BIG SLOW MOVERS: A LOOK AT WEATHERED-ROCK SLIDES IN WESTERN NORTH CAROLINA

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Abstract: The North Carolina Geological Survey (NCGS) is currently implementing a landslide hazard-mapping program in western North Carolina authorized by the North Carolina Hurricane Recovery Act of 2005. To date, over 2700 landslides and landslide deposits have been documented. A small number of these landslides are relatively large, slow-moving, weathered-rock slides, termed "big, slow movers" (BSMs). Three examples of BSMs are described in this paper.

The Toxaway River Slide is a composite BSM located in Transylvania County. This 4-acre slope movement likely began moving in 1916, and tree ring studies indicate subsequent movement relates to multi-year wet cycles. Recent reactivation of a 0.5-acre BSM at the Lake Logan Center, located southeast of Waynesville, was triggered by heavy rainfall in September 2004. High, antecedent soil moisture conditions and undercutting of the toe were the likely triggers for observed, recent movement. A 1.5-acre BSM is impacting homes in the Hunters Crossing subdivision, located just outside of the Waynesville city limits. Residents first noted movement in September 2005, and to date, four homes have been severely damaged and four others are endangered.

BSMs appear to have geomorphic and geologic settings similar to each other, and are often difficult to recognize without detailed field investigations.

INTRODUCTION

In 2000, the North Carolina Geological Survey (NCGS) began collecting information about geologic hazards throughout the state. This work was expanded in 2003 with funding from the North Carolina Division of Emergency Management to include maps and databases of information on sinkholes, earthquakes, abandoned mines, arsenic in groundwater, and landslides. This included the development of a slope movements and slope movement deposits database for all of North Carolina with a focus on the western part of the state.

In September 2004 the remnants of Hurricanes Frances and Ivan tracked over western North Carolina, dropping over 30 inches of rainfall in a 10-day period on parts of the Appalachian Mountains. The heavy rainfall triggered over 140 landslides that damaged or destroyed at least 30 buildings and killed five people. As a result of the heavy damage, the North Carolina state legislature mandated funding for the NCGS to implement a landslide hazard-mapping program as part of the Hurricane Recovery Act of 2005 (Wooten, *et al*., 2007).

NCGS staff collect information on slope movements and slope movement deposits. Such data include geographic, geomorphic, geologic and hydrologic parameters of slope movement initiation zones and the apices of slope movement deposits. These data are compiled into a Microsoft Access™ database that currently has over 2700 entries. One specific type of slope movement encountered is the very slow to slow moving, weathered-rock slide also described as a "big slow mover" (BSM). The term "weathered-rock" is used for rocks that are classified as "partly decomposed" or "completely decomposed" according to the Unified Rock Classification System (Williamson, 1984). The term "big" is a relative term applied by the NCGS that typically refers to failures larger than 0.5 acre. According to Cruden and Varnes (1996), these are classified as very slow to slow because rates of movement range from 0.5 to 36 feet per year (velocity class of 2 to 3). BSMs have complex geologic and geomorphic characteristics, sharing components of both rock and debris/earth slides. These aspects make it difficult to identify and predict the movements and behaviours of BSMs.

Although the occurrence of BSMs is less common in North Carolina's Blue Ridge physiographic province than debris flows and debris slides, several were identified in the early stages of the NCGS's landslide hazard-mapping program. Three BSMs discussed in this paper include those identified at the Toxaway River (Transylvania County), the Lake Logan Center (Haywood County), and the Hunters Crossing development (Haywood County). Figure 1 shows the locations of these failures. Although each one occurs under a unique set of circumstances, similarities observed may improve prediction of these features in the future. Work continues to better characterize the causes and triggers of BSMs and to establish ways to recognize topographic and geomorphic features associated with them.

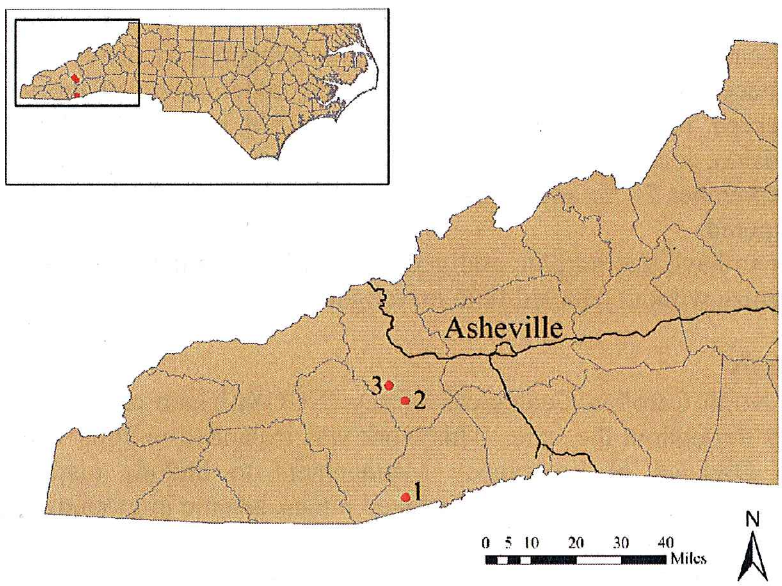

Figure 1. Location map of three big, slow moving, weathered-rock slides (BSMs) in western North Carolina: 1. Toxaway River. 2. Lake Logan Center. 3. Hunters Crossing.

TOXAWAY RIVER

The Toxaway River slide is a very slow, composite, translational, weathered-rock slide located in Gorges State Park in Transylvania County, North Carolina (Wooten *et al.*, 2003*a*). This 4-acre BSM most likely began moving when the Lake Toxaway dam failed on August 13, 1916 as the last of three hurricanes tracked over western North Carolina in the summer of 1916, sending a torrent of water and debris down the Toxaway River. The torrent likely scoured material from the toe of the pre-failure slope, which is located on an outside bend in the channel.

The slide mass is covered with leaning and curved trees that indicate active movement. The total offset since movement began is around 60 feet averaging roughly 8 to 9 inches of movement per year depending on rainfall.

Geologic Setting

The Toxaway River BSM is on the Blue Ridge Escarpment in western North Carolina, a large, steep, erosional feature that separates the mountainous Blue Ridge physiographic province to the northwest, from the much lower, rolling topography of the Piedmont physiographic province to the southeast. This slide appears to be propagating east and upslope along a shallow, west-dipping, planar rupture surface (Figure 2). This rupture surface cuts across the moderately east-dipping foliation and contacts between interlayered units of middle Proterozoic-age Toxaway layered/megacrystic, biotite, granitic gneiss and Late Proterozoic to early Paleozoic-age Tallulah Falls Formation metagraywacke and schist (Wooten *et al.*, 2003*b*). The contact zone between the Tallulah Falls metasediments and surrounding Toxaway Gneiss is a mylonitic, pre-to syn-metamorphic thrust fault.

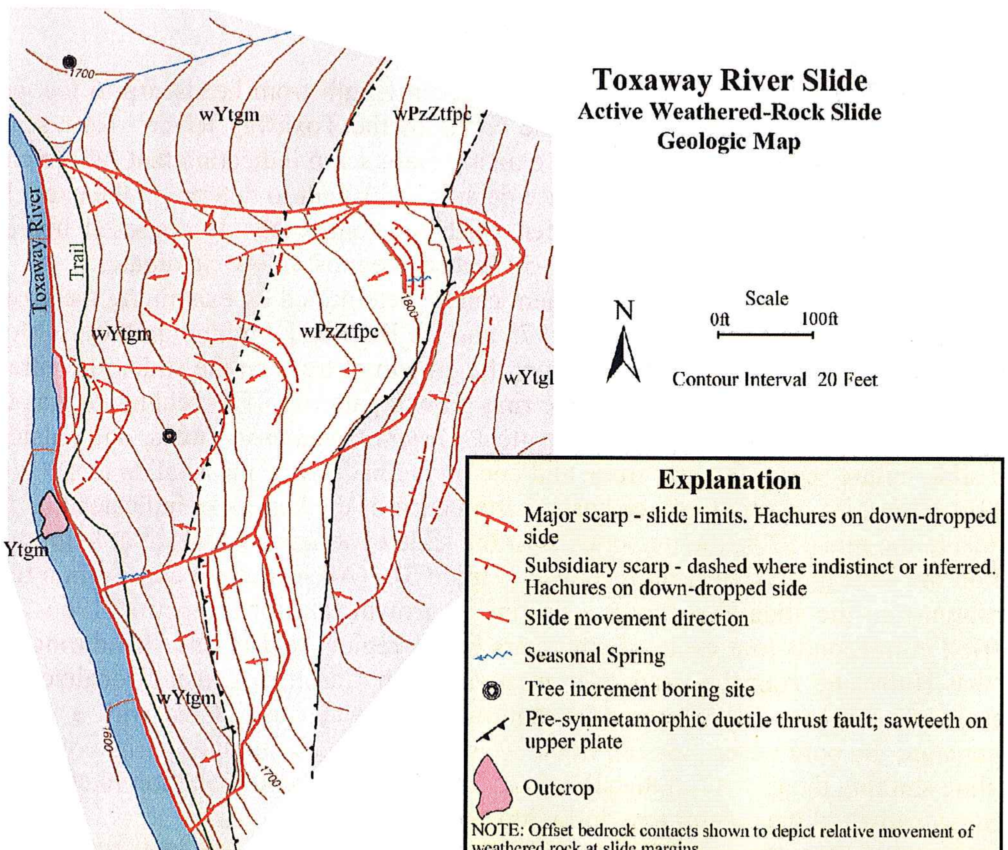

Figure 2. Geologic map of the Toxaway River BSM. Ytgm – megacrystic biotite, granitic gneiss of the Toxaway Gneiss. wYtgm – partly to completely decomposed, megacrystic biotite, granitic gneiss that weathers to a mica-bearing, silty sand. wYtgl – partly to completely decomposed, layered, biotite, quartzo-feldspathic gneiss of the Toxaway Gneiss that weathers to a mica-bearing, silty sand. wPzZtfpc – partly to completely decomposed feldspar and mica porphyroclastic schist and metagraywacke of the Tallulah Falls Formation, which weathers to a micaceous sandy silt. Both rock types are mylonitic along the thrust fault. Adapted from Wooten *et al*, 2003*b*.

The Toxaway Gneiss weathers into a residuum typified by silty sands, and the Tallulah Falls metasediments weather into micaceous, silty sands. A thin veneer of colluvium overlies the residuum. Near the eastern headscarp of the BSM, the foliation and the mylonitic contact dip between 25 and 52 degrees to the southeast, forming a geomorphic resequent (anti-dip) slope. In contrast, a west-dipping, moderate-angle (between 35 and 60 degrees) fracture set forms a geomorphic dip slope that likely acts as the sliding surface(s). Also creating a dip slope is a high-angle (between 75 and 87 degrees), west-dipping fracture set. This fracture set also serves as an avenue for downward migration of surface water (Wooten *et al.*, 2003*a*).

From a geomorphic perspective, the Toxaway River BSM is located at the toe of a west-facing resequent slope situated along an outside bend of the Toxaway River, which is a third order stream. The toe of the right (north) flank of the BSM is bounded by Panther Branch. The headscarp resides in a subtle, concave-to-the-west hillslope hollow where shallow groundwater is likely concentrated. This correlates to a wet-weather spring near the BSM headscarp (that also corresponds to the mylonitic fault contact between the Toxaway Gneiss and Tallulah Falls Formation). An auger hole bored in the headscarp area also yielded shallow groundwater.

Slide Characteristics

The Toxaway River BSM measures over 500 feet in length from headscarp to toe, and over 700 feet in width at its widest part along the banks of the Toxaway River. New scarps and tension cracks are developing upslope of the existing main scarp indicating that failure continues to propagate upslope. With limited subsurface data, it is difficult to determine the exact location of the failure plane, but the contact between partly to completely decomposed bedrock and competent bedrock (approximate depth of 10-50 feet) is the most likely candidate.

Studies indicate that relative slide movement can be determined by examining the growth rate of tree rings on and off a slide (Terasmae, 1975 and De Boer and Archibold, 2001). Movement of the slide mass can disturb the roots and stunt the growth of trees on the slide; in contrast, trees outside the slide will show more normal tree ring growth patterns. This technique was tested at the Toxaway River BSM on two Eastern Hemlock (*Tsuga Canadensis*) trees, one outside of the mapped slide failure scarps (control tree), and one on the main slide mass (slide tree) (Wooten *et al.*, 2003*a*) (Figure 2). A study of tree corings from each of the hemlocks indicates that from the mid-1960s to the mid-1970s, the tree outside of the slide experienced considerable growth while the tree on the slide grew significantly slower (Figure 3). (An increment core from a red maple (Acer rubrum) on the slide also shows a decline in growth rate for the period 1965-74). This time period corresponds to a cycle of wet years in the region, and it was also during this time period that Hurricane Agnes passed over western North Carolina, causing localized flooding (Wooten *et al.*, 2003*a*). The increase in shallow groundwater associated with a wet-weather cycle increased the pore water pressure in the weathered bedrock and likely triggered movement on the slide stunting the growth of the slide tree. This increase in precipitation likely contributed to increased growth of the control tree during this period.

Subsequent, shorter time periods of above-average precipitation in the 1980s and 1990s yielded similar, small-scale responses in the growth of the control tree and the slide tree. A precipitation peak in 1989 could indicate continued movement of the slide. This corresponds to a decrease in the growth rate of the landslide tree and an increased growth rate for the control tree (Figure 3).

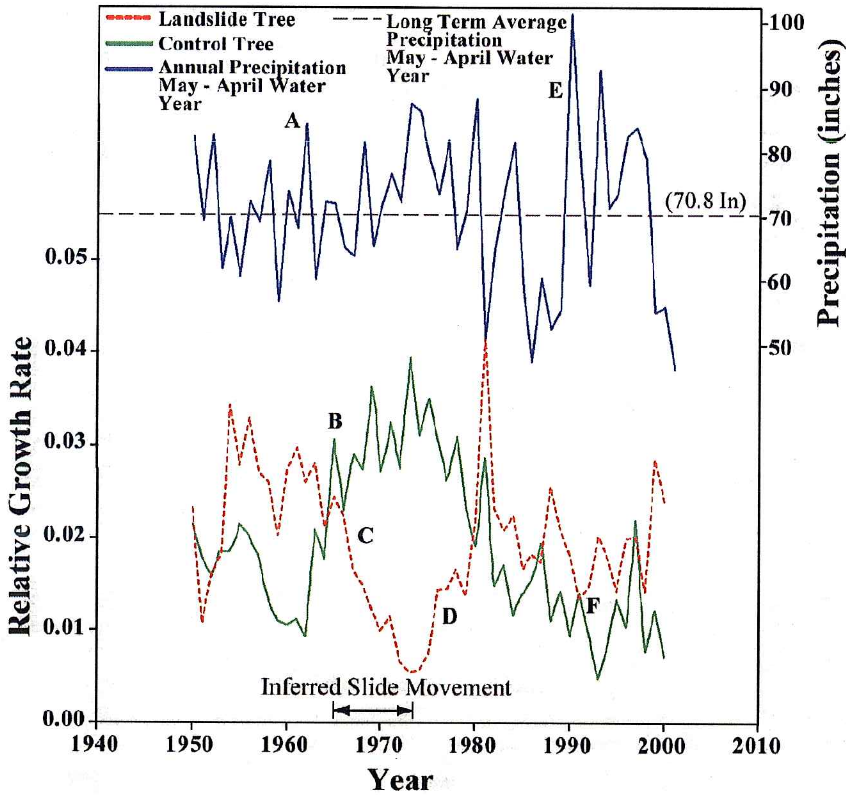

Figure 3. Plot showing the correlation between precipitation and the relative growth rate of an Eastern Hemlock on the Toxaway River BSM and a control tree off of the slide mass. While an increase in precipitation (A) corresponds to increased growth of the control tree (B), it also corresponds to decreased growth of the tree on the slide (C). This suggests that above average precipitation during the mid-1960s to the mid-1970s triggered movement of the slide, disrupting the root network of the tree on the slide and stunting its growth while causing the tree off the slide to grow more rapidly. The rapid growth of the slide tree during the late 1970s and early 1980s (D) could be the result of bulking of the tree on one side in an attempt to re-establish vertical growth (Jacoby, 2000). Shorter periods of above average precipitation in the 1980s and 1990s (E) produced similar responses in tree growth rate but on a smaller scale (F) (Adapted from Wooten *et al.*, 2003*a*).

It should be noted that a number of other factors could affect the relative growth rate of these trees including: temperature, relative humidity, wind damage, previous year carbohydrate storage, timing of precipitation (i.e., growth season versus dormant season), and subsurface hydrology (the factor about which least is known because of limited subsurface data). For example, while precipitation was below average in 1980, both trees exhibited spikes in growth rate (Figure 3). This counter-intuitive situation could be explained by the season during which the precipitation occurred; although total precipitation for the year was low, a higher percentage of precipitation for that year fell during the growing season compared with the dormant season. Therefore, water availability was adequate during the growing season at both coring sites, while the shortage of precipitation occurred during the dormant season.

Hazards

Fortunately, the Toxaway River BSM is in uninhabited public land and threatens no structures or private property. Continued movement could encroach on the river, and catastrophic failure, although unlikely, could temporarily dam the river. A trail crosses the toe of the slide, and continued steady movement could cause minor damage to it. The left flank of the scarp at the southern end of the failure has some large (at least three-foot diameter) boulders that pose a potential rock fall threat as slow movement continues (Wooten *et al.*, 2003*a*).

LAKE LOGAN CENTER

The Lake Logan Center is a private camp located in Haywood County approximately 6.5 miles southeast of Waynesville. The Lake Logan BSM is situated at the southern end of the camp, adjacent to a bend in the north-flowing West Fork of the Pigeon River (Figure 4). The largest, most recent movement of this BSM occurred in September 2004 as the remnants of Hurricanes Frances and Ivan passed over the western part of the state. This area received over 9.5 inches of rain during Hurricane Frances, and 6.5 inches of rain eight days later during Hurricane Ivan (USGS, 2006).

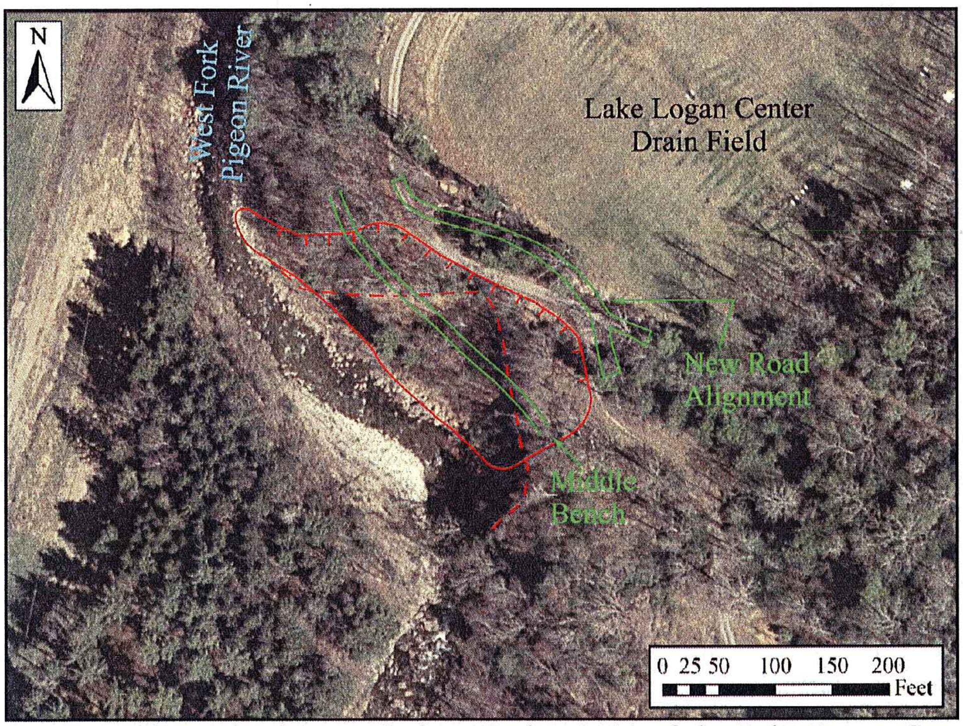

Figure 4. True-color orthophotograph from Spring 2004 of the Lake Logan Center BSM. September 2004 failure approximated by solid red line; hachures are on the down-dropped side. Red dashed line outlines a possible pre-existing scarp in the vicinity of the more recent failure. The north flowing, West Fork of the Pigeon River may have eroded the toe of the slope triggering the initial and recurring failure. Approximate locations of selected slope repairs are shown in green for reference.

In response to the damage caused by the 2004 hurricanes, the Natural Resources Conservation Service provided funding through the Emergency Watershed Protection program to stabilize the slope. This was primarily because of the impact the failure was having on the West Fork of the Pigeon River located at the toe of the slide. Repair options were limited because of the proximity of the slide to the onsite wastewater treatment system upslope. Final plans called for removal of soil in the upper half of the slide and installation of two benches: one in the middle of the slope and one at the toe (i.e., floodplain) (Figure 4). Realignment of the road along the headscarp allowed for the removal of material in the upper portion of the slide; an earthen berm was installed along the roadway to divert surface runoff away from the slide. Large boulders were placed at the toe to attempt to prevent erosion and undercutting by future flood events. Subsequent to remediation efforts, the NCGS was contacted with concerns about continued slide movement. Near the end of construction, cracks and scarps began to develop in the middle bench and in freshly exposed weathered bedrock upslope indicating movement likely along old pre-existing slip surfaces.

Geologic Setting

The Lake Logan Center BSM is located on a steep, west-facing hillside that borders the West Fork of the Pigeon River (Figure 4). Early slide movements propagated through an interlayered rock unit of principally metasandstone and schist mapped by Merschat (2005) as part of the Late Proterozoic- to Cambrian-age rocks within the Great Balsam Mountain window. In contrast, materials exposed in the newer, active scarp consist of garnet mica schist, micaceous metagraywacke, and amphibolite gneiss. The schist and micaceous metagraywacke are decomposed to a micaceous, low plasticity sandy silt. The amphibolite is also completely decomposed forming a residuum of red, micaceous, sandy, clayey silt. A partially decomposed pegmatite also cross cuts these units and was exposed along the new failure plane in the constructed bench. There is a thick (>5 feet) colluvial deposit on the left flank of the slide where material is also failing.

Several generations of slip surfaces were exposed during slope repairs. These manganese-iron oxide coated failure planes with down-dip slickenlines dip steeply west (downslope) toward the river and act as the sliding surface in the reconstructed slope. The orientation of these planes often corresponds to the orientation of the intrusive pegmatite contact, and they also roughly parallel a possible regional lineament. These manganese-iron oxide coated slip surfaces also appear to have formed on pre-existing fracture planes in the bedrock during near surface weathering processes. The strike of the dominant foliation in these weathered rocks varies across the failure, but dips are greater than 85 degrees, creating either resequent or oblique slip surfaces.

The geomorphic setting of the Lake Logan BSM is similar to that of the Toxaway River BSM. The failure occurred at the toe of a concave-to-the-west facing slope. In addition, the slide toe occurs along an outside bend of the West Fork of the Pigeon River, which is a fourth order stream. Finally, the left flank of this BSM is bordered by a small stream. Little is known about the subsurface hydrology at this location because no borings were done.

Slide Characteristics

The Lake Logan failure that occurred in September 2004 does not appear to be the first slope movement at this location. True-color orthophotography flown of the area in Spring 2004 indicates this slide may have started to fail prior to the hurricanes (Figure 4). Little is known about the slope configuration at the time of the initial failure. NCGS staff did not visit the site until after remediation efforts were underway. Reports indicate that the failure occurred rather quickly and encompassed roughly 0.5 acre of slope area.

When NCGS staff first visited the site in August 2005, a new scarp had developed at the southeast end of the newly constructed middle bench (Figure 4); displacement was approximately two feet. By December 2005, ten feet of offset had occurred at this location. No bulging or displacement was readily observed at the toe. This could indicate that the river is eroding material as movement takes place and progresses, the toe daylights in the riverbed or confined failure is occurring. No drilling was done to confirm the depth of the failure plane, and it is not clear whether movement is translational or rotational. The lack of bulge or oversteepened ground at the toe suggests movement is likely translational, possibly along the contact between residuum and competent bedrock and facilitated by pre-existing, iron-manganese oxide coated slip surfaces. The depth of the rupture surface within the slide mass itself has not been determined.

Causes

Although the heavy rainfall associated with the remnants of Hurricanes France and Ivan in September 2004 likely raised pore-water pressure which triggered the initial failure, the continued slow to very slow movement is likely due to the orientation of iron-manganese oxide coated slip surfaces that were possibly reactivated during the large failure. Continued erosion of the toe slope at the river's edge is likely a contributor to this movement, even with its mantling of riprap. Effluent flowing through a drain field located upslope of the slide area could also contribute to the slow movement, however, it appears that water would likely flow due west from the drain field well north of the right flank of the current failure. Also, a potential exists for fracture-flow groundwater in bedrock to migrate laterally from the beneath the drain field and daylight in the slide area, although this has not been observed.

Hazards

Movement continues at this site, and no remediation efforts are scheduled for this location in the near future. Although failure currently appears to be concentrated in the middle bench of the reconstructed slope, it is possible that failure will propagate upslope. Should this happen, the realigned road could be compromised along the upslope margin of the slope repairs. The Lake Logan Center drain field could also be affected if the failure grows, but there is no indication that the scarp is progressing toward the right flank of the initial failure at this time.

HUNTERS CROSSING

The Hunters Crossing BSM is an active, very slow to slow, rotational weathered-rock slide located in Haywood County within the town of Waynesville Extraterritorial Jurisdiction. Homeowners in the Hunters Crossing community contacted the NCGS in November 2005 with concerns about a possible slope movement. They reported popping sounds in their homes at night and cracks in a nearby retaining wall. Since then, numerous site visits by the NGCS and work by an environmental consulting firm acting on behalf of the community indicate that an approximately 1.5-acre area involving about 65,000 cubic yards of completely decomposed rock is moving downhill at the rate of inches per month. This movement is not only destroying two condominiums, and possibly affecting a third condominium constructed on the slide, but is also damaging three houses located at the toe (Figure 5).

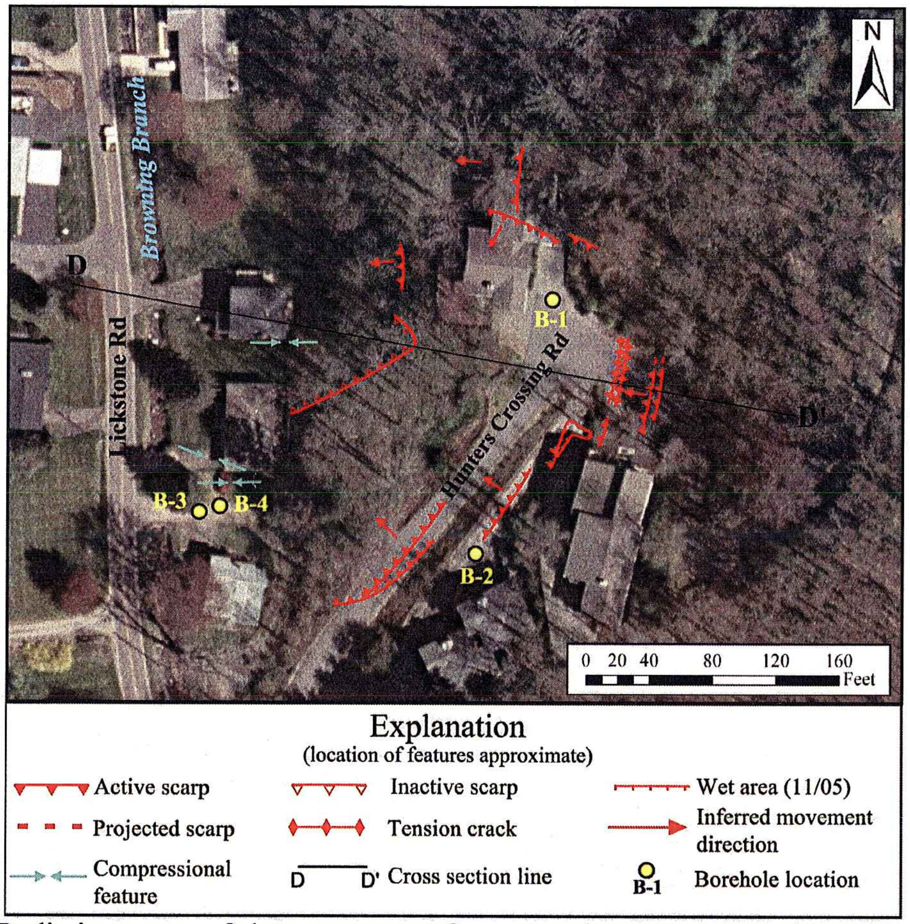

Figure 5. Preliminary map of slope movement features at the Hunters Crossing BSM. The two-unit condominium adjacent to borehole B-1 has been condemned for occupancy. The three houses on the east side of Lickstone Road at the base of the failure are currently unoccupied due to damage to the structures and the potential for future failure. The slide mass covers an area of approximately 1.5 acres.

Geologic Setting

The Hunters Crossing community is located in a migmatitic biotite gneiss unit of the Late Proterozoic Cartoogechaye terrain (Merschat, 2005). Completely decomposed rock observed in road cuts in the development is composed of migmatitic metagraywacke and schist with minor amphibolite pods. Residuum varies from micaceous silty sand to micaceous silty clay. Foliation typically dips steeply (>75 degrees) to the northeast but is highly variable across the site. These near vertical, planar discontinuities likely provide avenues for infiltration of surface water, increasing the weathering rate of bedrock and the thickness of the residuum.

From a geomorphic standpoint, the slide occurs at the toe of a west-facing, convex slope which encroaches on the narrow flood plain of Browning Branch Creek, a third order stream. Aerial photography from the 1950s reveals unusually steep toe slopes prior to the construction of a majority of the houses on or adjacent to the slide toe. It is possible that this oversteepened toe could be the result of undercutting of the base of the slope by Browning Branch, possibly associated with widespread flooding in August 1940. However, NCGS field reconnaissance also indicates the presence of a debris flow scarp within the bounding scarps of the current slide, suggesting the possibility that this slide area was also active in the past.

Slide Characteristics

Several mappable scarps cross the slope at Hunters Crossing. Figure 5 shows an aerial view of the community overlain by mapped scarps and tension cracks. Cracking walls and ground bulges at the base of the slope indicate that movement is primarily rotational. Figure 6 shows a schematic cross section through the slide. The homeowners association retained Alpha Environmental Sciences, Inc. (AES) in late 2005 to conduct a more detailed analysis of the slope movement. AES drilled two boreholes in the upper part of the slide (Figure 5) to depths of 46 and 50 ft without encountering groundwater, competent bedrock, or a distinguishable failure surface. Boring B1 was terminated at 50 ft without auger refusal, and the material encountered is predominantly silty sand with varying amounts of mica and some relict bedrock structural fabric. Boreholes B3 and B4 at the toe of the slide predominantly contain silty sand, and auger refusal occurred at depths of eight feet and ten feet respectively.

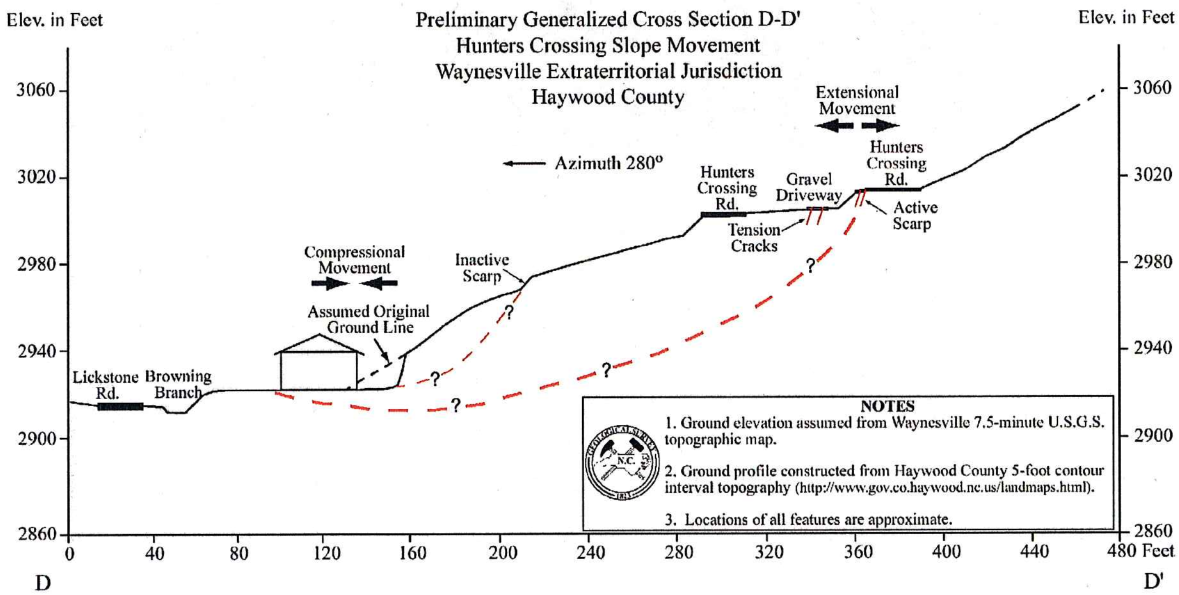

Figure 6. Generalized preliminary cross section through the Hunters Crossing BSM. Lightweight red line indicates the location of the potential failure surface that extends down from an inactive scarp. Heavy weight red line indicates the possible location of the deep-seated failure plane along which movement is currently occurring. Near the active scarp, buildings are being pulled apart due to the extensional movement. At the base of the slope, buildings are being compressed by uplift forces exerted by the slide toe. See Figure 5 for location of cross section.

Benchmarks were also installed across the slope for surveying the vertical and horizontal displacement across the slide. Baseline measurements were made on January 10, 2006 with subsequent surveys performed on January 16, 2006 and March 3, 2006. January 16 readings appear to be more representative of the movement than the March 3 readings, so for comparison purposes, measurements from that survey were evaluated. Figure 7 shows the vector displacement at each survey point on the slope. Areas north and east of the known scarps and tension cracks show the greatest displacement indicating the size of the failure could be considerably larger than initially thought. Future monitoring is planned in conjunction with Western Carolina University.

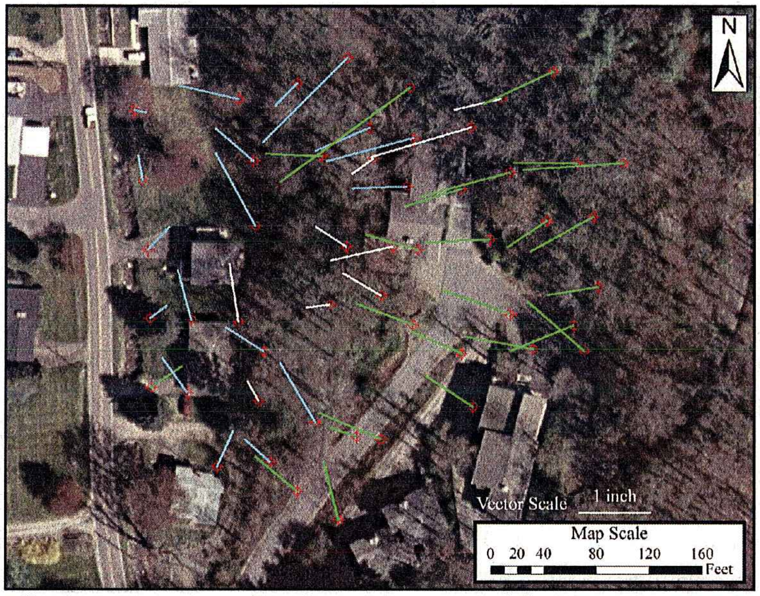

Figure 7. Vector displacement map showing movement of the Hunters Crossing BSM. This represents movement between an initial January 10, 2006 survey, and a second survey conducted on January 16, 2006. Vector colors indicate elevation changes between surveys. Blue indicates an increase in elevation, green a decrease in elevation, and white indicates no elevation change (Survey data from Herron Surveying, PC).

Causes

The cause of this landslide is unclear. Residents began to notice problems in September 2005 after extremely high water bills indicated leaks on two different water lines in the community. About the same time, a retaining wall began cracking and shifting and ground fissures and masonry cracks opened in the basement of one of the condominiums. In August 2005, a localized, intense storm triggered several landslides in neighboring Jackson County and, according to North Carolina Division of Emergency Management, caused major flooding along Allen Creek and Browning Branch Road, which is located north and downstream of the Hunters Crossing community.

Another possible explanation is that this is an ancient landslide reactivated by the remnants of the 2004 hurricanes. Heavy precipitation from these events may have triggered the modern movement, and because the failure is so deep, it did not manifest a surface expression until water lines began showing distress subsequently adding additional water to the moving mass nearly a year after the hurricanes. So far there has been no hard evidence to confirm this hypothesis. Further studies need to be performed to determine the relationship between a precipitation event and measurable movement of this slide.

Hazards

Movement continues at Hunters Crossing despite persisting drought conditions throughout the past few months. Two condominiums have been deemed uninhabitable. Three homes at the base of the slope are vacant due to potential future damage and the threat of catastrophic failure. Four additional condominiums are being monitored for signs of structural distress, and water to these units has been cut off to minimize the potential for accelerated movement triggered by the leaking water lines. Crack gages installed by AES across foundation cracks in one of these units indicates possible displacement between January 4, 2006 and February 8, 2006, which could be an indication that slide movement is migrating upslope. Review of the data collected to date indicates the potential for problems to develop at a fourth house near the north end of the toe, as this location has experienced the greatest displacement during monitoring.

CONCLUSIONS

BSMs typically occur in geomorphic and geologic settings similar to each other and are often difficult to recognize without detailed field investigations. The three examples described above provide some insight into better prediction and recognition of future BSMs.

Similarities

These three landslides all have several factors in common including their geomorphology. The geomorphic position of all three failures is similar in that that are all situated along the toe of a slope in subtle concavities. Both the Toxaway River BSM and the Lake Logan BSM have third or forth order streams that continue to erode the toes of the failures. Although the Hunters Crossing slide appears to be unaffected by the creek along its toe, the creek may have migrated over time and could in the past have undermined the toe of the slope. The toe of the slope at Hunters Crossing could also have been removed to construct housing pads for the homes built along Lickstone Road. All three landslides occur on west- to southwest-facing slopes. Although possibly pure coincidence due to the small population, this slope aspect in combination with other features could contribute to thicker accumulations of weathered residual material. More information needs to be collected to statistically assess this potential relationship.

Certain geologic aspects of the three locations are also similar. All three slides have steeply dipping discontinuities in the bedrock. These steep fractures could be responsible for the thick weathering profile observed at these failure locations by acting as avenues to transport surface water into the bedrock. These features also form oblique or resequent slopes that, in some cases, also form either a main or secondary scarp. The residual soil formed by the weathering process is usually silty sand or sandy silt with a high mica content. The basal sliding surface for all three failures appears to be above or at the contact with competent bedrock.

Detailed subsurface information from borings drilled on all three of these slides, piezometers and inclinometers would yield more information to establish correlations between them. As more data are collected on BSMs in western North Carolina, more similarities and patterns will hopefully be established.

Future work

As landslide hazard mapping continues in western North Carolina, recognition of BSMs increases. The use of LiDAR (Light Detecting and Ranging) in the NCGS's landslide mapping of Macon County indicates that BSMs have some unique, though subtle topographic shapes and slope configurations. These signatures are being utilized to at least narrow down possible locations of BSMs for field verification. Work is also beginning in both Buncombe and Watauga counties, and LiDAR digital elevation models (DEMs) and orthophotography are being examined to try to pinpoint possible locations of this type of landslide. Culled LiDAR data are being acquired to reconstruct DEMs at a higher resolution than initially processed. The contract scale LiDAR is 20-foot resolution, and attempts are in progress to refine this scale down to five to eight foot resolution. If successful, DEMs generated at this detail, and viewed in ArcScene™ 3-D imaging, will hopefully reveal slope breaks or even indicate surface slope reversals.

There is a possibility that studies will be done on the clay mineralogy to determine if this plays a role in which locations develop into big slow movers. This could be particularly important for determining the role of reactivated failure planes and slip surfaces similar to those observed at Lake Logan.

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