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APPALACHIAN LANDSLIDE CONSULTANTS, PLLC

Debris Flows, Rock Slides, Rock Falls and Big Slow Movers: Who Could Ask for Anything More?

Field Course #3

Association of Environmental & Engineering Geologists 62nd Annual Meeting

"Old Mountains...New Beginnings. Using the Past to Map the Future."

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September 17, 2019

Field Course Leaders
Jennifer Bauer, Appalachian Landslide Consultants, PLLC
Stephen Fuemmeler, Appalachian Landslide Consultants, PLLC
Jody Kuhne, North Carolina Department of Transportation
Rick Wooten, North Carolina Geological Survey

Field Course Volunteers and Guides
Tommy Douglas, North Carolina Geological Survey
Jesse Hill, North Carolina Geological Survey
Dave Korte, North Carolina Geological Survey
Corey Scheip, North Carolina Geological Survey

Guidebook Editor
Jennifer Bauer, Appalachian Landslide Consultants, PLLC

Cover photos clockwise from top left: Debris flow deposits and damage, May 18, 2018 Pacolet Valley; Debris slide on Howard Gap Road, starting May 2018; Hickory Nut Falls, Chimney Rock State Park, Debris flow deposits and damage, May 18, 2018 Pacolet Valley.

Contents and Schedule

Acknowledgements. Heather Clark, AEG Meeting Coordinator, contributed much toward the field course with transportation logistics, food and admission arrangements at Chimney Rock State Park. Susan Arvitt, AEG Field Course Coordinator for the 2019 meeting kept us on track and reasonably on time with patience and good humor.

Introduction

This field course will highlight recent and past landslides of various types in the area of the Columbus Promontory of the Blue Ridge Escarpment (BRE), the steep mountain front extending from Georgia to Virginia. In North Carolina the BRE marks the transition from the rolling hills of the Piedmont physiographic province to the mountainous terrain of the Blue Ridge physiographic province to the west (Fig. I-1). The crest of the BRE in North Carolina generally coincides with the Eastern Continental Divide.

In North Carolina and Virginia the BRE is an area of frequent landslide activity (Witt and Wooten, 2015; Wooten, et.al, 2015). High relief, steep slopes, and the dissected nature of the BRE, in combination with its orographic influence on rainfall, make it susceptible to debris flows. Regional orographic forcing of rainfall along the BRE in North Carolina is identified by greater rainfall totals as compared to the surrounding regions for the storms of July 15–6, 1916 (Scott, 1972; Witt, 2005), and August 10–17, 1940 (US Geological Survey 1949).

Ongoing research in North Carolina reveals a pattern of recurring landslide events within structurally controlled topographic reentrants into the BRE (Bauer et al., 2019; Gillon et al. 2009; Hill, 2013, 2018; Hill and Stewart, 2018; Wooten and Witt, 2018). Smaller scale structurally controlled escarpments and reentrants prone to debris flows occur on the Nantahala Mountains Escarpment and in the Wayah reentrant in Macon County, North Carolina. (Wooten et al.,2008). Research to date indicates these reentrants are controlled by Mesozoic to Cenozoic W- and WNW-trending fractures and brittle faults that cross-cut Paleozoic ductile thrust faults. In this field course we will examine landslides in the Pacolet and Hickory Nut Gorge reentrants that transect the Columbus Promontory of the BRE.

The bedrock geologic framework for the field course, and stop locations are shown in Figure I-2. The Columbus Promontory is underlain by a series of stacked Paleozoic thrust sheets comprised of Late Proterozoic to Early Paleozoic metamorphosed sedimentary and igneous rocks intruded by Ordovician-Silurian and granitic gneisses (Davis, 1993; Davis and Yanagihara, 1993). All of the rocks in the area were subjected to intense deformation (folding and faulting) and metamorphism during the Paleozoic mountain-building events. A more detailed geologic overview is given in the description of Stop 4 at Chimney Rock State Park.

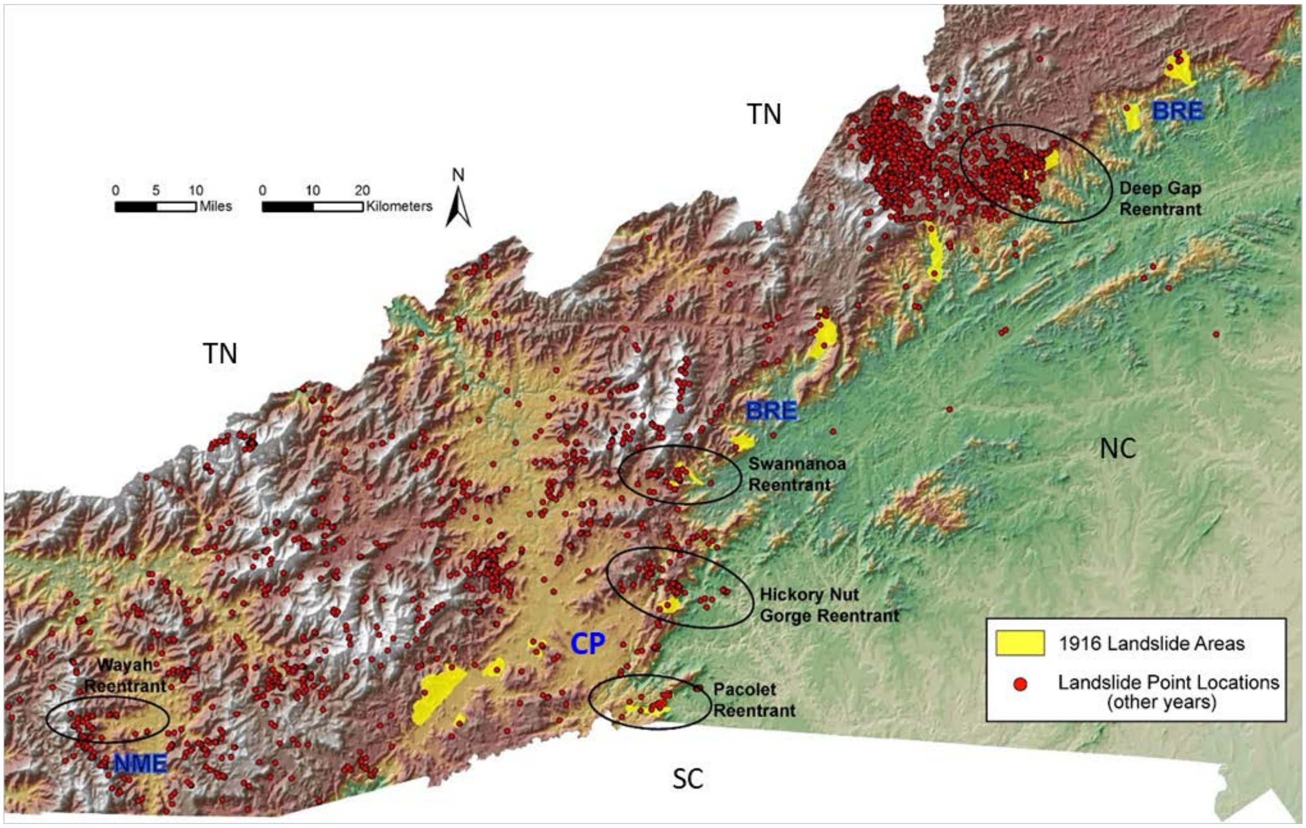

Figure I-1. Map showing point locations for landslides and July 15-16, 1916 landslide areas for western North Carolina from the NCGS landslide geodatabase. The Columbus Promontory (CP) of the Blue Ridge Escarpment (BRE) is shown, as well as named structurally controlled reentrants into the BRE. Map base is a shaded relief map and a color-coded elevation gradient derived from a 6-meter pixel resolution LiDAR digital elevation model.

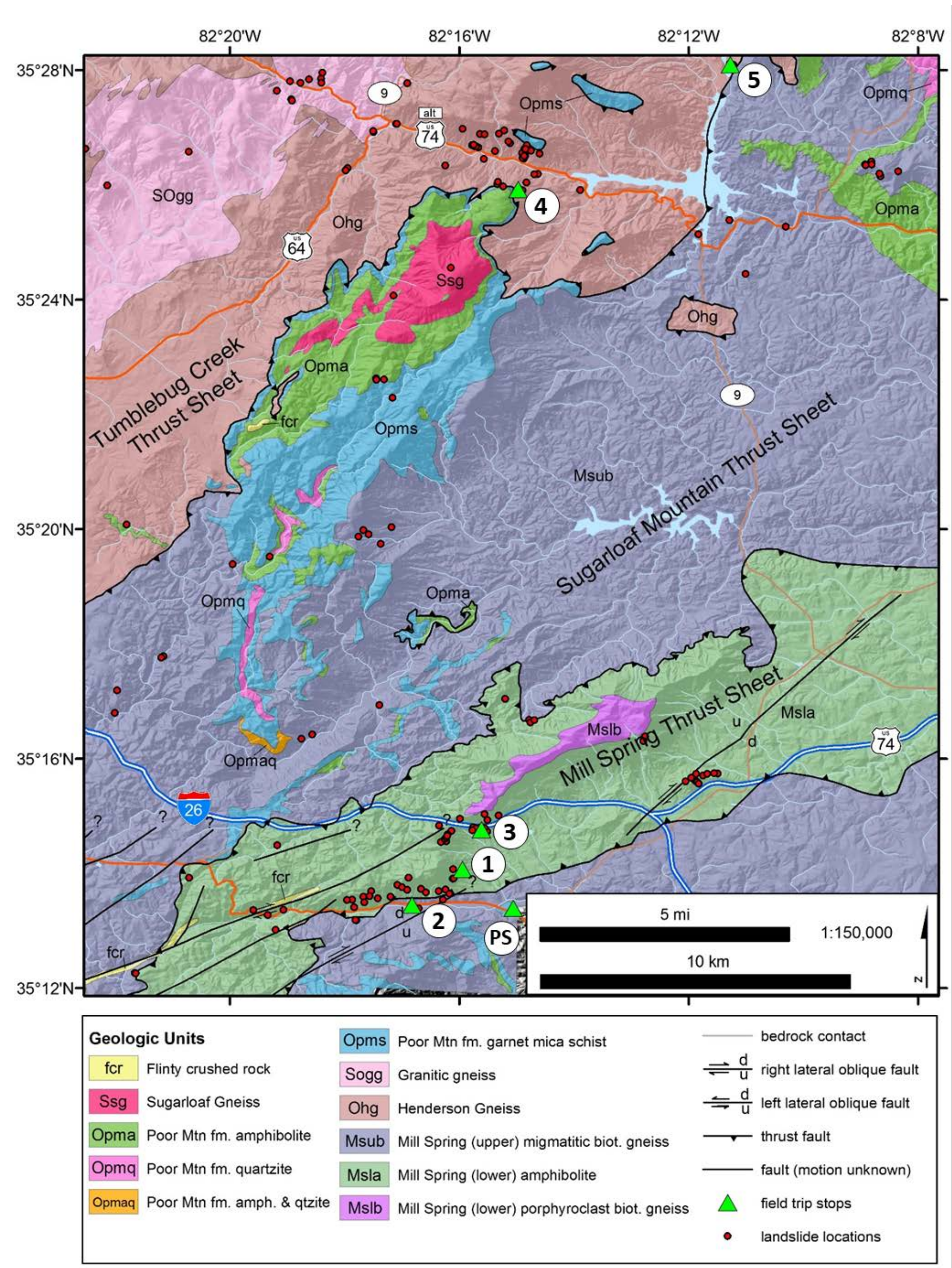

Figure I-2. Compilation geologic map of the Columbus Promontory area showing field course stop locations. **Stop 1** - Meadowlark Drive debris flows; **PS** – pit stop at Harmon Field; **Stop 2** Pacolet Valley debris flows; **Stop 3** – Howard Gap debris slide; **Stop 4** – Chimney Rock State Park rock fall, debris flows and debris slides; **Stop 5 -** Buffalo Creek debris slide. Map sources compiled by the NCGS: Davis, 1993; Davis and Yanagihara, 1993; Garihan et al., 1993. Mill Spring map units show here as mapped by Davis and Yanagihara (1993) are correlated with Tallulah Falls formation. Landslide locations from the NCGS and Appalachian Landslide Consultants, PLLC landslide geodatabases. Digital cartography: Jesse Hill.

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Stop 1. Meadowlark Drive

Leaders: Jennifer Bauer, Rick Wooten

Location. Latitude 35.234503° Longitude -82.265768° Meadowlark Drive, Polk County, North Carolina.

Purpose. The purpose of this stop is to observe a reactivation of a deep-seated debris slide impacting a private driveway. We will also observe debris flow impacts from the May 18, 2018 storm.

Summary

The North Pacolet River Valley, near Tryon, NC, is at the base of the Blue Ridge Escarpment (BRE). This valley has a long history of debris flows, as indicated by the ancient landslide deposits in the valley. On May 18, 2018, heavy rainfall triggered >27 debris flows which damaged or destroyed at least 6 homes and led to one fatality. (Figure 1.1)

Antecedent moisture conditions combined with intense intervals of rainfall totaling up to 20 cm (8 inches) triggered over 27 debris flows on May 18, 2018 (Fig. 1.2). Many of these initiated above cliffs near the top of the Blue Ridge Escarpment where rainfall was more intense.

Debris Flows

A cluster of debris flows impacted the Meadowlark Drive area. These debris flows severed two roads and damaged several homes (Fig. 1.3). The two longest, debris flows 1 and 3, initiated at the colluvium/bedrock boundary, traveling 2,700 ft (815m), and 2,800 ft (855 m), respectively, down a concave drainage (Fig. 1.4). Debris flow 2 initiated in colluvium and traveled 230 ft (70 m) down to a convex slope. Debris flow 4 initiated in residual soil and traveled 130 ft (40 m) down to a convex slope. Debris flows 1 and 2 had springs within the slide area, and 1, 2, and 3 had surface water flowing into the initiation zone.

Debris and/or downed trees impacted trees within the track, indicating that debris was at least 12 feet thick (Fig. 1.5). The tracks for debris flows 1 and 3 coalesced just upslope of the driveway for 1080 Meadowlark Drive. The driveway was taken out by the debris flows (Fig 1.6). It is unknown if these debris flows occurred at the same time, or were separate pulses. The track continued down the drainage, and debris from the debris flows covered Valley View Lane, plugging the culvert, and flowing across the road, as well as down the road, over the embankment, and behind the home at 502 Meadowlark Drive (Fig. 1.7). From there it flowed down Meadowlark Drive, filling the area around at least one other house basement.

Debris Slide

Since May, 2018, a deep-seated debris slide has been covering the upper portion of Meadowlark Drive, blocking the driveway to the home at the end of the road (Fig 1.8). This slide appears to be a reactivation of a larger dormant-old landslide, based on a review of the lidar and field verification of older scarps upslope of the active scarp (Fig. 1.3).

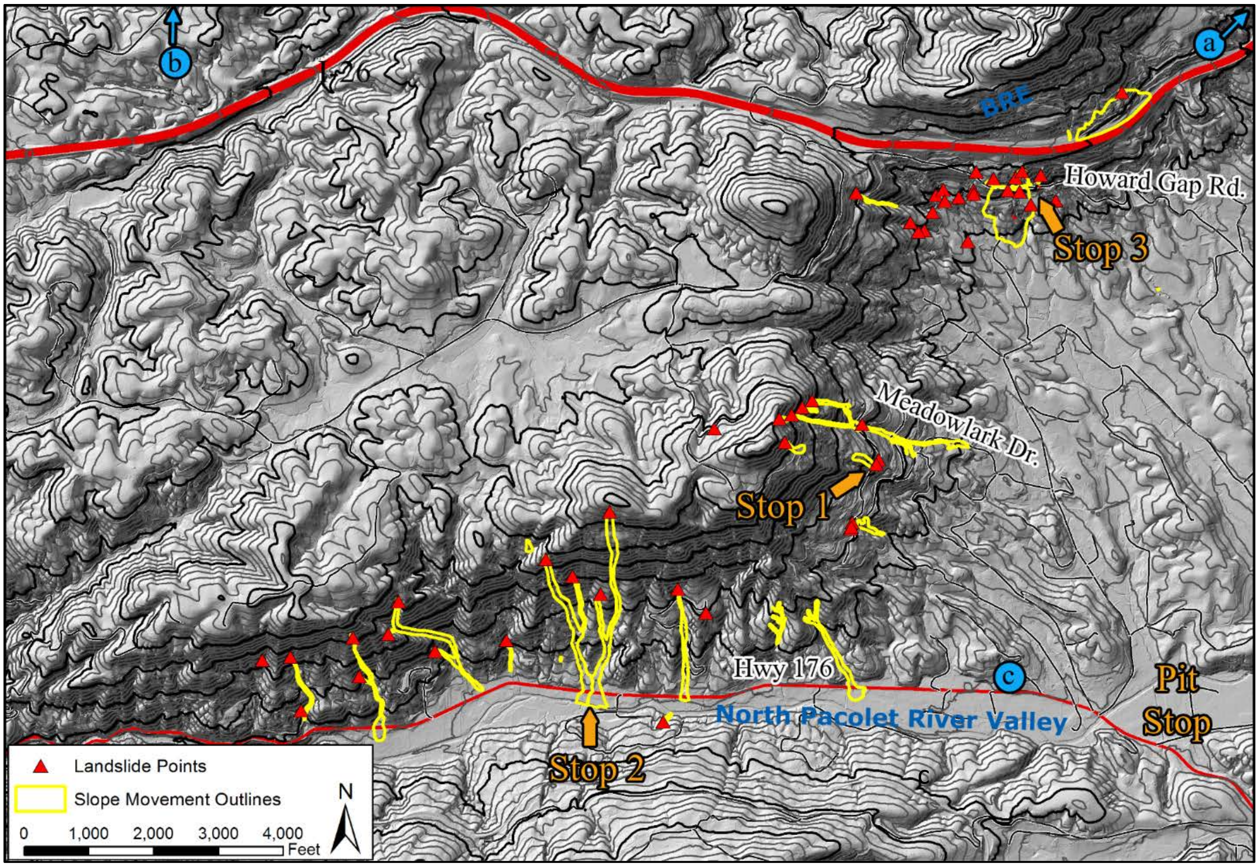

Figure 1.1. Map of North Pacolet River Valley area indicating locations of Stops 1, 2, and 3. Map base is a shaded relief map derived from a QL1 (0.5m) pixel resolution LiDAR digital elevation model with 40 ft contour interval. Data sources: North Carolina Geological Survey; Appalachian Landslide Consultants, LLC.

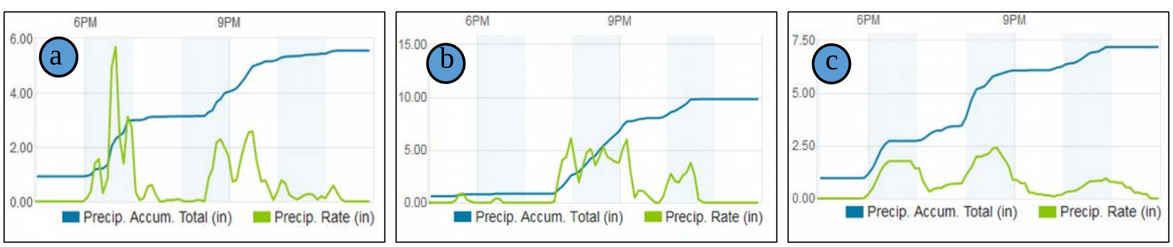

Figure 1.2. Provisional rainfall data from NOAA-NWS & Weather Underground. Locations in blue dots on Figure 1.1. a) Camp Skyuka, (N. of I-26), b) Brushy Mtn House (N. of I-26), c) Pacolet R. Valley

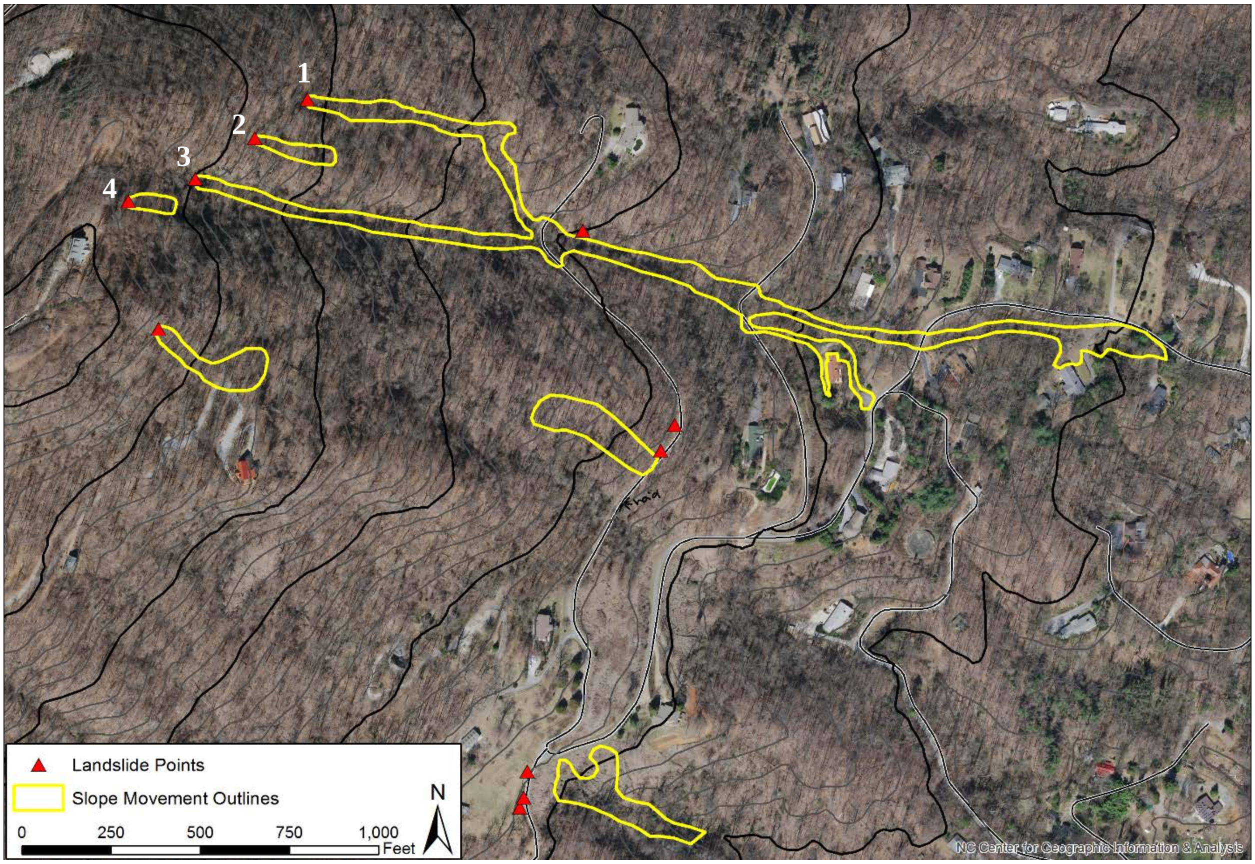

Figure 1.3. Map of Meadowlark Drive debris flows and debris slide. Map base is 2015 air photo from NC Center for Geographic Information and Analysis. Data sources: Appalachian Landslide Consultants, LLC.

Figure 1.4. Debris flow 3 initiation zone. Failure plane is at colluvium/bedrock contact. Bedrock observed in center of photo. Photo by Appalachian Landslide Consultants, PLLC on May 23, 2018.

Figure 1.5. Looking down slope of track for debris flows 1 and 3 upslope of driveway for 1080 Meadowlark Dr. Debris and/or trees were at least 12 ft (4 m) deep, based on tree nick marks. Photo by Appalachian Landslide Consultants, PLLC on May 23, 2018.

Figure 1.6. Tracks for debris flow 1 and 3 coalesced just upslope of driveway for 1080 Meadowlark Dr. Majority of driveway was taken out. Photo by Appalachian Landslide Consultants, PLLC on May 23, 2018.

Figure 1.7. Debris covering Valley View Ln. upslope of 502 Meadowlark Dr. Road is under debris on right side of photo. Culvert is completely blocked. Photo by Appalachian Landslide Consultants, PLLC on May 23, 2018.

Figure 1.8. Toe of debris slide on driveway for 1080 Meadowlark Drive. Photo by Appalachian Landslide Consultants, PLLC on January 21, 2019.

Acknowledgements

ALC would like to acknowledge Harry Goodheart and Jim and Terry Batchler-Smith for allowing us access to their property and telling their story.

Stop 2. Highway 176

Leaders: Rick Wooten, Jennifer Bauer, Bart Cattanach

Location. Latitude 35.224120° Longitude -82.280407° Highway 176, Polk County, North Carolina.

Purpose. The purpose of this stop is to observe debris flow impacts from the May 18, 2018 storm.

Debris Flow Impacts

A cluster of debris flows initiated from below Little Warrior Mountain on May 18, 2018 (Fig 2.1). The home of Mr. and Mrs. Case was located at the valley bottom below and was initially hit by a debris flow from the eastern drainage above their home (Fig. 2.2, Fig. 2.3). Mrs. Case was not able to leave the home due to health complications. Mr. Case assisted Mrs. Case into a detached garage next to the home. He then left, wading through the mud trying to get help, when a second debris flow from the western drainage behind the home hit the garage (Figure 2.3.A). Mr. Case tried to get back to the house to get to his wife, but was unable to do so. NCGS geologists assisted the Polk County Emergency Management to determine if slopes above the home were stable enough for crews to get to Mrs. Case. Sadly, she was not alive when crews were able to access the garage.

NCGS and ALC geologists identified areas impacted by these debris flows, and those with potential for future movement, and communicated this to Polk County EM. Meteorologists with the National Weather Service in Greenville-Spartanburg, SC met with EM to discuss potential significant rains from Subtropical Depression Alberto, which was forecast to arrive the week after the May 18 debris flows. Polk County EM issued a voluntary evacuation based on potential rainfall and landslide impact areas.

Debris flows in this valley are not a new occurrence. There is evidence of multiple debris flow deposits within the scoured stream banks of the debris flows that impacted the Case home (Figure 2.4). There is also a series of debris fans along the edge of the valley (Figure 2.1).

Summary

Although relatively narrow and shallow, debris flows can cause significant damage and even fatalities because of long run out distances and proximity of residences to the drainages.

While the post-May 18 emergency response and pre- Alberto planning was well organized and interdisciplinary, the public awareness about landslide hazards in the valley was lacking because the landslide hazard mapping had not been undertaken, and therefore, no evacuations were called-for.

Landslide mapping was again funded for the NC Geological Survey in 2018. Communication about landslide hazards will be an important component to the landslide mapping program. As this tragic event exemplifies, mapping + communication and awareness is necessary to save lives.

More information about this event can be found in the paper: Bauer, J.B., Wooten, R.M., Cattanach, B.L., Fuemmeler, S.J., 2019, Debris flows in the North Pacolet River Valley, Polk County, North Carolina - case studies and emergency response, *In:* Kean, J.W., Coe, J.A., Santi, P.M., Guillen, B.K. (eds.), Debris-flow Hazards Mitigation: Mechanics, Monitoring, Modeling, and Assessment, Proceedings of the 7th International Conference on Debris-flow Hazards Mitigation, Golden, CO, USA, AEG Special Publication 28, p. 549.

Available online: http://dx.doi.org/10.25676/11124/173172

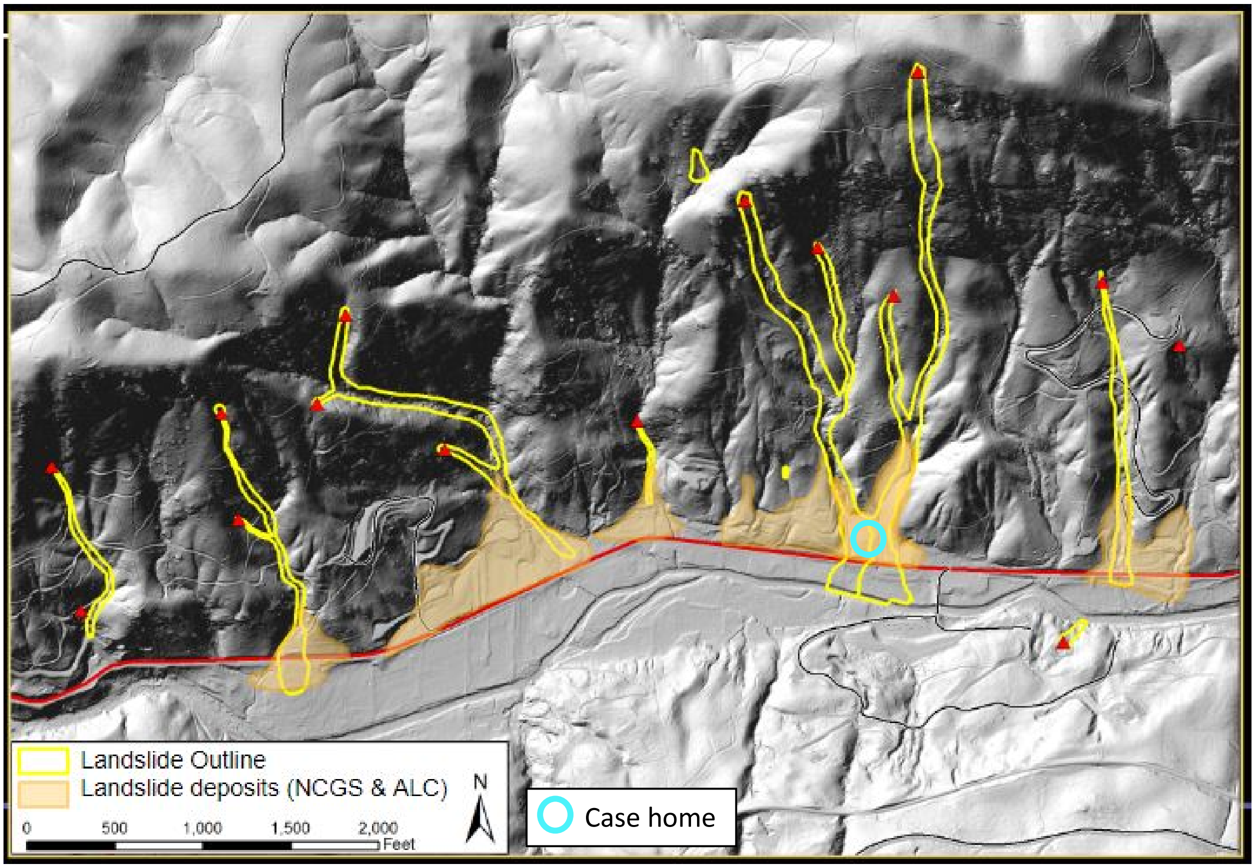

Figure 2.1. Landslide outlines from May, 2018 event. Landslide deposit polygons drawn from 2004 lidar. Map base is a shaded relief map derived from a QL1 (0.5m) pixel resolution LiDAR digital elevation model with 40 ft contour interval. Data source: North Carolina Geological Survey; Appalachian Landslide Consultants, LLC.

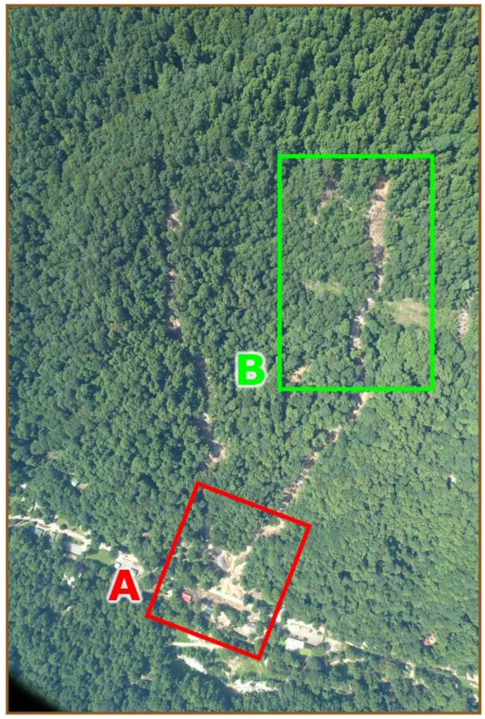

Figure 2.2. Two debris flows merged at the base of Little Warrior Mtn at the Case home. 2018 Aerial Image from the NC Forest Service.

Figure 2.3. Locations of these photos are shown on previous figure. A) Original location of Case home and detached garage outlined in black. Georegistered 2018 UAV Image from the NC Geodetic Survey. B) Debris flow initiation zone (IZ) upslope of cliffs on the edge of the Blue Ridge Escarpment.

Figure 4. Landslide debris deposit exposed by scour in western drainage upslope of Case home. Multiple vintages of deposit evident in the cross-section. Photo by NC Geological Survey May, 2018.

Acknowledgements

The authors would like to thank the residents of the Pacolet Valley for sharing their stories, heartbreaks, and community during the days and months following the May 18 event. They would also like to thank the Polk County Emergency Management, the National Weather Service Greenville-Spartanburg office, the NC Forest Service, and the NC Geodetic Survey for sharing information and data during this event response. Nick Bozdog, Sierra Isard, and Rebecca Latham assisted with post-event data collection.

Stop 3: Howard Gap Debris Slide

Leaders: Rick Wooten, Jennifer Bauer, Bart Cattanach, Stephen Fuemmeler

Location. Latitude 35.246007° Longitude -82.260223° Howard Gap Road, Polk County, North Carolina.

Purpose. The purpose of this stop is to observe damage to infrastructure and private property from an active composite debris slide; and to discuss ongoing collaborative mapping and monitoring efforts by the North Carolina Geological Survey (NCGS), Appalachian Landslide Consultants (for NC Department of Transportation), the U.S. Geological Survey (USGS) and the University of North Carolina-Chapel Hill (UNC-CH).

Introduction

The Howard Gap debris slide is located on the south-facing slopes of the Columbus Promontory section of the Blue Ridge Escarpment in Polk County, North Carolina (Figs. 3.1 and 3.2). Continuing slide activity adversely impacts public transportation and utilities through closure of Howard Gap Road, and damage to electric transmission lines and emergency water supply lines connecting the towns of Saluda and Tryon (Fig. 3.3) Roughly 5% of the active slide area affects the Howard Gap Road corridor, with the remaining 95% of the slide area impacting private property below Howard Gap Road. Continued advancement of the slide presents a potential threat to the home, outbuildings, and roads on private property. Additional threats could materialize as rapidly moving debris slides and debris flow originating from the over-steepened face ('bulge phase') of the slide body (Figs. 3.2, 3.4, 3.5).

The first known reports of landslides in the Howard Gap area are those triggered by the July 15-16, 1916 tropical cyclone. Scott (1972) recounts a July 18, 1916 Atlanta Journal Constitution article that referred to the Saluda to Tryon road where "...landslides from the mountains buried the road for long distances."

Many slope stability problems were encountered during the construction of I-26 through Howard Gap along the Saluda grade (Sams and Gardner, 1976). Construction of I-26 along the Saluda Grade begin in the late 1960's, and cut-related slides began in November 1968. By September of 1969, sliding was overwhelming the project along the cuts, as well as within a large waste area. Construction was stopped, and consultants were hired for an initial report in 1970, and a more detailed investigation and report, which was finalized in 1974. After these investigations, the slides were defined into seven major areas, a waste area, and the Y-12 (Howard Gap Road) alignment (Glass, 1977 Figure 7).

Based on the investigations, the I-26 design grade was realigned to allow for more space between the sliding material and the roadway, and the grade was raised to reduce the amount of excavation needed. Each slide area was remediated dependent upon its characteristics. Slopes were benched and flattened, and retention structures and counterweights were used. In an attempt to dewater the slides, 401 horizontal drains and a collector drain system were installed (Glass, 1977). Inclinometers and piezometers were installed in select locations to monitor the effectiveness of the horizontal drains and slope movement.

Between Howard Gap Road and I-26, a 200-foot long slide in colluvium and saprolite began blocking Howard Gap Road at the toe, and scarps came within 3 feet of a former transmission line pole. To remediate the slide at the road, horizontal drains and a collector drain system were installed below grade, and the road was rebuilt. Horizontal drains were installed around a spring near the head of the slide as well. At the toe, steel H pilings on four-foot centers, reinforced with batter piles, with timbers between the pilings was constructed (Glass, 1977). Since installation of this wall, the toes of slides initiating upslope are covering the bench behind the wall. Recent cracks have formed within the older slide material as well. On the right flank of the large, older slide, a weathered rock slide has occurred within weathered rock within the last year.

More recently, Howard Gap road and the adjoining private property were heavily impacted by slide activity triggered by rainfall from intense thunderstorms on the evening of May 18, 2018 (Wooten, et.al, 2018; Bauer et al., 2019). Appalachian Landslide Consultants (ALC) and NCGS geologists identified 14 smaller debris slides in the vicinity on May 25, 2019. Howard Gap Road was damaged and closed as a result of several slope failures related to the May 18 storm, and subsequent rainfall from subtropical storm Alberto that followed on May 28-31, 2018. Displacement along the main scarp of the Howard Gap slide forced the closure of this segment of Howard Gap Road in January 2019 following heavy rains in the region on December 28, 2018 (Fig. 3.3). Concerned about falling trees, and increased stream sediment, the owner of the property below Howard Gap Road contacted the County Emergency Management Department, who in turn requested the NCGS to make a site visit on March 14, 2019. As part of the ongoing landslide hazard mapping in Polk County by the NCGS, the detailed studies at the Howard Gap slide aim to provide information in the interest of public safety, primarily for the area outside of the North Carolina Department of Transportation (NCDOT) right-of-way. ALC has been working for TGS Engineers, Inc., a consultant to the NCDOT, to map landslide features within the NCDOT right-of-way as part of a study for rehabilitating the road.

Debris Slide Characteristics

The Howard Gap debris slide, and potential slide area encompasses approximately 45,170m^2 (~11.2 acres or ~8.5 football fields), with 40,565m^2 (~10 acres) being on private property (Fig. 3.2). The area with the most visible activity encompasses roughly 29,730m (7.3 acres or ~5.6 football fields). The upper elevation of the main scarp is ~439m (1440 ft), and the toe elevation is ~347.5m (1140ft), resulting in about 91.5m (100ft) of topographic relief for the displaced mass. The length of the slide, including a possible older toe is ~285m (935ft) with a median width of ~180m (590ft). Length of the actively moving slide is ~165m (540ft). Although unknown, the maximum thickness of the slide mass is estimated to be on the order of 30-40m (~100ft-130ft). The volume of the displaced mass is estimated to be in the range of 665,000m^3 (~869,790yd^3) to 885,900m^3 (~1,158,700yd^3).

As of July 2019, maximum vertical displacement on the main scarp was on the order of 8m (~25ft). Road fill is exposed in the main scarp; however, the bulk of the displaced mass involves thick deposits of coarse-grained debris from past slope movement activity on the Blue Ridge Escarpment. The debris generally consists of a poorly sorted, matrix- to clast- supported mixtures of gravel- to boulder-sized clasts and a clayey, silty, sand matrix. Debris deposits are well-exposed in the scarps of secondary debris slides developed on the steep slopes of the main body (Fig. 3.6). Rock blocks and boulders are mainly amphibolite and hornblende gneiss, with lesser amounts of biotite gneiss derived from upslope exposures of the lower Mill Spring complex mapped by Davis and Yanagihara (1993), (Fig. I-2, field trip introduction). The largest rock block observed to date is roughly ~7m (23ft) wide x 10m (33ft) long. Slides within the toe bulge exposed saprolite/completely decomposed weathered rock, which may be blocks of displaced saprolite, moved from previous slides, or movement within previously undisturbed material.

Here, as in many large debris deposit complexes in western North Carolina, variations in matrix color (e.g., medium reddish-orange to medium brown), and differing degrees of weathering of rock clasts indicate that the deposit is made up of components with different ages representing multiple episodes of past debris flow and debris slide events (see for example Mills, 1998). The overall landform suggests that the Howard Gap slide may be a reactivated portion of a relict(?) debris slide. The position of the slide mass on the steep slopes of the BRE coupled with the large volume of available disrupted debris indicates the potential for long run-out debris flows originating from the steep face of the slide body.

Mapping and Monitoring

In general, our observations indicate that in western North Carolina large debris slides activate or reactivate in response to extended periods (i.e., months) of above normal rainfall. Outside of possible cases where these types of slides have been monitored by the NCDOT or others, we know very little about any correlations between the specific rates and amounts of slide movement with rainfall, seasons, or weather patterns over the long term. The objective of the mapping and monitoring is to better understand behavior of the slide over the long term, and hopefully be able to identify any precursors to rapid, large-scale movements that could present an immediate threat to public safety. Such precursors could be accelerated rates of slide movement, and increased deformation, particularly along the steep face of the slide mass.

Field mappers use GPS-equipped field computers with base map layers derived from LiDAR (Light Detecting and Ranging) digital elevation models (legacy 6m, and QL1 0.5m pixel resolution respectively). Initial phases of UAV imaging are underway with flights by the USGS on May 29, 2019, and UNC-Chapel Hill on July 1, 2019. Subsequent flights are planned to aid in basic mapping and change detection. Georegistered orthomosaic imagery from the May 29 and July 1, 2019 flights (Fig. 3.2) are valuable mapping and monitoring aids. Follow-up flights by the USGS are planned during the next after leaf-off season.

On-the-ground monitoring equipment was provided by the USGS, and installed by the USGS and NCGS on May 6-7, 2019. A solar panel/battery-powered monitoring station (HG-1) at the left lateral scarp is equipped with a cable extension transducer (CET), a tiltmeter, and a tipping bucket rain gauge all linked to a data recorder (Fig. 3.7). The CET is configured to detect slide movement across the left lateral scarp through shortening of the cable. A survey station hub and targets at toe area (HG-2) is designed to detect slide advancement where slide debris overrides the original ground surface. As of July 24, 2019, data collected at HG-1 does not indicate definitive movement, with the possibility 2.5mm (0.1in) of cumulative displacement recorded by the CET (which may not represent actual ground movement).

Summary

We anticipate that mapping and monitoring at the Howard Gap debris slide will be a long term, cooperative undertaking. The NCDOT has plans to stabilize this section of Howard Gap Road; however, it is possible that even with such remediation a large portion of the slide on private property may remain active or intermittently active for the foreseeable future.

Acknowledgements

Contributions by Francis Ashland, Jessica DeWitt, Kelsey O'Pry of the USGS are gratefully acknowledged. Francis provided the time, expertise and equipment to set up the monitoring sites. Jessica and Kelsey are providing UAS flight support and image processing. Kevin Stewart, UNC-CH Department of Geological Sciences, graciously provided the July 1, 2019 UAS flight and images. We thank NCGS geologists Nick Bozdog, Tommy Douglas, Jesse Hill, Sierra Isard, David Korte, and Corey Scheip for their contributions to the mapping and analysis of the Howard Gap Road slide.

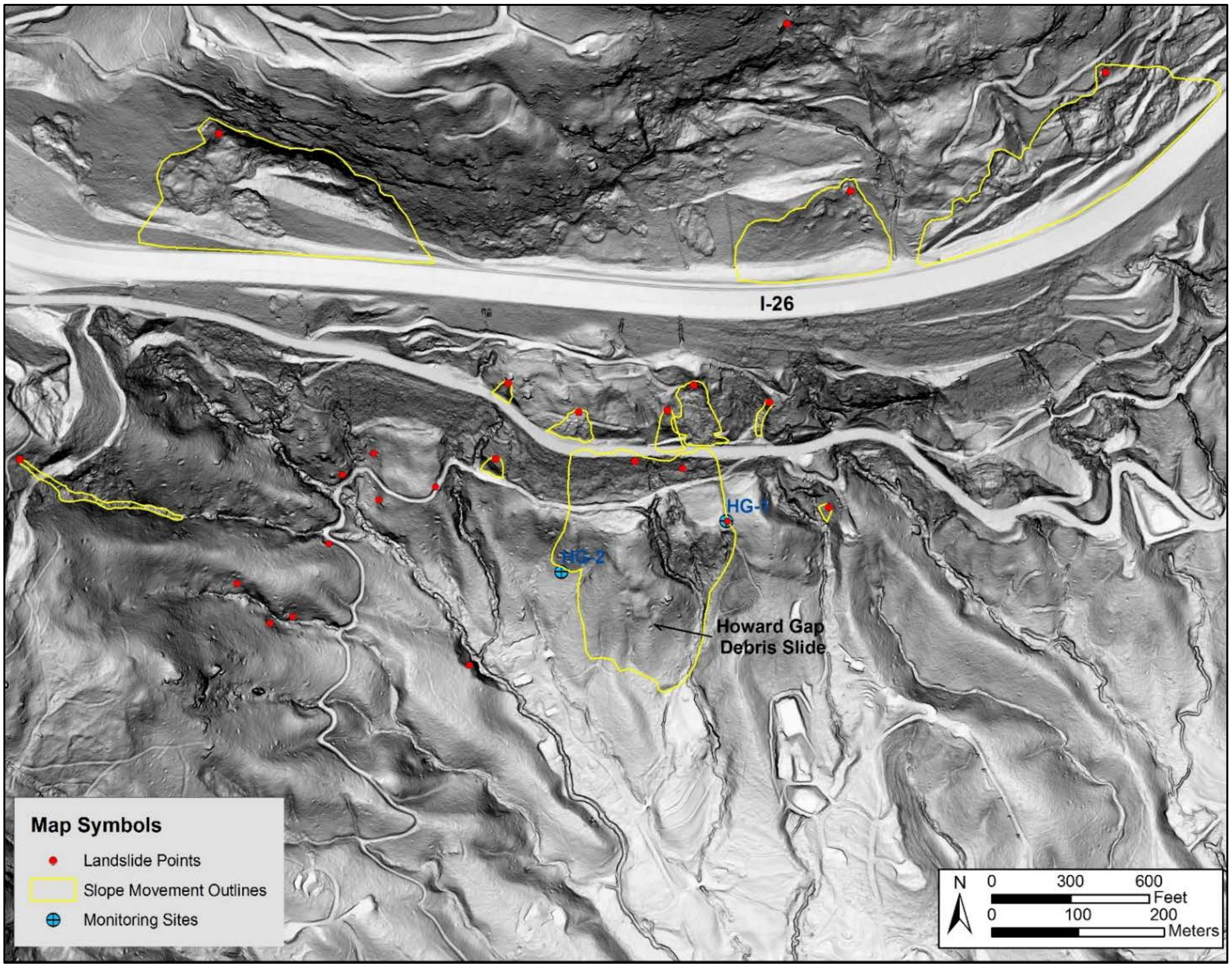

Figure 3.1. Map of landslide locations in the Howard Gap area. Map base is a shaded relief map derived from a QL1 (0.5m) pixel resolution LiDAR digital elevation model. Data sources: North Carolina Geological Survey; Appalachian Landslide Consultants, LLC; Sams and Gardner, 1976.

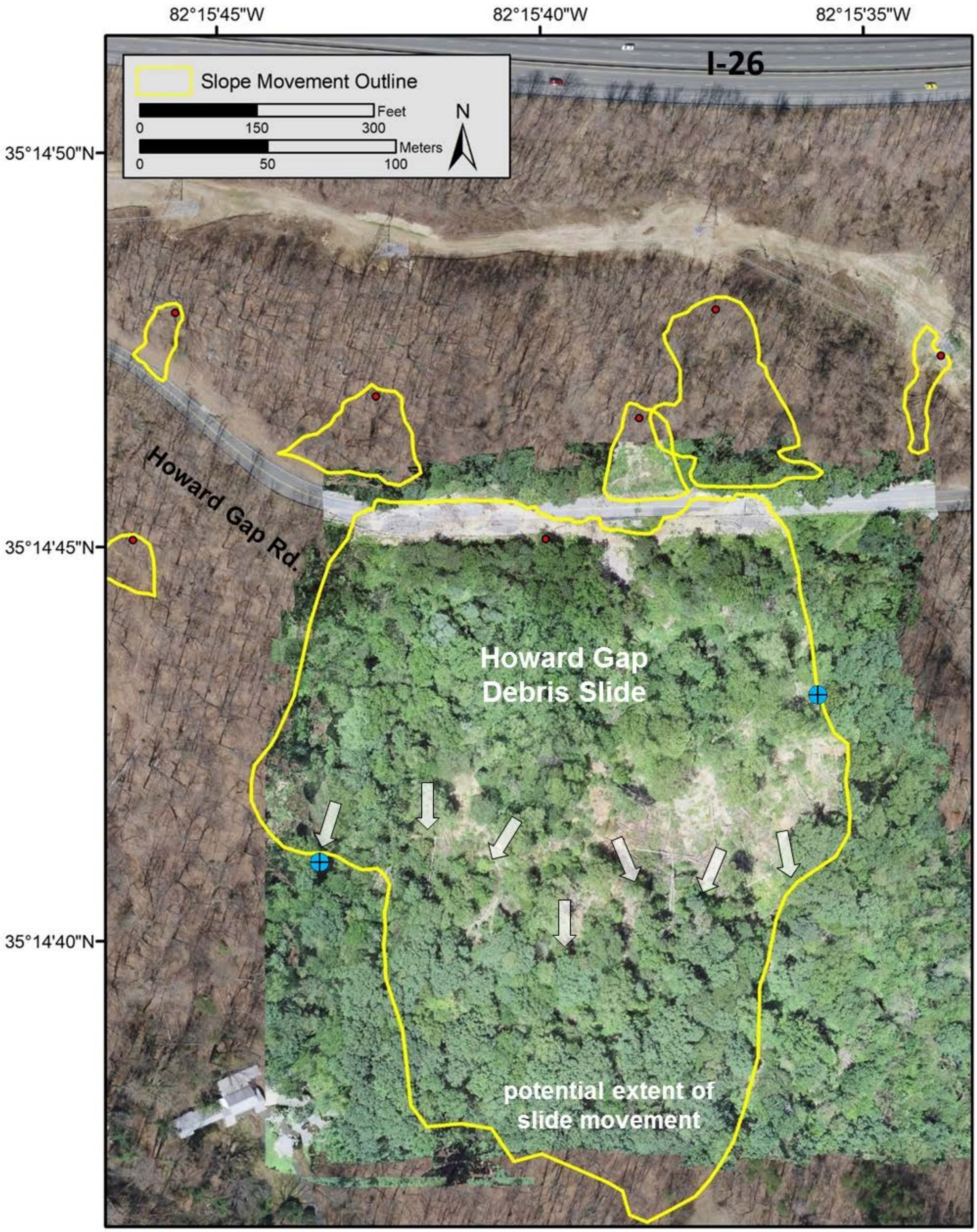

Figure 3.2. Map of landslide locations in the Howard Gap area. Map bases are: leaf-off 2015 ortho-imagery; and a leaf-on July 1, 2019 UAS orthomosaic courtesy of Kevin Stewart, UNC-Chapel Hill. White arrows indicate the movement directions in the active 'bulge phase' of the slide body which generally coincides with the area of downed trees and exposed slide debris in the July 1, 2019 UAS image. HG-1 and HG-2 = monitoring stations. Landslide data sources: North Carolina Geological Survey and Appalachian Landslide Consultants, LLC.

Figure 3.3. View of the eastern segment of the main scarp of the debris slide cutting across Howard Gap Road. Slide movement is toward the left (south). View looking west. Damage from the slide resulted in closure of the road to vehicles, making it *bearly* passable to local residents. 2018/06/14 NCGS C. Scheip photo.

Figure 3.4. View of the south-facing slope of the slide with trees downed from slide movement. Slide movement is toward the right (south). View looking east. 2018/03/14 NCGS photo.

Figure 3.5. View of the south-facing slope of the slide with trees downed from slide movement. Boulders in foreground left are clasts within the debris deposit. Slide movement is away from viewer toward the home (south). 2018/03/14 NCGS photo.

Figure 3.6. Vertical displacement on the right lateral scarp of the debris slide. Boulders exposed in the scarp are clasts within the pre-existing debris deposits on the slope. NCGS geologist Bart Cattanach stands on the slide mass. View looking south-southwest, slide movement is toward the south. 2019/03/14 NCGS photo.

Figure 3.7. NCGS geologists Corey Scheip (L) and Jesse Hill (R) downloading data at monitoring site HG-1 located along the left lateral scarp (red dashed lines) of the Howard Gap debris slide (see Fig. 3.2 for location). Yellow arrows indicate slide movement direction toward the south. A and A' = anchor posts for the cable extension transducer; B = tipping bucket rain gauge. 2019/05/22 NCGS photo.

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Stop 4: Chimney Rock State Park: rock falls, debris flows, debris slides in Hickory Nut Gorge

Field Trip Leaders: Rick Wooten, Jennifer Bauer, Bart Cattanach (co-author)

Location: Chimney Rock, NC. (Longitude -82.250294º, Latitude 35.432733º)

Purpose: Examine the Henderson Gneiss and landslide hazards in the Chimney Rock area of Hickory Nut Gorge. Enjoy the scenery and the Chimney Rock State Park experience.

Itinerary

Have lunch at the lower parking lot at 1:00-1:45 p.m., then ride shuttle busses to the upper parking lot. Discuss the retaining wall failures in the upper parking lot, and plans for reconstruction. Hike up to the Chimney top for a view of landslide features in Hickory Nut Gorge. Depart the upper parking lot and hike to the Hickory Nut Falls trailhead. Proceed 1 mile along the flat trail to the site of the November 14, 2012 rockfall that damaged the trail. Continue along the trail to Hickory Nut Falls, then return to the upper parking lot. Depart Chimney Rock S.P. 3:45 p.m. (to include optional stop at Buffalo Cove debris slide) or 4:30 p.m. (skip the Buffalo Cove stop) and return to the Renaissance Hotel.

Geologic Overview

Geologically, Chimney Rock State Park lies within the western Inner Piedmont portion of the Tugaloo Terrane, a package of metamorphosed sedimentary and igneous rocks. Key rock types include the Henderson Gneiss (Ohg), Tallulah Falls Formation metagraywacke (Ztfb) (correlated with Mill Spring units – see Fig. I-1 Introduction) Ordovician-Silurian granitic gneiss (SOgg), Poor Mountain amphibolite (Opma), Poor Mountain garnet-mica schist and quartzite (Opms), and the Sugarloaf Mountain gneiss (Ssg) (Figs. I-1 and 4.1)

Most of the rock making up Chimney Rock Mountain, Hickory Nut Gorge and the areas north and west of Lake Lure is Henderson Granitic Gneiss. It is typically light gray with distinctive oval-shaped feldspar clasts called "augen", the German word for eyes. The Henderson Gneiss crystallized approximately 448 million years ago during the Late Ordovician period (Moecher et al., 2010). West and north of the Bat Cave community, younger granitic gneiss (SOgg) intrudes the Henderson Gneiss. Radiometric dating indicates that the SOgg is around 438 million years old (Odom and Russell, 1975).

The tops of Chimney Rock, Round Top, Rumbling Bald, and Shumont Mountains are made up of Poor Mountain Formation, a group of 500 to 470 million-year-old metamorphosed sedimentary and volcanic rocks. Rock types within the Poor Mountain Formation include amphibolite, schist, and quartzite. The tops of Sugarloaf, Stony and Poplar Mountains are composed of Sugarloaf Mountain gneiss, a granite body with a crystallization age of approximately 490 Ma (Vinson, 1999).

South and east of Lake Lure, the topography is lower and more gently rolling. The underlying rocks are mostly metamorphic schists and gneisses of the Mill Springs units defined and mapped by Davis and Yanagihara (1993) (see Fig. I-1 Introduction) and correlated here with the Tallulah Falls Formation. During the Neoproterozoic to early Cambrian, Tallulah Falls Formation sediments were deposited in basins on the eastern edge of Laurentia (proto-North America). After a period of deposition and erosion, siltstone, sandstone and mafic volcanic rocks of the Poor Mountain Formation were unconformably deposited upon Tallulah Falls Formation rocks during the Early to Middle Ordovician (Hatcher, 2002).

All of the rocks in the area were subjected to intense deformation (folding and faulting) and metamorphism during the Paleozoic mountain-building events. In the vicinity of Chimney Rock Park, the Sugarloaf Mountain thrust placed the Poor Mountain Formation on top of the Henderson Granitic Gneiss. The tops of Chimney Rock, Sugarloaf, Stony, Poplar, Round Top, Rumbling Bald, and Shumont Mountains are all remnants of rocks emplaced above the Henderson Granitic Gneiss along the Sugarloaf Mountain thrust (Davis, 1993; Davis and Yanagihara, 1993; Bream, 2002).

Hickory Nut Gorge

Hickory Nut Gorge is a WNW-trending lineament that transects the Columbus Promontory of the BRE. WNW-trending lineaments and associated subparallel joint sets are common in this region, and have been related to brittle faulting in the Skyland 7.5-minute quadrangle 17 miles to the WNW near Asheville (Cattanach et al., 2014, Wooten et al., 2010). One objective of the ongoing research collaboration between Western Carolina University and the NGCS is to better understand the controls these brittle bedrock structures have on rock slope failures and debris flows in Hickory Nut Gorge.

Hickory Nut Gorge which includes Chimney Rock has a long record of historical landslide events including those in 1916, 1994, 1996, 2008, 2014 and 2018. Extensive rock boulder and block footslope deposits show that steep gorge walls are prone to Quaternary debris flows and debris slides, and rock falls (Soplata, 2016). Cliffs in the Gorge walls were formed by rock falls along the prominent WNW fracture set common in the area. Massive blocks of Henderson Gneiss detach along these joint surfaces, contributing large boulders to the hillslope and valley deposits below. Numerous debris flows have also deposited block- and boulder-sized debris in tributary streams to the Rocky Broad River. Descriptions of landslide events to be viewed and discussed during the field trip follow in chronological order, beginning with the recent events of 2018 and ending with those that occurred in 1916.

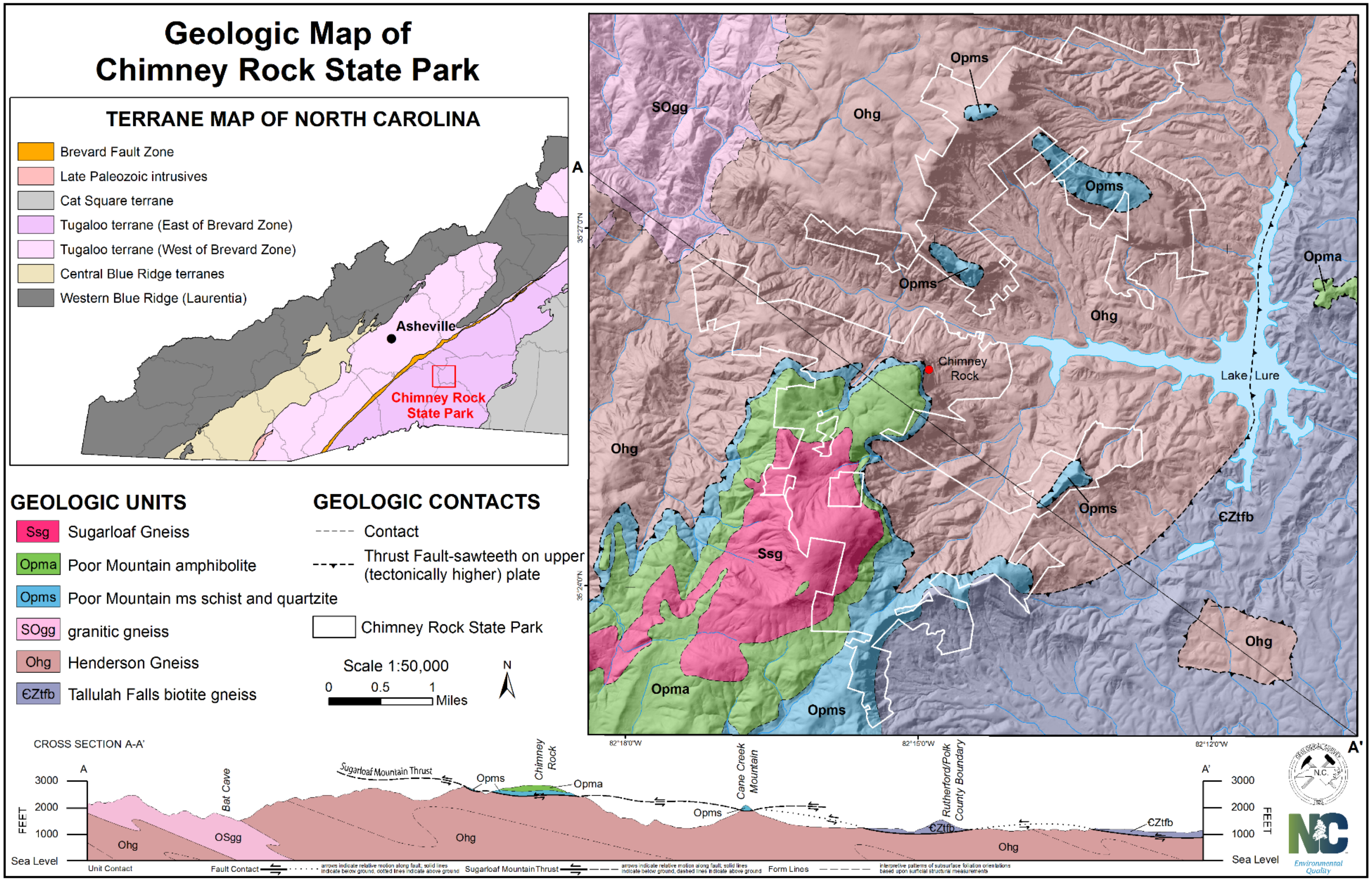

Figure 4.1. Geologic map and cross section of Chimney Rock State Park.

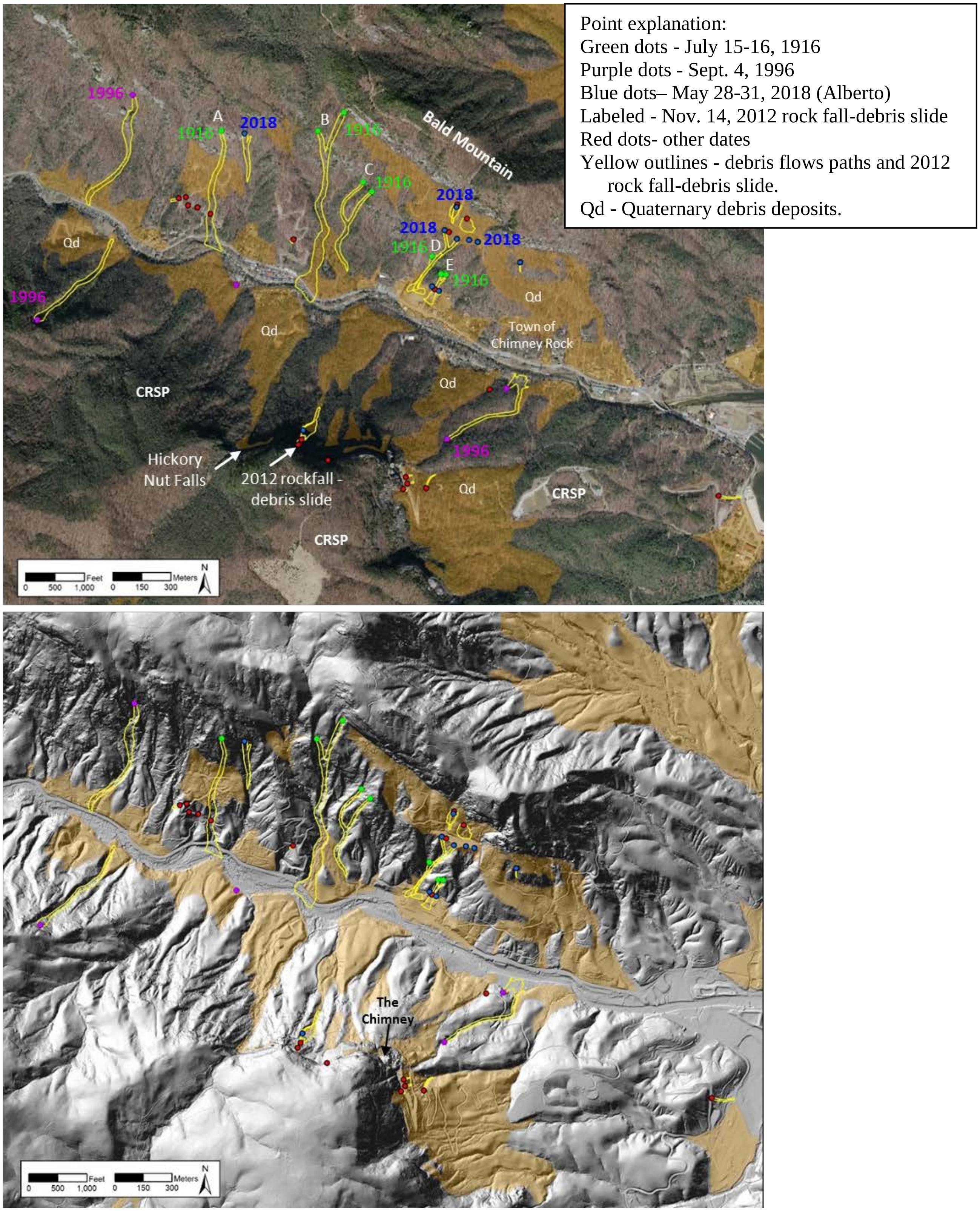

Figure 4.2. Top: Slope movement features in Hickory Nut Gorge in Chimney Rock State Park (CRSP) and Town of Chimney Rock. Lettered locations correspond with debris flows in Figs. 4.14 and 4.15. **Bottom:** Same slope movement features as top map. Map base is a shaded relief map derived from a QL1 LiDAR digital elevation model. Data sources: NCGS landslide geodatabase; Soplata, 2016.

Debris Flows and Debris Slides – Alberto, May 28-30, 2018

Rainfall from remnants of subtropical depression Alberto triggered six known damaging debris flows and debris slides in the Chimney Rock area of Hickory Nut Gorge, mainly on the south-facing slopes of Bald Mountain. Two debris flows converged into one stream channel (Fig. 4.3 left, Fig. 4.4) and caused property damage to a Village of Chimney Rock park. These two debris flows initiated as embankment failures originating in the former Silver City amusement park. The red ground-rupture line in Figure 4.4 represents a series of scarps and tension cracks in the embankment material observed in June 2018 and in June 2019, indicators of unstable embankment material that could mobilized into future damaging debris flows. The NCGS notified the Town of Chimney Rock of the situation. Two debris slides (cut slope failures) damaged the Chimney Rock Volunteer Fire Department (Fig. 4.3 right, Fig. 4.4). The 2018 debris flows and debris slides shown here coincided with areas affected by debris flows triggered by rainfall the July 15-16, 1916 storm (see debris flows labeled D and E in Figs. 4.4 and 4.15).

Figure 4.3. Left: View looking upslope (north) along the path of the debris flow (embankment failure) that damaged a Village of Chimney Rock park. 2019 NCGS photo. **Right**: Damage to the Chimney Rock Volunteer Fire Department (CRVFD) by a May 30, 2018 debris slide (cut slope failure) triggered by subtropical depression Alberto. View looking northwest. 2018/05/30 CRVFD photo.

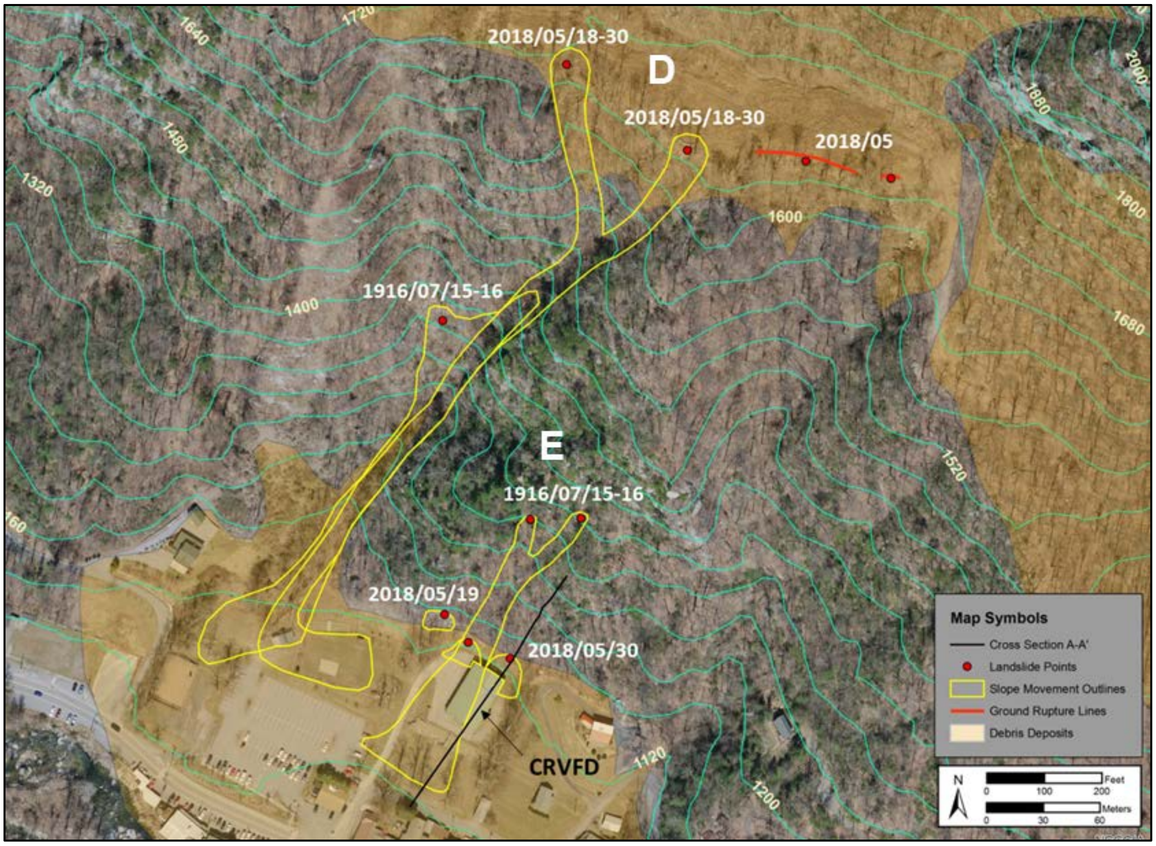

Figure 4.4. Locations of debris flows, and debris slides triggered by rainfall from Alberto, May 28-31, 2018 in the same areas affected by debris flows from the July 15-16, 1916 storm. CRVFD = Chimney Rock Volunteer Fire Department. Lettered locations correspond with debris flow locations in archival photographs in Figures 4.14 and 4.15. Map base is 2015 orthophotography; topographic contours (40-ft contour interval) derived from a LiDAR 6m (20ft) digital elevation model. Data sources: NCGS; Soplata, 2016.

November 14, 2012 Rockfall – Debris Slide: Chimney Rock State Park

During the night of November 14, 2012 a major rock fall occurred in Chimney Rock State Park in Hickory Nut Falls Gorge (Figures 4.5-4.10). A 1,400-2,000-ton rock slab dislodged from an overhanging outcrop ledge about 340 feet in elevation above the trail to Hickory Nut Falls. The block fell and shattered into boulders when it impacted a rock slope immediately below the overhang. A portion of the boulder debris severely damaged a 210-foot-long section of trail and destroyed a section of a steel girder footbridge. Some of the boulder debris impacted a colluvial deposit upslope of the trail triggering a debris slide resulting in approximately 3,000 yd^3 of unstable material remaining on the slope above the trail. Fortunately, the rock fall occurred after park hours, as the trail to Hickory Nut Falls (Fig. 4.11) is a popular. Our report on the rock fall event (Wooten et al., 2012) supported the Division of Parks and Recreation's effort to obtain funding to remediate the trail and remove the hazardous material above the trail before it reopened to the public. This rock fall and other NCGS responses to landslide events is summarized in Wooten et al. (2017).

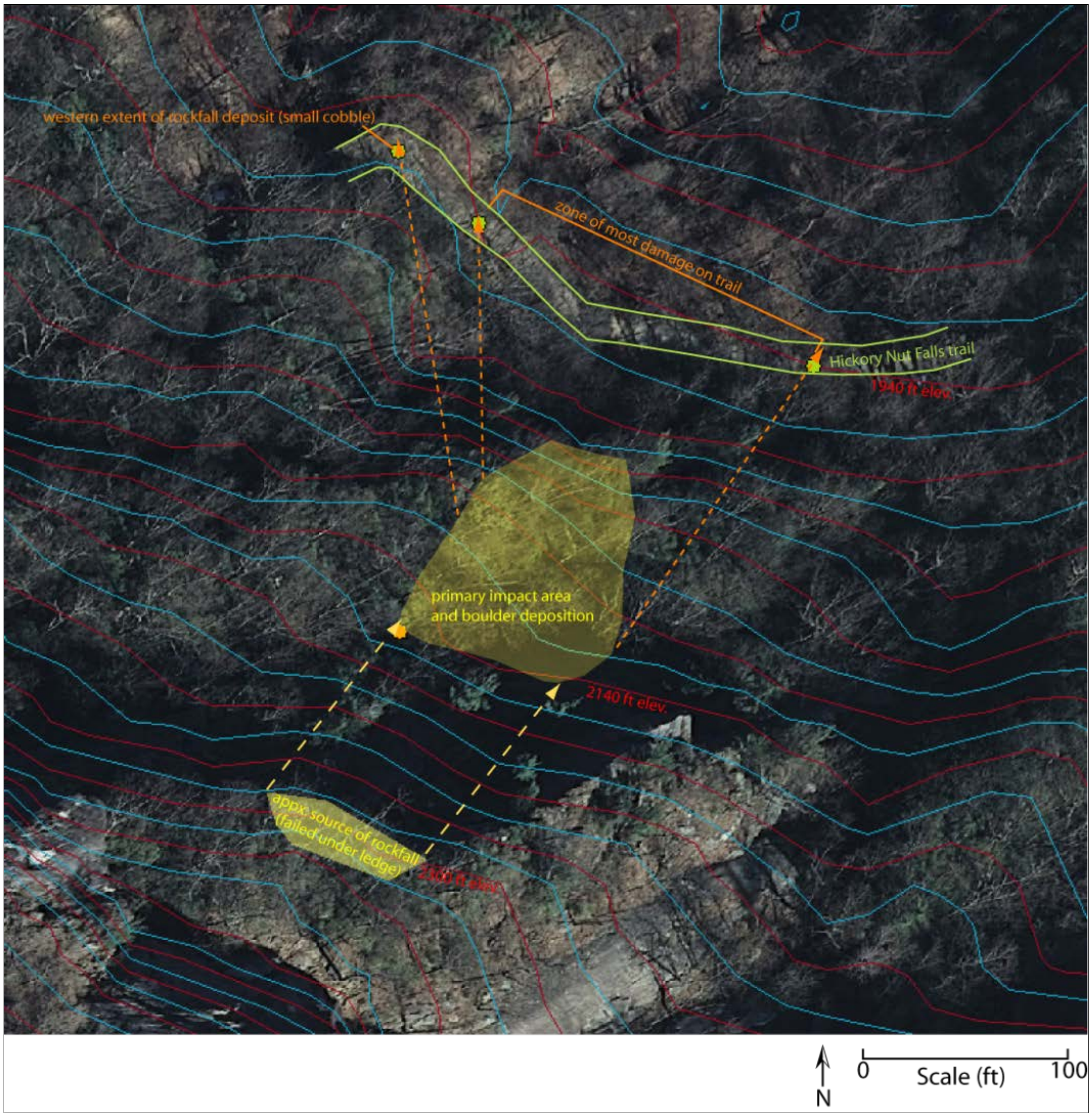

Figure 4.5. Schematic map showing approximate location of the November 14, 2012 rockfall, including the source area, boulder deposit area, and damaged trail area. Map base is 2012 orthophotography. Topographic contours are derived from the Light Detecting and Ranging (LiDAR) digital elevation model. Contour interval = 20 feet.

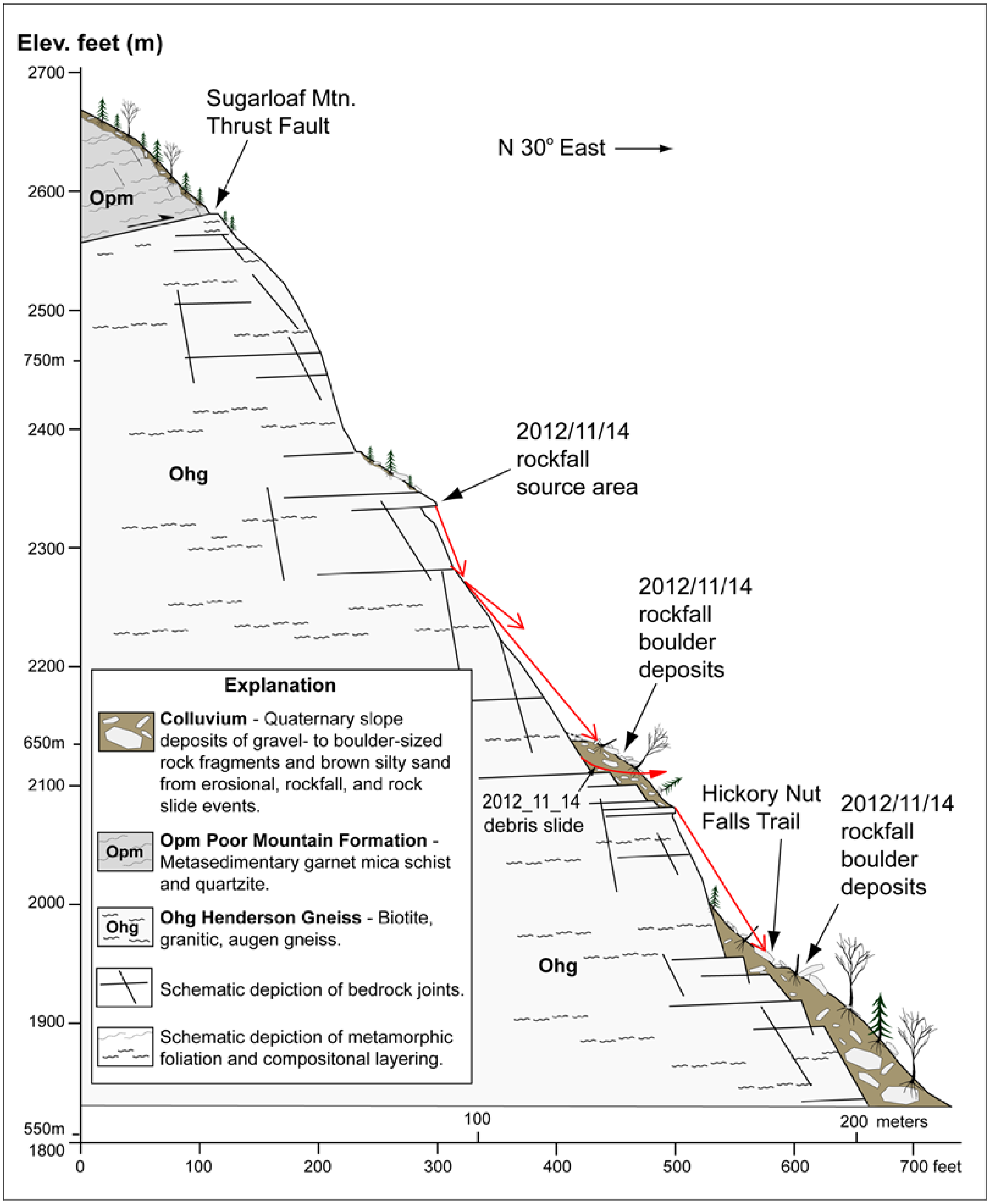

Figure 4.6. Schematic geologic cross section through the area of the November 14, 2012 rockslide showing the rockfall source area, and the rockfall boulder deposit and unstable debris slide above the Hickory Nut Falls trail. Letters correspond to locations of photographs included in the report. Topographic profile derived from theLiDAR digital elevation model (20-ft pixel resolution) with 20-foot topographic contours. Geology adapted from Davis and Yanagihara, 1993.

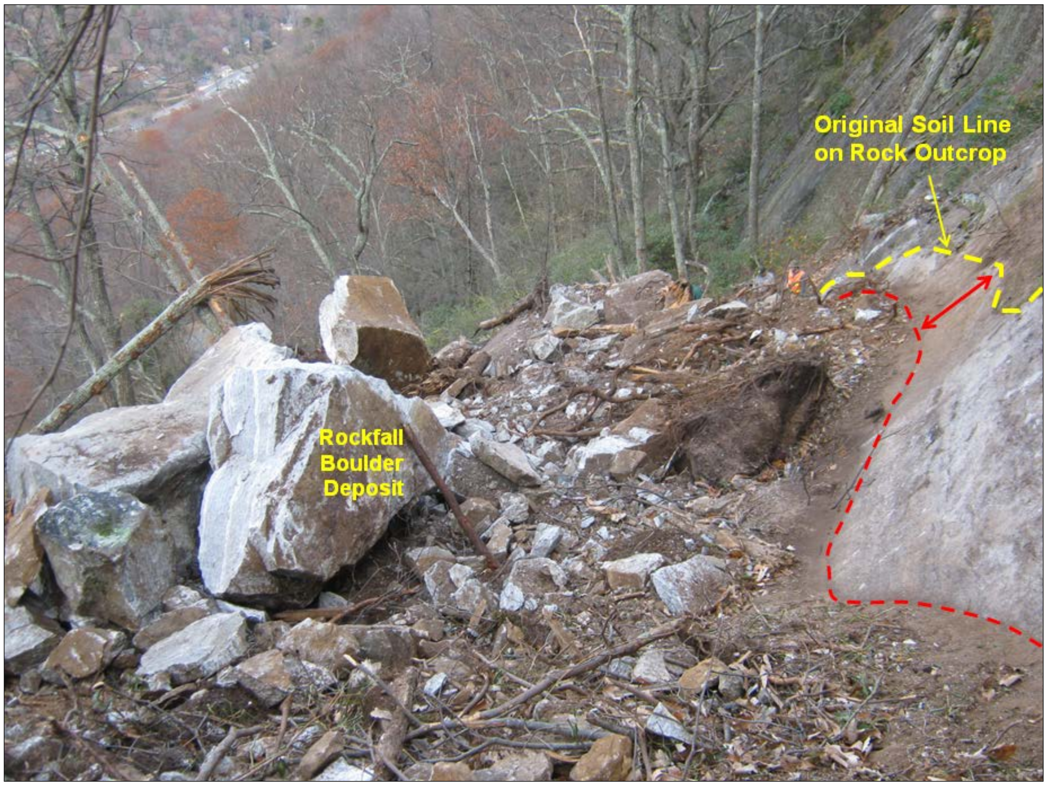

Figure 4.7. Displacement along the scarp of the debris slide developed here along the contact between bedrock and pre-existing rocky colluvium overlain by boulders from the November 14, 2012 rockfall event. The displacement is shown by the distance between the yellow and red dashed lines. 2012/11/19 NCGS photo.

Figure 4.8. Unstable boulder deposit and trees damaged by the November 14, 2012 rockfall event. 2012/11/19 NCGS photo.

Figure 4.9. Severe damage to the footbridge on Hickory Nut Falls trail caused by rockfall and trees downed by the rockfall. 2012/11/19 NCGS photo.

Figure 4.10. Arrow points to rock projectile from the November 14, 2012 rockfall imbedded into a tree below the Hickory Nut Falls trail. The rock fragment is about 8-10 feet above the base of the tree. 2012/11/19 NCGS photo.

Figure 4.11. View of Hickory Nut Falls from the Skyline Trail (currently closed) in Chimney Rock State Park. View looking west. 2012/11/26 NCGS photo. The tree line just above the cliff face coincides roughly with the trace of the Sugarloaf Mountain thrust fault which places the Poor Mountain formation (Opm) over the Henderson Gneiss (Ohg) (see Fig. 4.6 cross section).

Hickory Nut Gorge - September 4, 1996 Flash Flood and Debris Flow Event

The September 4, 1996 rainfall event is of particular interest with respect to the meteorological influence of the Hickory Nut Gorge. High intensity rainfall measuring 317mm (~12.5 in) within a 3-hour period triggered flash flooding (Johnstone and Burrus, 1998), and at least four debris flows and one debris slide (Soplata, 2016; L. Haydock, personal communication) in the Chimney Rock area (Fig. 4.2). Johnstone and Burrus (1998) posit that Hickory Nut Gorge provided a "V" shaped opening in the BRE that acted as focusing point for upslope flow and intense rainfall resulting from interactions between a low in eastern Tennessee and the approaching Hurricane Fran (Fig. 4.12).

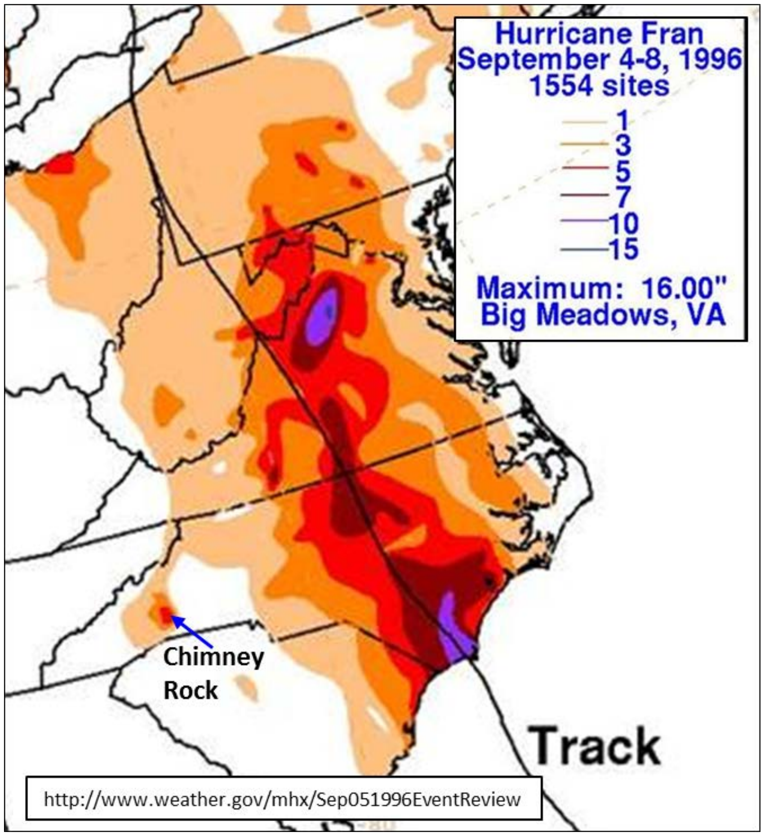

Figure 4.12. Rainfall total map for Hurricane Fran showing the inferred distal influence of the tropical cyclone on the rainfall in the Hickory Nut Gorge and Chimney Rock area. Map courtesy of NOAA-NWS.

The Blue Ridge Escarpment and Debris Flows – The July 15-16, 1916 Storm

The distribution of the generalized locations of areas affected by debris flows and other landslides for the July 15-16, 1916 event (Figure 4.13), generally coincide with the Blue Ridge Escarpment (BRE) (Wooten et al., 2015) including those in the Chimney Rock area shown in Figures 4.2, 4.14 and 4.15.

Geologically, the high relief, steep slopes, and highly dissected nature of the BRE make it susceptible to debris flows. Orographic forcing of rainfall along the BRE is shown by the greater rainfall totals along the BRE as compared to the surrounding regions for the remnants of hurricanes in July 15-6, 1916 (Scott 1972) and August 10-17, 1940 (US Geological Survey, 1949) and is also a major factor contributing to the frequency of debris flows along the BRE. The July 1916 storm was the storm of record for the French Broad watershed (Witt, 2005) and set the 24-hour rainfall record for North Carolina of 22.2 inches at Altapass on the crest of the BRE in Mitchell County near North Cove. Extensive flooding and numerous landsides resulted in at least 50 fatalities, with 18 of those related to landslides. Refer to Figures 4.2, 4.14 and 4.15 for locations for July 15-16, 1916 debris flows in Chimney Rock area.

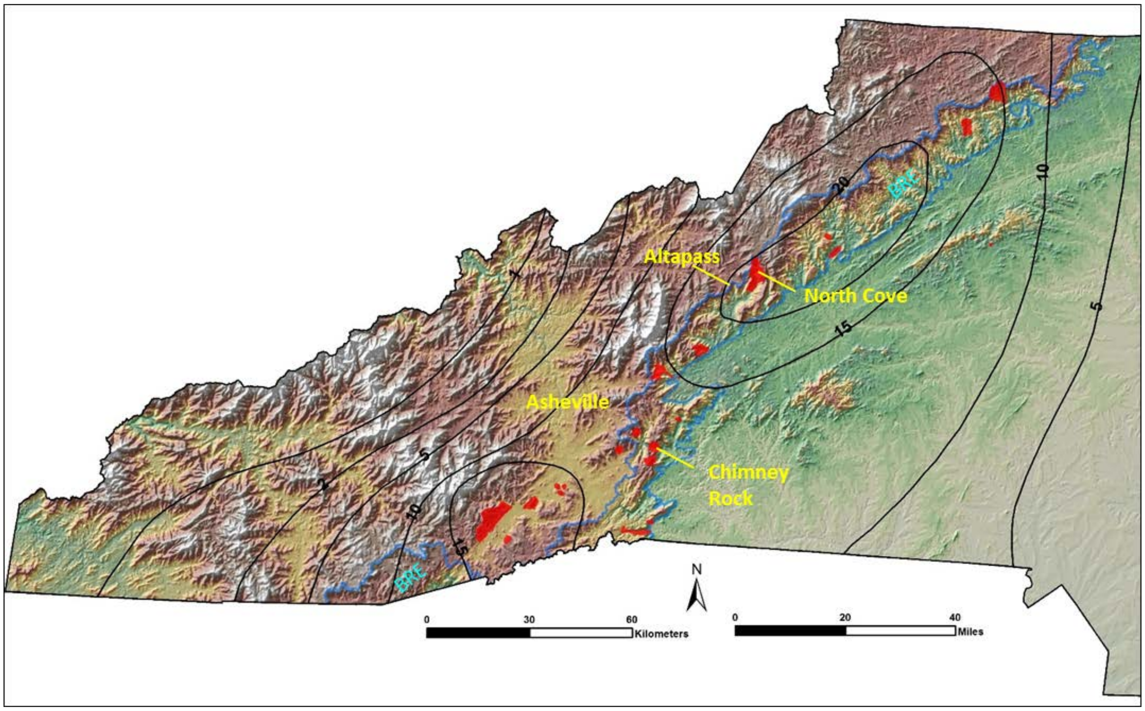

Figure 4.13. The generalized distribution of landslides reported for the July 15-16, 1916 storm compiled by the NCGS (red areas), and storm total rainfall amounts in inches from Scott (1972). BRE = Blue Ridge Escarpment.

Figure 4.14. Chimney Rock Park view down from the APPIAN WAY 1920-1922. William A. Barnhill N. C. Collection – Pack Memorial Library. View looking north. Lettered locations for the debris flow tracks from the July 15-16, 1916 storm correspond with those on Figure 4.2.

Figure 4.15. 1920's era photograph 'Mountain View from Devils Head Chimney Rock,' EM Ball Collection N932 UNC-Asheville. View looking northeast. Arrows point to July 15-16, 1916 debris flow deposits. The Mountain View Inn was damaged by the western debris flow. Lettered locations for the debris flow tracks from the July 15-16, 1916 storm correspond to those on Figs. 4.2 and 4.4. The bridge over the Rocky Broad River is at its present location. Description of photograph content courtesy of LuVerne Haydock.

Acknowledgments

The cooperation and support shown by the Park Rangers and staff of Chimney Rock State Park over the years is gratefully acknowledged, especially that of Park Superintendent James Ledgerwood and Ranger Katherine Scheip. We thank LuVerne Haydock for her recollections and records of her family's history in the Chimney Rock area related to the storms of 1916 and 1996.

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Stop 5 (Optional) Buffalo Creek Debris slide

Leaders: Rick Wooten, Jennifer Bauer, Bart Cattanach (co-author)

Location: Latitude 35.46819º Longitude -82.18782º Buffalo Creek Road (SR 1314), Rutherford County, North Carolina.

Purpose: The purpose of this stop is to observe damage to transportation infrastructure and private property from an active debris slide. The North Carolina Department of Transportation, and Appalachian Landslide Consultants, PLLC have conducted investigations of various aspects of the debris slide. The report prepared by the North Carolina Geological Survey for the Town of Lake Lure is reprinted and adapted here with permission.

Field Investigation and Provisional Map of the Buffalo Creek Debris Slide
Rutherford County, North Carolina

May 13, 2019

Richard M. Wooten, PG
Senior Geologist for Geohazards and Engineering Geology

Bart L. Cattanach, PG
Senior Blue Ridge and Western Piedmont Mapping Geologist

G. Nicholas Bozdog, GISP
Project Geologist

Sierra J. Isard, PG
Geologist I

North Carolina Geological Survey

Introduction

This report accompanies the map of the Buffalo Creek debris slide requested by the Town of Lake Lure. Figure 5.1 is a location map for the slide area and vicinity. Figure 5.2 is the map that shows the approximate limits of the active slide zone and the provisional limits of a precautionary zone around the slide as observed by the North Carolina Geological Survey (NCGS) geologists. The intent of the report and maps is to convey some of the relevant geologic conditions in and around the debris slide area as they pertain to public safety. They are not intended to be a detailed account of the slide history and geologic conditions related to the slide.

The included map (Fig. 5.2) is a reference guide for planning purposes and not a substitute for a site map prepared by a licensed land surveyor. Map unit boundaries shown are subject to change in the future as: 1) slide conditions evolve; 2) new information becomes available; and, 3) ground disturbing activities or environmental conditions that influence slide movement occur.

Methods and Data Sources

NCGS geologists conducted field investigations of the slide area on March 3, March 13, and April 2, 2019 and collected data using field computers equipped with mapping grade global positioning satellite (GPS) location systems. Topographic contours, and shaded relief and slope maps derived from a 20-foot pixel resolution Light Detecting And Ranging (LiDAR) digital elevation model were used for geomorphic analyses. Orthophotography dated 1993, 1998, 2010 and 2015 augmented the mapping. The North Carolina Department of Transportation (NCDOT) Geotechnical Engineering Unit provided selected historical reports, recent maps, monitoring data, and georegistered unmanned aerial systems (UAS) imagery. The Town of Lake Lure also provided UAS imagery. Specific data sources are given in the references section.

Background

Bedrock exposures outside of the slide area are comprised of weathered granitic orthogneiss designated as the Henderson Gneiss (Davis and Yanagihara, 1993). Rock fragments within the debris deposits that make up surface exposures in the slide area are gravel- to boulder-sized clasts of weathered (stained state to completely decomposed state) Henderson Gneiss.

The Buffalo Creek debris slide has a documented history of movement over a 45-year period. A 1988 NCDOT memorandum (NCDOT, 1988) documented that NCDOT investigated the slide in 1974 and 1980. In that memorandum the author concluded that, "The slide has the potential to continue movement indefinitely, varying in speed with the seasons. Movement will be faster in the rainy season, but is unlikely to stop completely." Reconnaissance by NCGS geologists in 2006 noted distress to Buffalo Creek Road (SR 1314) in this area indicative of slide movement at some time. Recent movement became apparent in May of 2018 at which time the NCDOT took measures to the repair SR 1314. The NCDOT was notified of further movement on January 2, 2019 and subsequently closed the road to traffic.

Slide movement has also damaged houses and utilities. The 1980 NCDOT memorandum states that one house appeared to be affected by the slide with erratic foundation settlement; another house was moved to avoid ground movement; and water supply lines were disrupted. In March 2019 the Rutherford County Building Inspections Department condemned one home in active slide area at 140 Sleeping Bear Lane because of severe damage to the foundation.

Two homes outside of the active slide zone but located in the precautionary zone were recently condemned because of severe foundation damage, one at 1641 Buffalo Creek Road, and one at 159 Young's Mountain Drive. Foundation distress at these two locations does not appear to be directly connected to the recent movement in the active slide zone but related to slope and/or foundation conditions specific to the house sites. These two houses are interpreted to be on the slopes of the south flank of the prehistoric-historic slope movement that predates the present-day Buffalo Creek debris slide.

Active Slide Zone

The active slide zone shown in Figure 5.2 encompasses the area with evidence of ground movement associated with the Buffalo Creek debris slide. The total area of the active zone is approximately 3.6 acres, which includes as much as 1 acre below lake level. Inclinometer data provided by the NCDOT indicate that slide movement is on the order of 42-55 feet below ground surface in portions of the slide. Depths and rates of movement within the slide mass vary. Rates of movement vary over time, and are probably on the order of inches/year to as much as feet/month. **Note:** Figures 5.3 and 5.4 are photographs of the active slide area appended here to the original report.

Evidence of ground movement within the active slide zone includes the following:

- Ground rupture (i.e., scarps and tension cracks)
- Leaning and/or downed trees
- Bulging and/or subsidence of the ground surface
- Cracked and broken pavement on Buffalo Creek Road (SR 1314)
- Displacement of NCDOT survey monitoring points
- Deflection of NCDOT slope inclinometer casings.

Precautionary Zone

The precautionary zone shown in Figure 5.2 delineates the area around the active slide zone that is potentially unstable, or could become unstable with enlargement of the active zone of the Buffalo Creek debris slide.

Slopes within the precautionary zone meet one or more of the following criteria:

- Deposits from past landslide activity are exposed at the ground surface and excavated slopes.
- Located within the area interpreted to be part of prehistoric and historic slope movements involving the present day Buffalo Creek debris slide.
- Ground cracks on the margins of the active slide area are present.
- Include small debris slides on steep slopes of adjacent drainage ways (flanks of related prehistoric-historic slope movements involving the present day Buffalo Creek slide).
- Ground slope is generally in excess of approximately 18-21 degrees (32%-38%) as estimated from a 20-foot pixel resolution LiDAR digital elevation model.

Findings and Recommendation

General

Given the long history of slide movement at this location it is reasonable to assume that the slide will continue to move intermittently for the foreseeable future. Periods of increased or decreased rates and magnitudes of movement will likely be related to wet and dry weather patterns.

Bald Mountain Lake likely contributes somewhat to the instability of the slide because it maintains saturated conditions at the toe of the slide. Rapid drawdown of Bald Mountain Lake may trigger or accelerate movement of the slide. Rapid drawdown of the lake in which the lake level drops faster than the internal water within the slide drains may result in slide movement. Any drawdown of the lake should consider possible effects to the slide and should be done under the guidance of qualified engineers and/or geologists. Installation of piezometers in the toe of the slide upslope of the lake level may aid in assessing lake lowering rates and ground water levels in the slide.

Issuance of building permits or property sales in the active slide or precautionary zones should be accompanied by disclosure of the information regarding the debris slide and potential hazards, including the potential for enlargement of the active and precautionary slide zones.

Repairs to structures to maintain their structural integrity in response to ground movements within the active and precautionary slide zones should be done under guidance of qualified structural and/or geotechnical engineers.

It is important to note that typical home owner's insurance policies in North Carolina do not cover damage related to landslide movement.

Long term monitoring of the active and precautionary slide zones is recommended, but is beyond the resources and authority of the North Carolina Geological Survey.

Active Slide Zone
Any new construction in the active slide zone is not recommended and should be done with extreme caution, and under the guidance of qualified geologists and/or engineers.

Slide movement can severely damage structures, access roads, driveways, and utilities including water and electrical supply lines, and septic systems.

Plumbing and electrical systems within homes can be compromised and result in damage such as flooding and fires.

Trees affected by slide movement can fall unexpectedly.

Structures and homes can be built to withstand certain levels of slide movement; however, such measures are likely to be expensive and should be done under the guidance of qualified structural and geotechnical engineers.

Precautionary Slide Zone
Siting new construction in the precautionary zone should be done by qualified geologists and/or geotechnical engineers.

It is recommended that foundation design in this zone should be done by a qualified geotechnical engineer.

References

Davis, T.L., Yanagihara, G., 1993, Geologic map of the Columbus Promontory, western Inner Piedmont, North Carolina, *In*: Hatcher, R.D., Davis, T.L., eds., Studies of Inner Piedmont Geology, with a focus on the Columbus Promontory, Carolina Geological Society Field Trip Guidebook, 144p., map scale, 1:48,000.

NCDOT, 1988, Slide on SR 1314 Fairfield Mtns. Development, Lake Lure; P. Winchester memorandum to A. Melnik, April 27, 1988.

NCDOT, 1980, Slide investigation on SR 1314, near Lake Lure, F.D. McKinley memorandum to W.D. Bingham.

NCDOT, georegistered UAS imagery dated January 21, 28, and March 22, 2019.

NCDOT, monitoring point surveys dated January 21, 28, and February 7, 2019.

NCDOT, Inclinometer readings dated Jan. 15, 18, 22, 26, 29, 2019.

North Carolina Geological Survey landslide geodatabase.

Town of Lake Lure UAS imagery dated March 13, 2019.

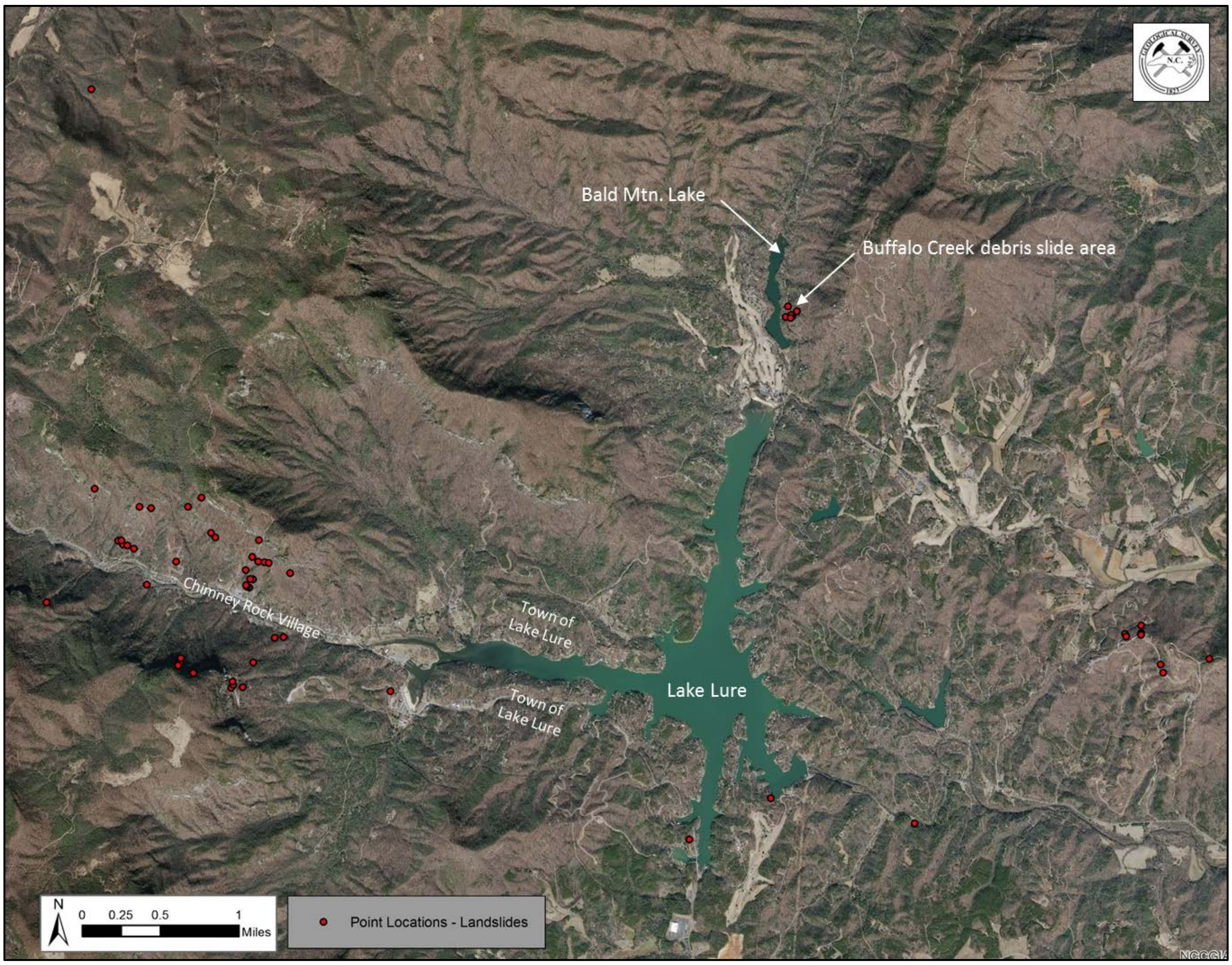

Figure 5.1. Location map for the Buffalo Creek debris slide area and vicinity with point locations for landslides in the NCGS landslide geodatabase as of 2019/04/02. Map base is 2015 orthophotography.

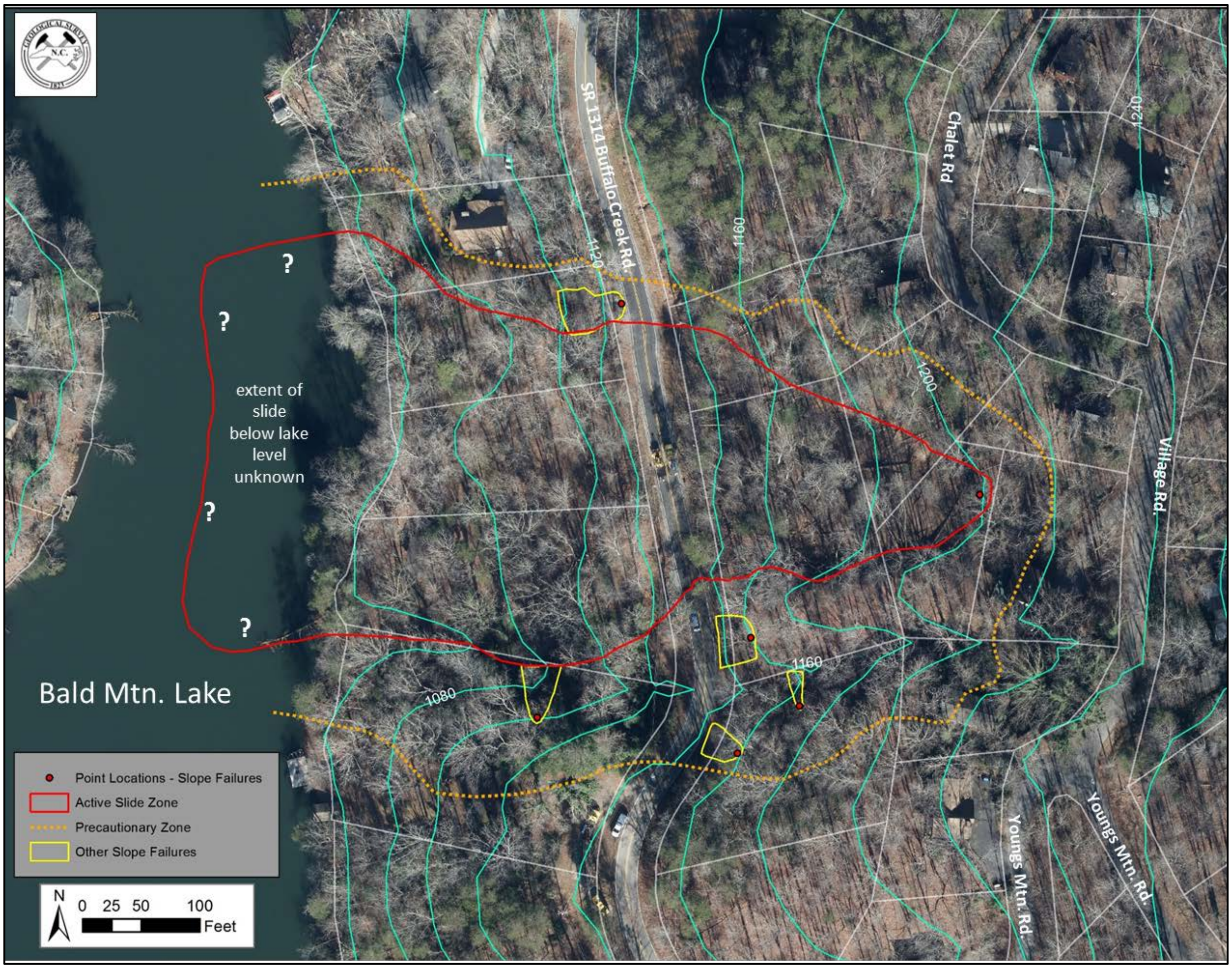

Figure 5.2. Provisional map of the Buffalo Creek debris slide area showing the active slide zone and precautionary zone and other slope movement features as of 2019/04/02. Topographic contours (20-foot contour interval) derived from a 20-foot pixel resolution LiDAR (Light Detecting And Ranging) digital elevation model. LiDAR data acquisition pre-dates recent slide movement. Approximate land parcel boundaries (white) courtesy of the Rutherford County GIS Department. Map base is 2019 unmanned aerial systems (UAS) ortho-mosaic provided by NCDOT. Data Sources: NCGS and NCDOT. **Notes:** 1. All locations and boundaries are approximate. 2. Areas of ground cracks within the active slide and precautionary zones are not shown. 3. Map unit boundaries are subject to change as slide conditions and extents may change. 4. This map is not a substitute for a map prepared by a licensed land surveyor.

Figures 5.3 and 5.4 appended here to the original report.

Figure 5.3. **Left:** Displacement of Buffalo Creek Road (SR 1314) on the left lateral scarp on the south side of the debris slide. View looking south. 2019/03/07 NCGS photo. **Right:** Displacement of Buffalo Creek Road (SR 1314) on the right lateral scarp on the north side of the debris slide. View looking north. 2019/04/02 NCGS photo.

Figure 5.4. **Left:** Leaning trees within the slide mass upslope of Buffalo Creek Rd. (SR 1314). View looking northwest toward the right lateral scarp. 2019/03/07 NCGS photo. **Right:** Displacement on the right lateral scarp on the north side of the debris slide downslope from Buffalo Creek Rd. (SR 1314). View looking north. 2019/04/02 NCGS photo.