiss (elev = 1960 ft, Whittier quadrangle).

Fig. 32- Distribution and types of slope deposits in the study area, shown on a digital elevation model hillshade. Magnification of Qdf deposits in lower box.

Fig. 33- Color-infrared aerial photograph showing vegetation-free scars (light-tone) of recent and historical debris flows. Route 411 is in the lower left (USGS NAPP 10716-5, acquired 4-02-1998).

Fig. 34- Debris flow scar on black slate of Anakeesta Ridge that occurred in 1984 and 1993 (elev = 5400 ft, Mt. Le Conte quadrangle).

Fig. 35- Debris flow scar on light-gray chloritoid slate on the Boulevard Trail; the scar occurred in 1993 (elev = 6400 ft, Mt. Le Conte quadrangle).

Fig. 36- Charlie's Bunion along the Appalachian Trail east of Newfound Gap is where a burned area experienced debris flows following a storm in 1939. (Photo courtesy of the Tennessee State Library and Archives).

Fig. 37- Debris flow scar at lower reach of Styx Branch occurred in 1984 (elev = 4400 ft, Mt. Le Conte quadrangle).

Fig. 38- Recent landslides are common in road cuts. A) Landslide in quartzite regolith along the Foothills Parkway, east of Cosby. B) Landslide in slate of the Anakeesta Formation on Rt. 441, west of Newfound Gap. C) Landslide along Rt. 321, east of Gatlinburg in the Pigeon Siltstone. D) Landslide along I-40 near Waterville.

Fig. 39- A) Boulder debris comprised of abundant boulders and blocks of metasandstone that transition down-slope to Thunderhead Sandstone colluvium. Fig. 39- B) Further downslope, boulder debris is covered with moss and lichen (elev = 3000 ft, Mt. Le Conte quadrangle).

Fig. 40- Moss-covered and forested boulder debris of Thunderhead Sandstone is incised by modern streams. The stream removes the fine material in the matrix and leaves a lag deposit of boulders referred to as coarse alluvium. (Steep Branch, along Rt. 441, elev = 2300 ft, Gatlinburg quadrangle).

Fig. 41- Vegetated boulder field of moss-covered metasandstone boulders (elev = 5800 ft, Luftee Knob quadrangle).

Fig. 42- Angular blocky colluvium derived from escarpment of Thunderhead Sandstone was transported by gravity. Bent trees suggest recent creep (elev = 4320 ft, Mount Le Conte quadrangle).

Fig. 43- Escarpment of 10m thick ledge of Thunderhead Sandstone with near flat-lying beds of massive metasandstone that are cut by longitudinal and strike joints. The joints widen by freeze and thaw cycles, cascading flood waters, and gravity. Large angular blocks fall to the base of the cliff and gradually move down slope. (elev = 3400 ft, Mount Le Conte quadrangle).

Fig. 44- Road cut showing angular unconformity between underlying schist and overlying colluvium. Rock hammer at left of center is for scale (along Rt. 284, elev = 3560 ft, Cove Creek Gap quadrangle).

Fig. 45- The east side of the Water Gap of Chilhowee Mountain, along the Little River, shows colluvium (boulder field and talus) of Nebo Quartzite unconformably above shale. The largest boulder (see arrow at left of center) is the size of a car (elev = 1100 ft, Kinzel Springs quadrangle).

Fig. 46- Boulder debris diamicton consists of a matrix of silt and clay that supports sub-rounded boulders and cobbles of Thunderhead Sandstone (elev = 2040 ft, Cove Creek Gap quadrangle).

Fig. 47- Very large boulders of metaconglomerate are on the surface of the boulder debris fan of Cherokee Orchard (also see fig. 8). A single boulder approximately 45 ft long was transported from Mount Le Conte and later broke into 3 blocks (elev = 2400 ft, Mt. Le Conte quadrangle).

Fig. 48- Boulder debris of metasandstone is exposed where the fan is incised about 2m by Abrams Creek (picnic area, elev = 1960 ft, Cades Cove quadrangle).

Fig. 49- A) Stream cut exposure shows the subsurface nature of a boulder debris fan (elev = 2800 ft, Mt. Le Conte quadrangle). Fig. 49- B) Close-up of diamicton of non-sorted boulders and cobbles supported by a matrix of sand and silt.

Fig. 50- Photographs of natural exposures of diamicton boulder debris. Fig. 50- A) Near horizontal beds of graded silt and sand, about 1m thick, with few metasandstone cobbles along the Little River Trail (elev = 2600 ft, Gatlinburg quadrangle). Fig. 50- B) Excavation along Rt.19 east of Soco Gap exposes diamicton about 10 m thick. Large boulder right of center is 2 m diameter. Upper center is a cross section of a channel with concentrated boulders of metasandstone (elev = 3640 ft, Bunches Bald quadrangle). Fig. 50- C) Diamicton along Big Creek shows oriented meter-long clasts of metasandstone (elev = 2040 ft, Luftee Knob quadrangle).

Fig. 51- Boulder debris is concentrated along Kephart Prong near Kephart Shelter (elev = 3600 ft, Smokemont quadrangle).

Fig. 52- A) Draw-down of Fontana Lake (horizontal water lines), reveals boulder debris concentrated in hillslope depressions. Fig 52- B) Boulder debris concentrated in channels illustrates gully gravure, or inversion of topography due to armoring of resistant boulders. The boulders fill a concave channel. Subsequent incision by streams into the adjacent softer schist produces a convex deposit of boulders (elev = ~1700 ft, Tuskegee quadrangle).

Fig. 53- The large fan complex of boulder debris at Cosby, TN. Looking south from the overlook on the Foothills Parkway (elev = 2080 ft, Hartford quadrangle).

Fig. 54- A) Surface and road cut exposure through a boulder debris fan (elev = 1940 ft, Hartford quadrangle). Most large metasandstone boulders have been removed from the surface during cultivation. Fig. 54- B) Close-up showing detail of highly weathered matrix of silt and clay with few cobbles of metasandstone. Rock hammer in center for scale.

Fig. 55 - Isometric perspective of digital elevation model looking south at boulder debris fan of Dunn Creek in Albright Grove (Jones Cove and Mount Guyot quadrangles). This fan forms the drainage divide of two tributaries for 2 mi (3 km) that diverge at the base of the fan and enter the French Broad River 25 mi (40 km) apart.

Fig. 56- Looking north at the lower part of a boulder debris fan that extends to the valley of Webb Creek. The possible source of the 2-m diameter metasandstone boulders in the foreground behind the fence is Greenbriar Pinnacle, 3 mi (5 km) to the south (elev = 1600 ft, Jones Cove quadrangle).

Fig. 57- The surface of an upper level fan of boulder debris shows a few scattered cobbles and boulders of metasandstone that overlie a beveled surface of Pigeon Siltstone. The upper level fan is approximately 200 ft (m) above Cosby Creek and the lower boulder debris fan. Daypack and rock hammer in center for scale (elev = 1840 ft, Hartford quadrangle).

Fig. 58- View to the southeast from the parking area on the northwest side of Cades Cove. Tree covered fans of boulder debris extend from the highlands to the valley floor.

Fig. 59- A) An excavation of a metasandstone debris fan in Cades Cove. Fig. 59- B) The excavation shows rounded cobbles and pebbles of metasandstone overlain by silt, suggesting fluvial deposition (elev = 1850 ft, Cades Cove quadrangle).

Fig. 60- Forest-covered upper level metasandstone debris fans extend from the slopes of Rich Mountain to the valley underlain by limestone in Tuckaleechee Cove. In the foreground is the lower debris fan that has been cultivated (elev = 1170 ft, Kinzel Springs quadrangle).

Fig. 61- A) Cobbles of quartzite (6 to 12 in across) litter the surface of fans on Chilhowee Mountain (elev = 1520 ft, Blockhouse quadrangle). Fig. 61-B) Excavations reveal a matrix of sand that supports cobbles of quartzite (elev = 2300 ft, Walden Creek quadrangle).

Fig. 62- Excavations of the upper level sandstone debris fans on Chilhowee Mountain reveal a deep red, clay-rich matrix that supports friable clasts of sandstone and quartzite (elev = 1640 ft, Blockhouse quadrangle).