Heather Gregory: Investigation of a Slow-Moving Landslide: Hunter's Crossing Subdivision Waynesville, NC

Hunter's Crossing Subdivision is located in Waynesville, NC. Figure one shows the approximate location of the Hunter's Crossing area. The picture on the left represents the western part of North Carolina, where the Hunter's Crossing area is denoted by the number 3. The other numbers are the locations of other "big slow movers" in North Carolina. The picture on the right is the approximate location of the Hunter's Crossing area on a map of the Waynesville area. It is located just outside the town of Waynesville, off of Lickstone Road, near Allen's Creek. (Alpha) December, 2006, North Carolina Geological Survey

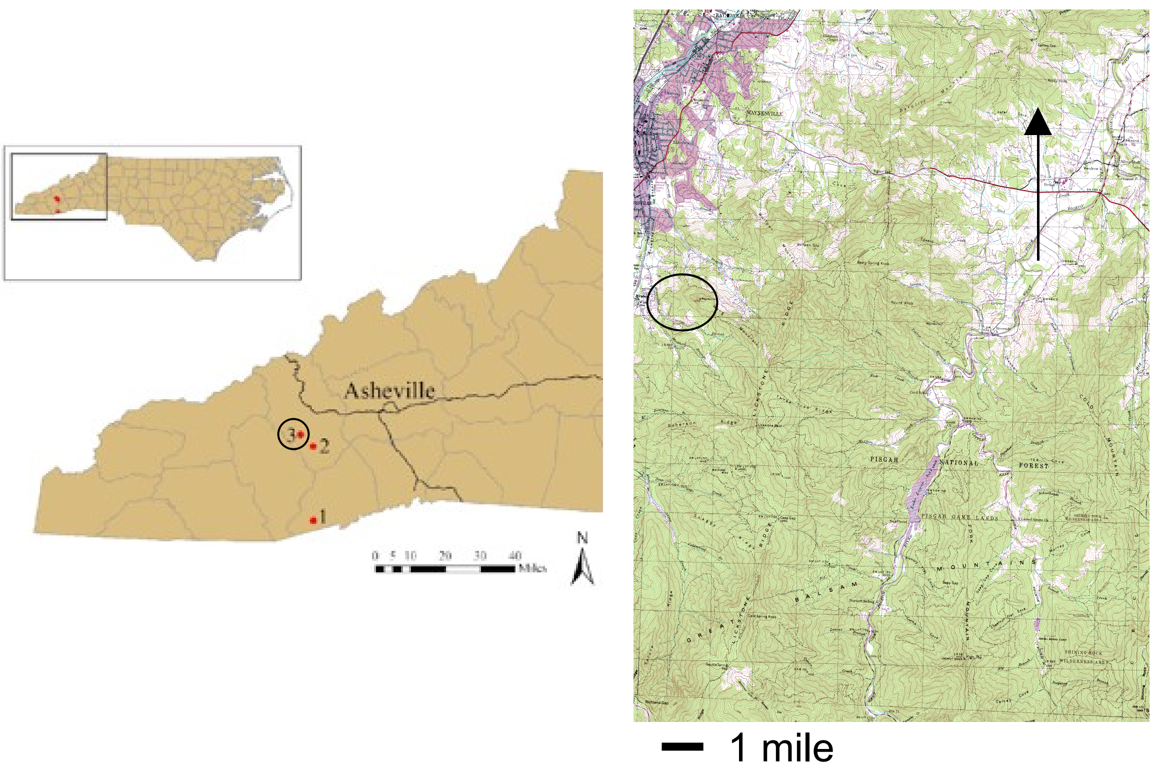


Figure 1

The investigation of the slow-moving landslide at Hunter's Crossing Subdivision began in 2005 when the residents of the community noticed damage to their houses and the surrounding property. The North Carolina Geological Survey was called upon to examine the site, whereupon they mapped the slope movement features, documented the damage to the residences, mapped an area of curved trees, and created maps and a cross section of the area. Alpha Environmental Services, Inc. was hired to drill bore holes, install crack monitors, and install total station stakes and monitor the movement of the slope from 2005-2006. The Western Carolina University geology capstone project at Hunter's Crossing was started in January of 2007. The capstone researchers continued the monitoring of the site from Alpha's crack monitors and total station points, collected data on new damage to the houses and property, analyzed the geology of the area, studied the background information, installed rain gauges, took measurements of the scarps and their extensions, and performed their own geologic analyses of the area including bedrock features, permeability of the sediment, mapped areas of curved trees, and performed sediment analysis from sediment cores taken. (Alpha) December, 2006, North Carolina Geological Survey

A brief timeline of the events that took place at the Hunter's Crossing community reveal that the slope has been moving for a longer time than when the residents first noticed damage to their houses and property. Starting from the 1950's to the 1970's, the toe of the slope was either eroded or was cut for the construction of the Lickstone residences. It shows signs of both. Figure 2 shows the toe of the slope, which is very steep, with one of the Hunters Crossing residences on the slope.

Figure 2

In 2001, the Hunter's Crossing community was constructed. In 2003, the first waterline ruptured due to the movement of the slope. In 2004, hurricanes Ivan and Frances swept through the area and dropped approximately 11 inches of rain on the area over 10 days. In 2005 the first damage was noticed and reported by the Hunter's Crossing residents. The second waterline rupture occurred, causing the water record to jump to 25,600 gallons. This is a large amount of water to be pumped into the sediments, possibly causing more instability, but that is unable to be proven at this time. The town of Waynesville shut off the utilities to the residences and forced the residents to vacate their properties. Figure 3 shows a sheared waterline at the toe of the slope and figure 4 shows damage to the foundation of a residence on the slope. Figure 5 shows damage to a carport on the slope, where the slope has pushed the carport so that it is leaning at an angle, and the beam has now become detached from the roof.

Figure 3

Figure 4

Figure 5

Figure 6 shows a buckled driveway at the toe of the slope due to the contractional movement of the toe of the slope.

Figure 6

From August of 2005 to March of 2006, NCGS monitored the site and Alpha collected their data. Figure 7 shows a crack monitor installed by Alpha, where the amount of deformation can be seen by how far the red line has been pulled away from the 0 line.

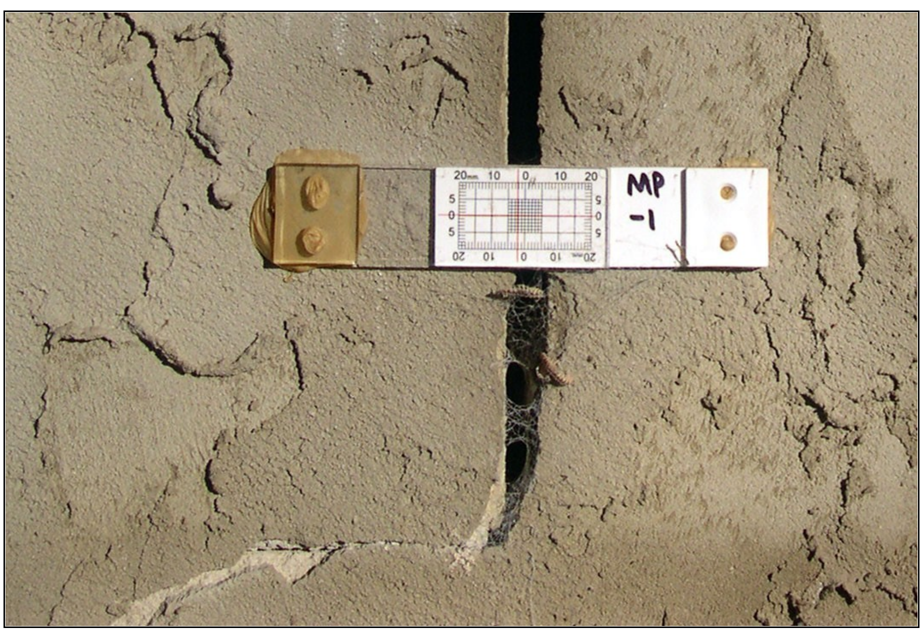


Figure 7

Figure 8 shows some of the curved trees on the slope. (Alpha) December, 2006, North Carolina Geological Survey

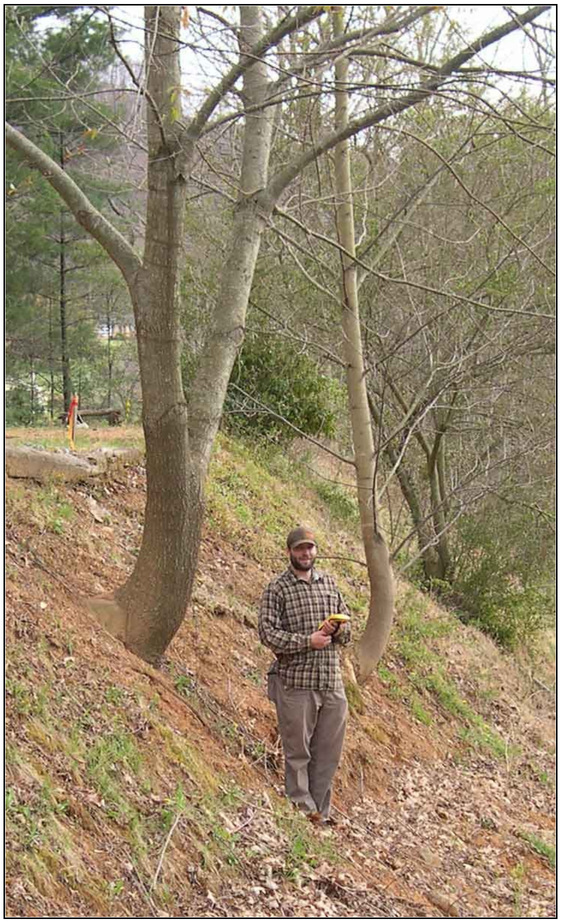


Figure 8

Some background on the Hunter’s Crossing area is that it is experiencing a slow-moving landslide, termed a “big slow mover.” A “big slow mover” is primarily creep or slump. In the case of Hunter’s Crossing, the area shows signs of both creep and slump. Creep is the slow movement down slope of sediment and soil, at less than 1 cm/year. Figure 9 is a representation of creep, with the sediment on the slope moving slowly downhill. As is illustrated in this picture, there are curved trees, a tilted fence, and tension cracks. The Hunter’s Crossing site is experiencing the same effects as shown in figure 9.

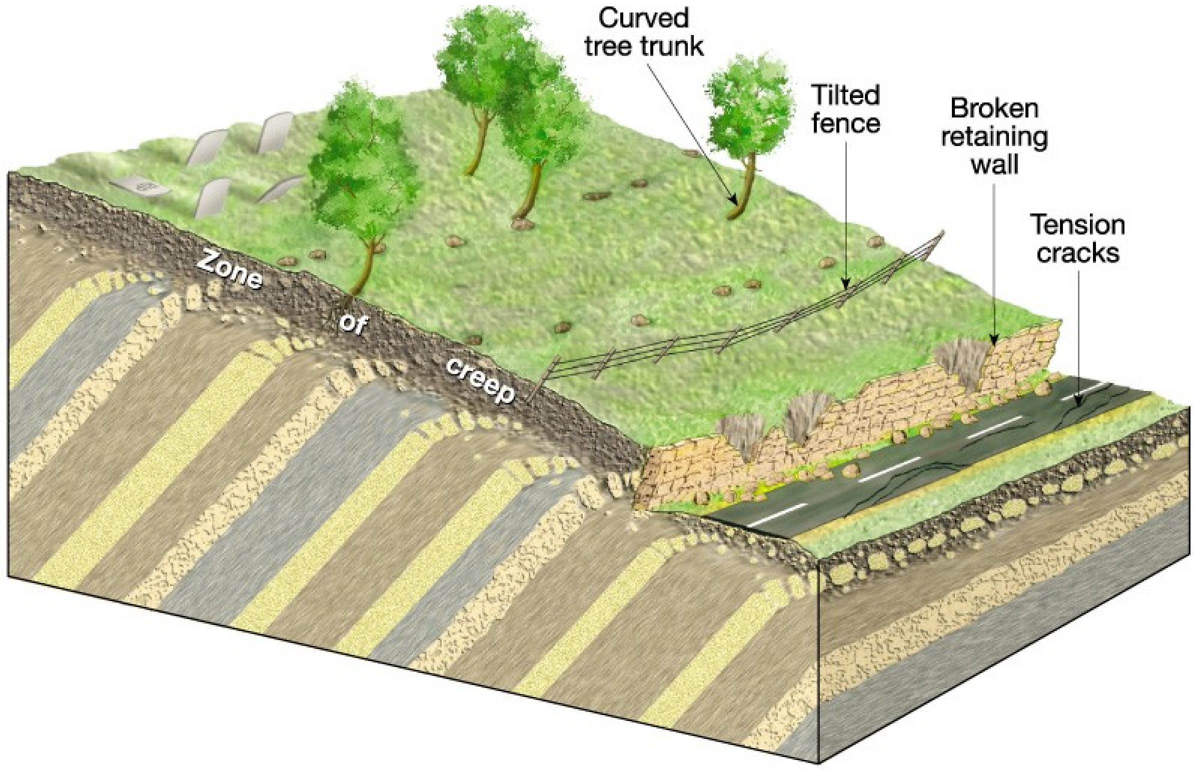


Figure 9, Marshak, Steven

Slump is the next type of “big slow mover.” The first characteristic of slump is rotational movement. The second is that the sediment on the slope travels only short distances. Third, slump is very common in sediment slopes, which is what the Hunter’s Crossing community was built upon. As figure 10 below shows, there is a head scarp, called the upper slump in figure 10, with active scarps below the head scarp, and the lower flow, which spreads out much as an iceberg would. The Hunter’s Crossing site has a head scarp located on Hunter’s Crossing road across from 88 Hunter’s Crossing, with active scarps located at other locations, which are described in more detail later.

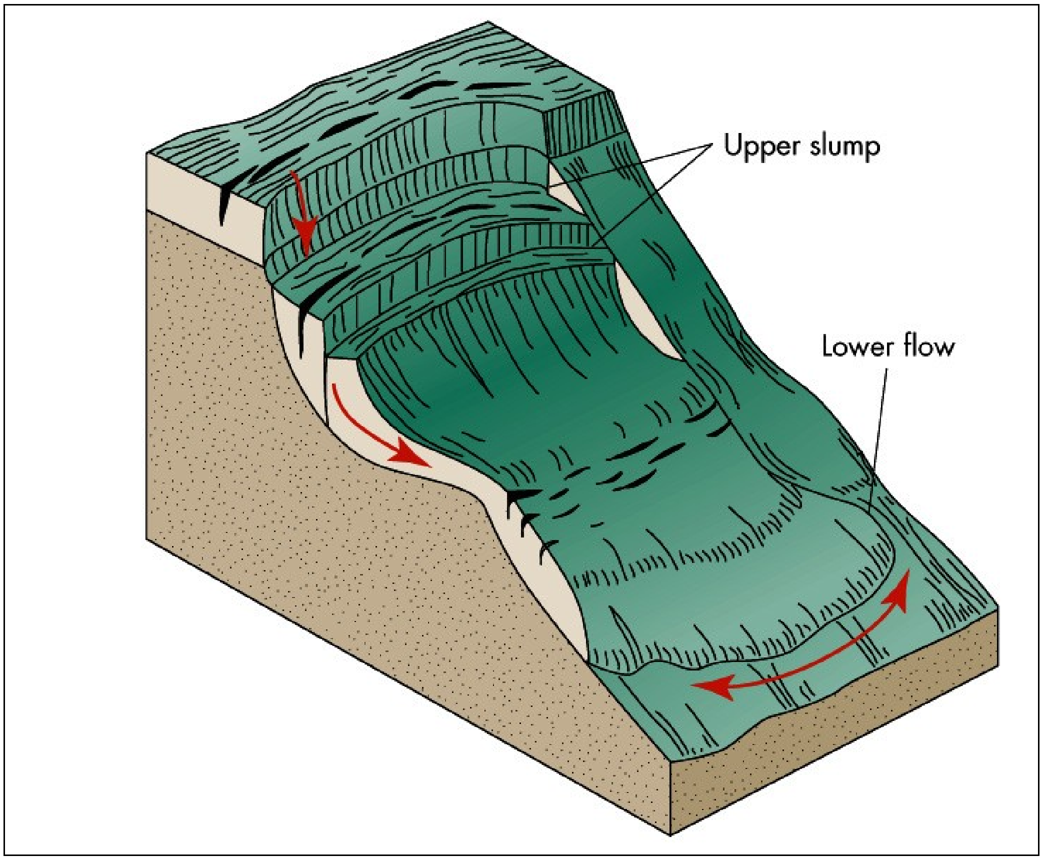


Figure 10, Marshak, Steven

Alpha drilled four bore holes, where they took the sediment samples from them and analyzed them for their properties. Bore holes B-3 and B-4 were on the floodplain near Allen's Creek and bore holes B-1 and B-2 were on the slope. At no point did they encounter bedrock or the groundwater table. This led them to determine that the failure surface was greater than the depth of their deepest bore hole at around 53 feet. They provided a cross section that interpreted their assumptions about the depth of the failure surface and where it was believed to propagate, as shown in figure 11. Also shown in figure 11 is a possible failure surface at around 35 feet, which is mentioned in depth later.

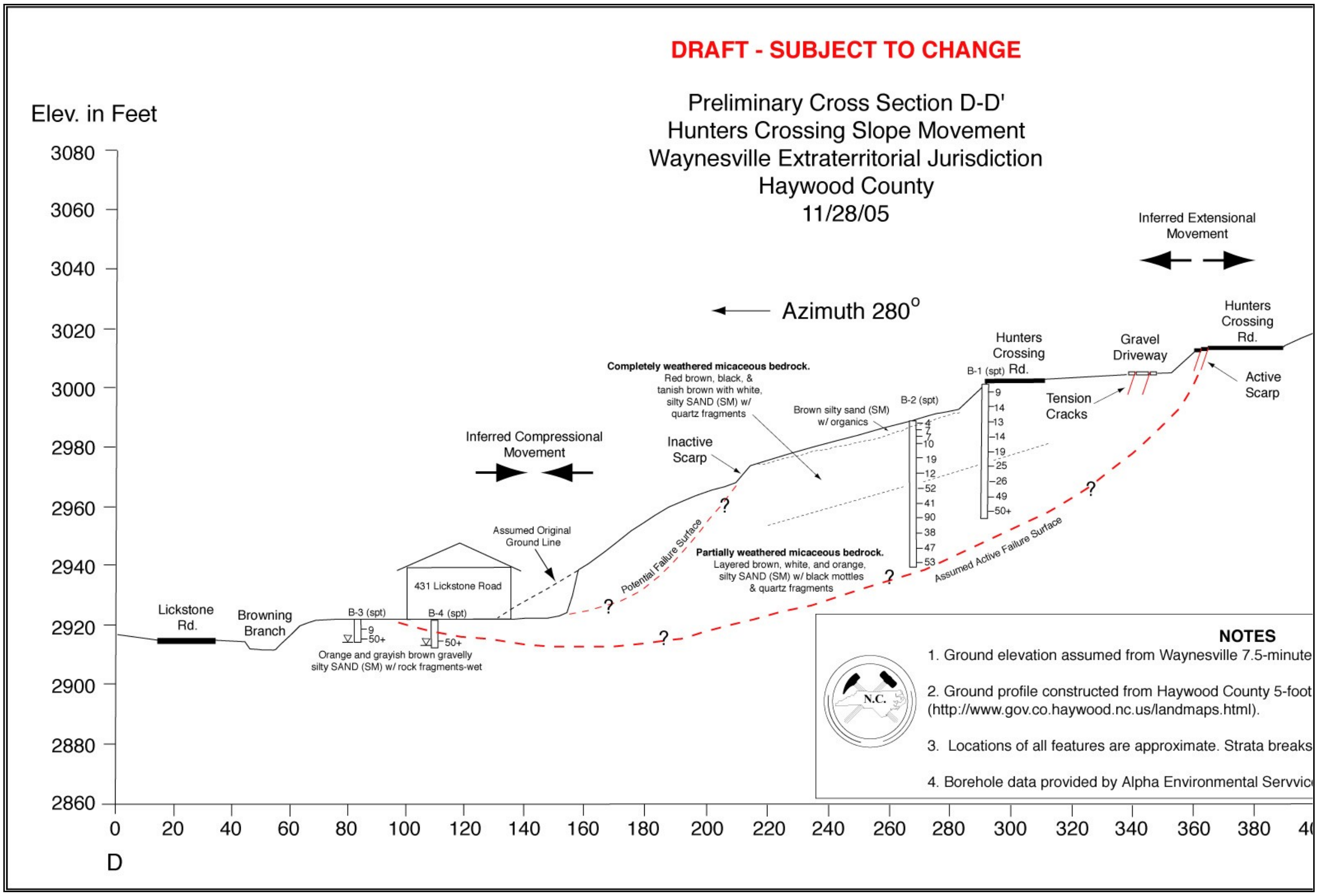


Figure 11

The bore holes provided a basis for determining the instability of the slope. The properties of the soils were mainly micaceous silty sands, and sandy sediments are less stable to build. This is primarily because sand is permeable, and during a storm event the rain could increase the pore pressure in the sediment, leading to more unstable conditions and possible failure of the surface. With the sediment that Alpha Environmental Services, Inc. analyzed being very sandy, that would result in the slope being less stable. Figure 12 illustrates the results of Alpha's bore hole samples. Note that the only possible failure surface is recorded in bore holes B-1 and B-2 at approximately 35 feet, in which there is an abrupt change in sediments, going from micaceous to non-micaceous sediment. This could be a possible failure surface because the sediment could be less permeable which could cause water to pool on the surface, creating a failure surface. At this time, this is the only possible failure surface that has been identified. (Alpha) December, 2006, North Carolina Geological Survey

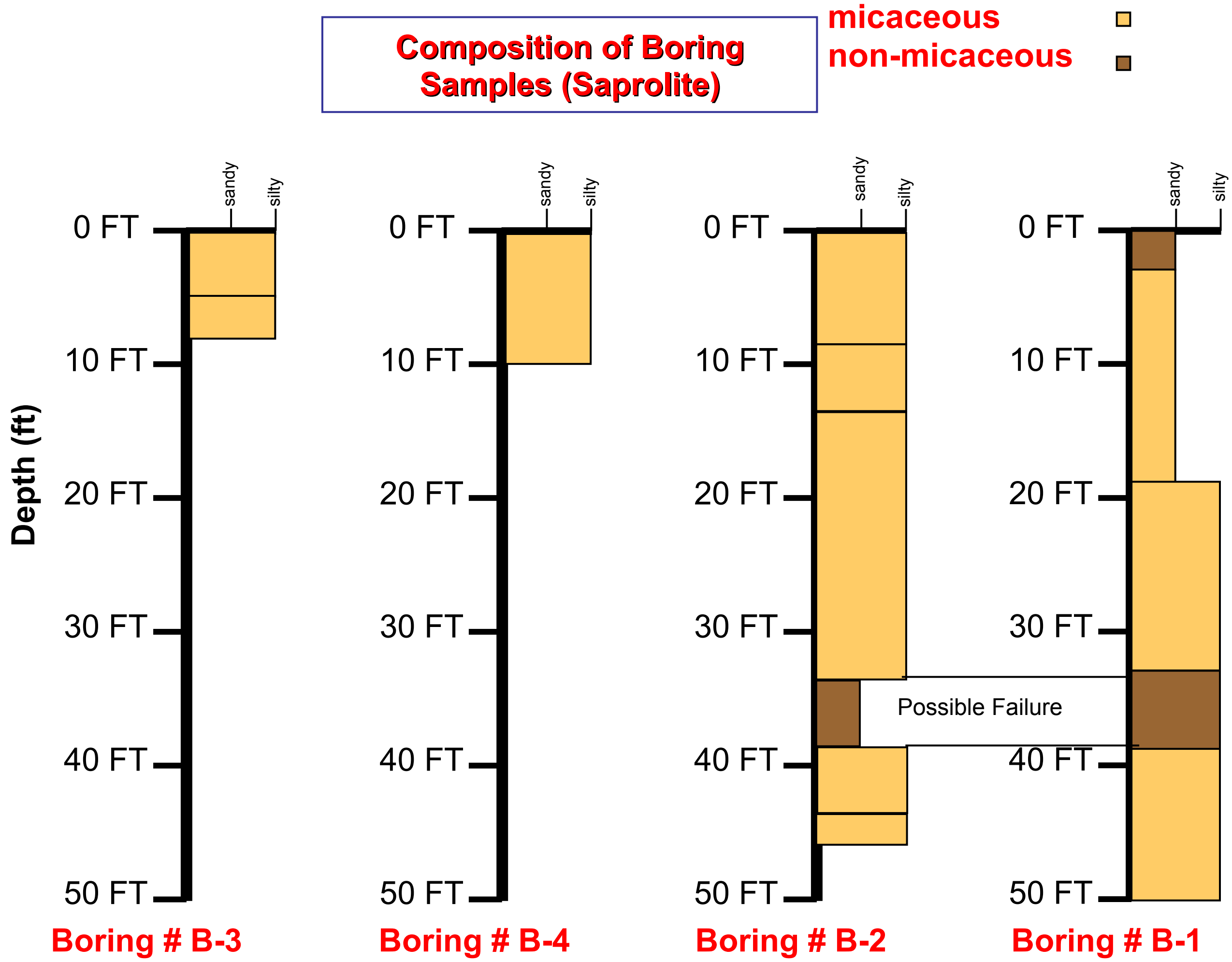


Figure 12

A further analysis of the scarps that the NCGS mapped provided more evidence for slope movement. A cross section was put together by the NCGS showing where some of the scarps are located, as shown in red in figure 13. The areas of trees that the capstone researchers mapped out are shown in olive green, while the area that the NCGS mapped is shown in brighter green. The cross sectional line is shown in bright red. The blue arrows refer to compressional features.

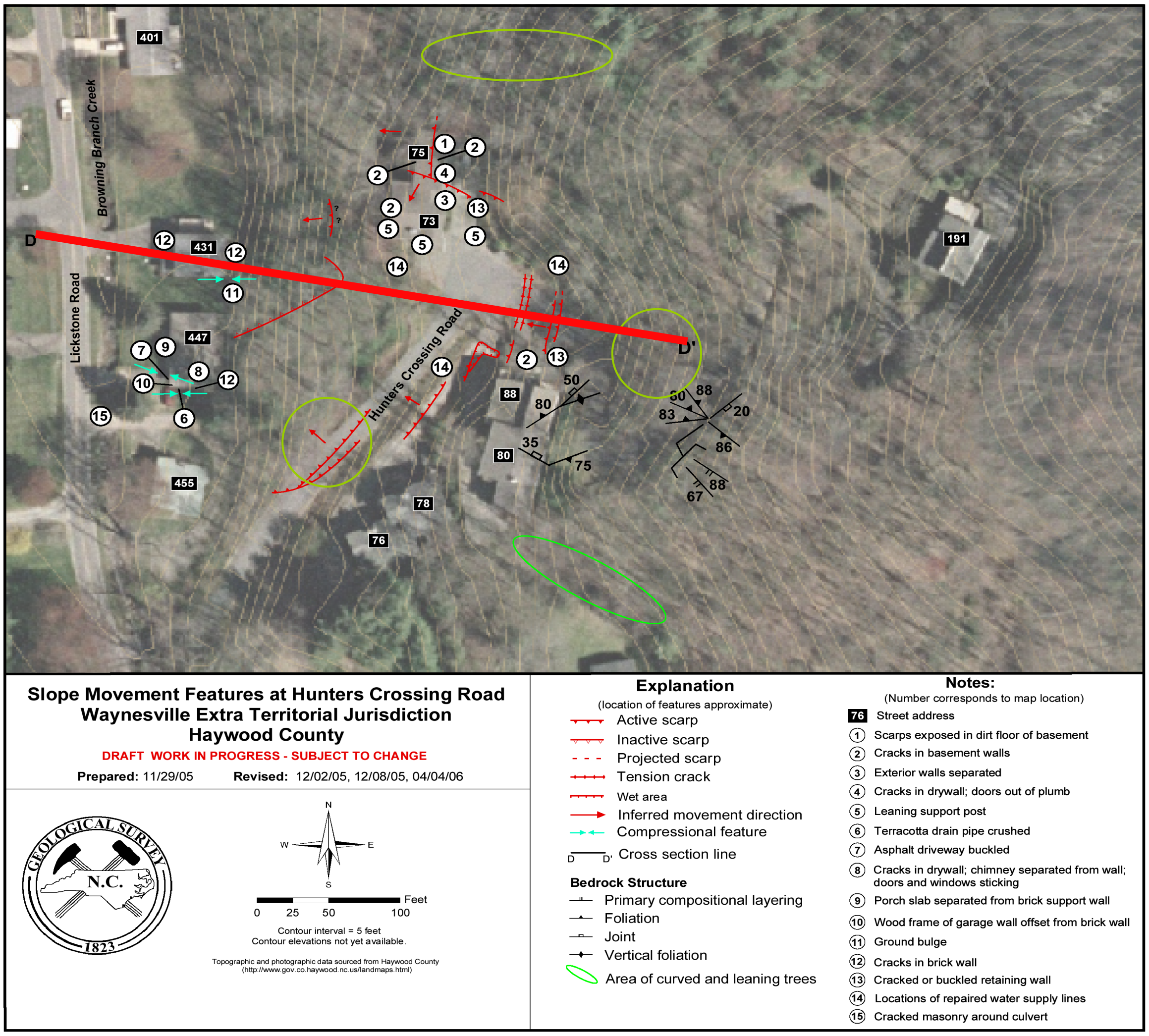


Figure 13

Another look at the cross section, provided in figure 11, shows the locations of the scarps. The head scarp is located at the top on Hunter's Crossing road, with scarp 1 below it, tension cracks located in the gravel driveway, and scarp 8 located below the tension cracks on Hunter's Crossing road at an angle to the cross section.

Figures 14 provides a close look at the measurement of the scarp 8, and figure 15 provides a close look at the measurement of the head scarp.

Figure 14

Figure 15

The movement of the scarps was recorded by measuring the horizontal and vertical displacement of the cracks, wherein the direction of movement was determined using a

Brunton compass. Figure 16 is an illustration of the direction and amount of movement of the scarp cracks, on a 1:4 scale.

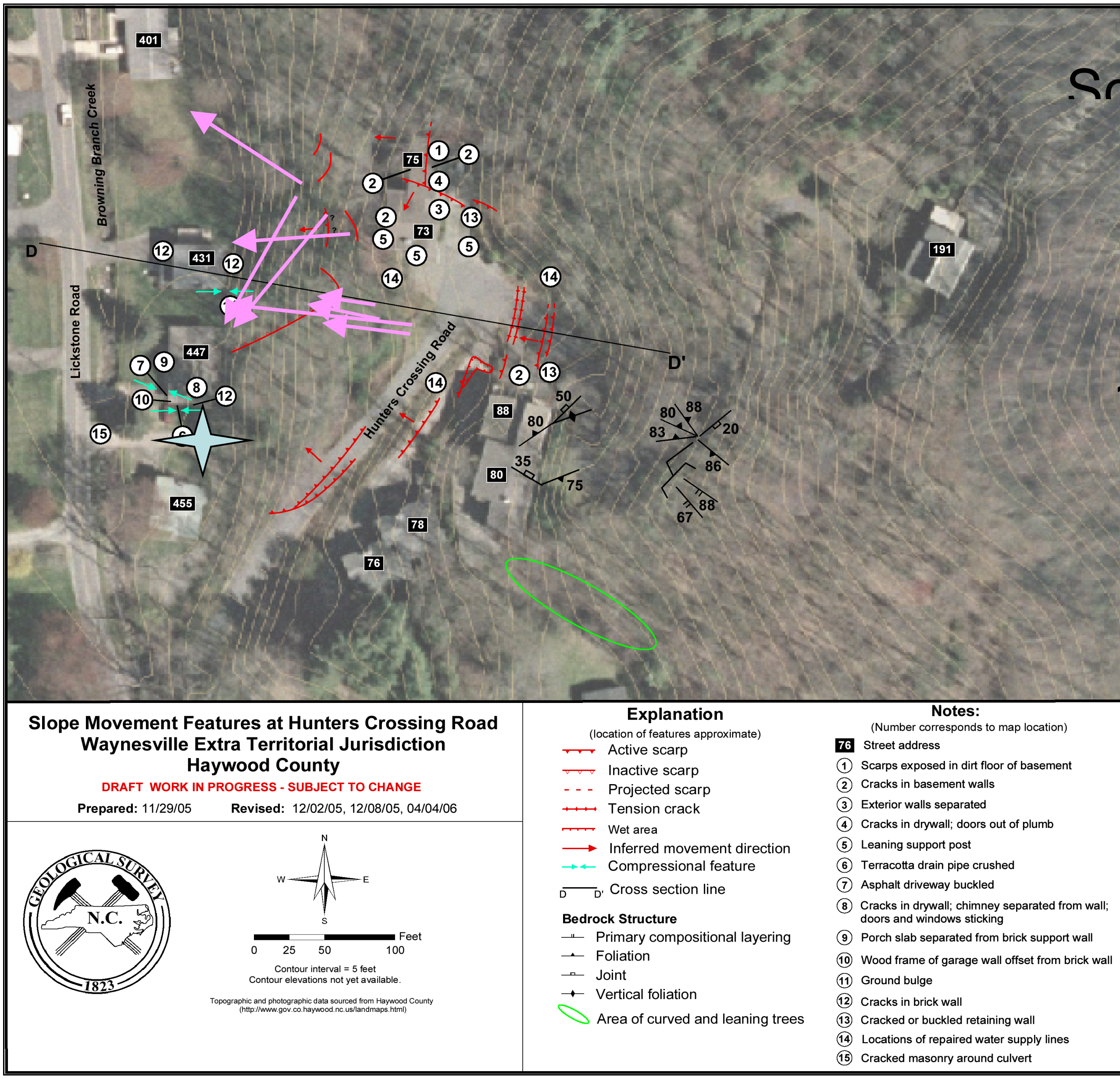


Figure 16

Scarp 8 is shown in more detail in figure 17. Scarp 8 is behaving as a normal fault would, with the Down side being the hanging wall and the Up side the foot wall. The black line is the normal fault while the blue lines are secondary extensional fractures due to the oblique movement of the fault. The large red arrow indicated the direction of the oblique movement, which is to the southwest. (Alpha) December, 2006, North Carolina Geological Survey

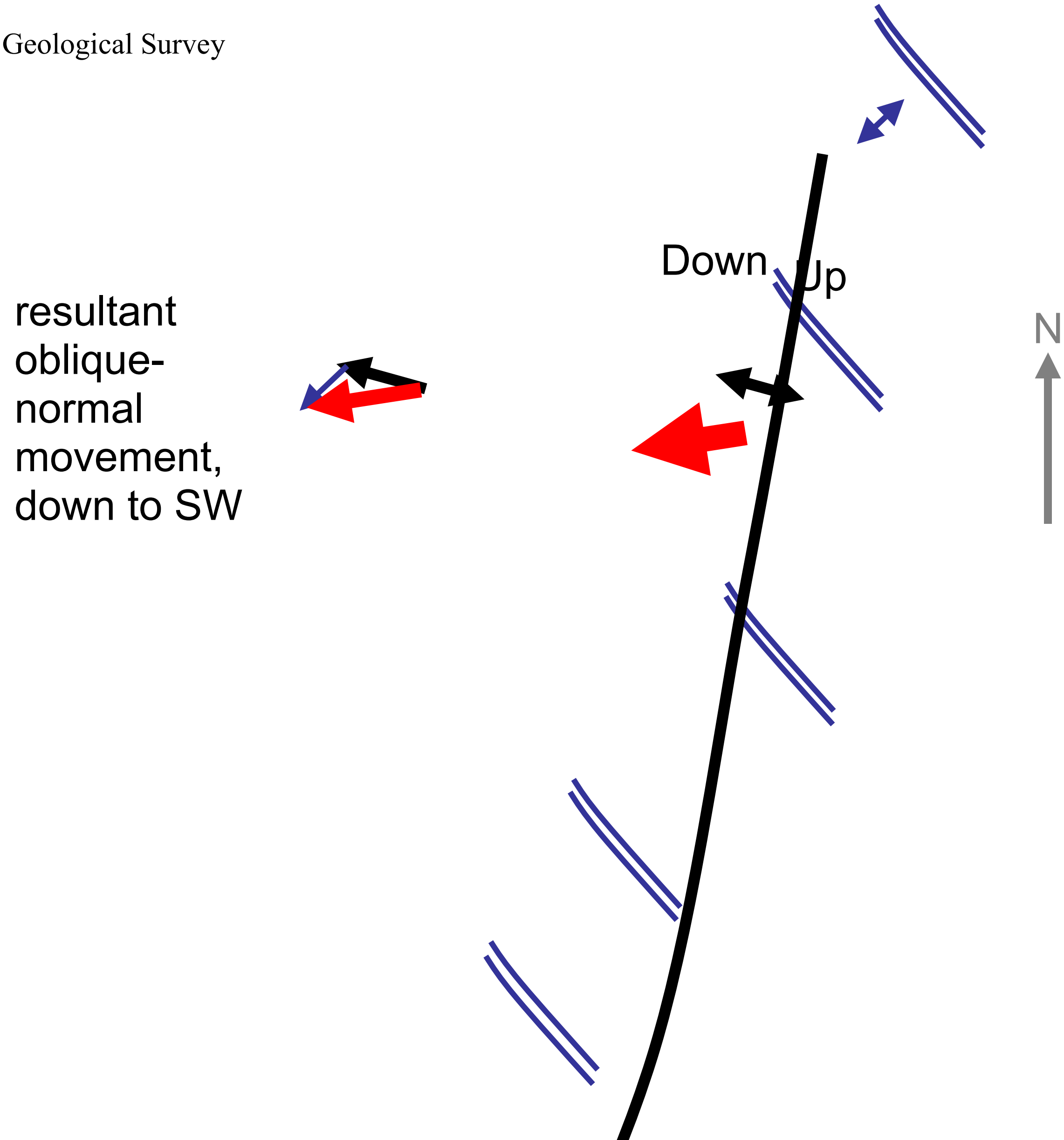


Figure 17

Figure 18 is a representation of the crack monitor deformation. The orange lines represent the amount of horizontal deformation while the positive numbers represent vertical movement up, and the negative numbers vertical movement down. The biggest deformation took place at MP1 where the crack monitor recorded a horizontal displacement of 2mm. The most vertical displacement took place at 88 Hunter’s

Crossing, where MP3-A, MP2, MP5, and MP4 are located. On the map, 1 inch is equal to 1mm of deformation. (Alpha) December, 2006, North Carolina Geological Survey

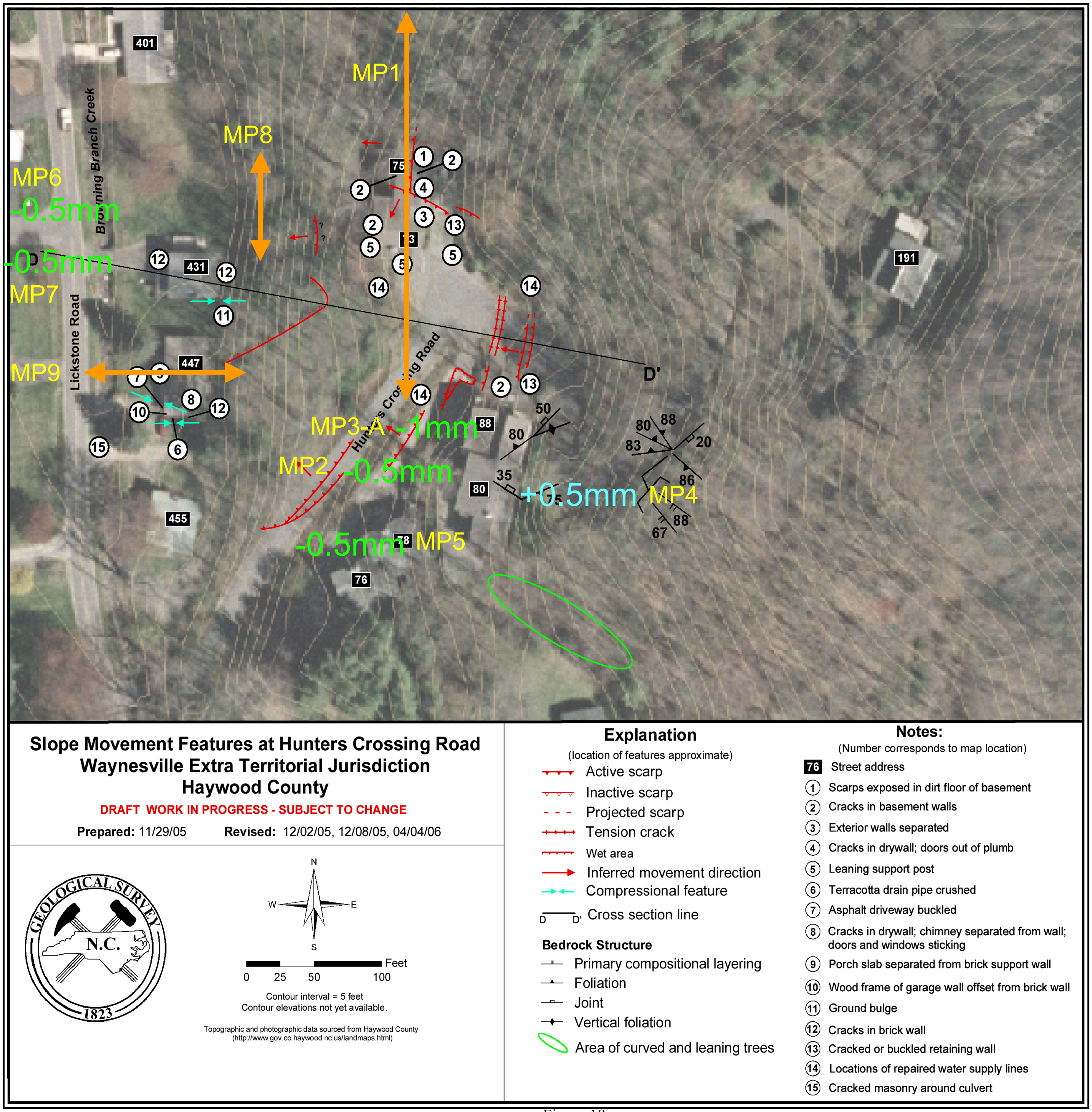


Figure 18

The total station data that was collected by Alpha was used as a base point for the capstone researchers to continue to monitor the site to determine if there had been any more movement. The vector map shows the results from the capstone researcher's results. The control point that Alpha had originally established was located on the other side of Lickstone road. But some of the points that they said were visible from the control point were not visible to the researchers. The white lines represent any significant movement greater than 0.05ft. 0.05ft was the margin of error calculated by the capstone researchers, so anything greater than that was considered to be significant. The orange lines represent possible significant movement. Not all points have vector lines on them because not all the movement was significant. The numbers represent any vertical movement that was significant. Figure 19 is a vector map of the capstone researchers' results.

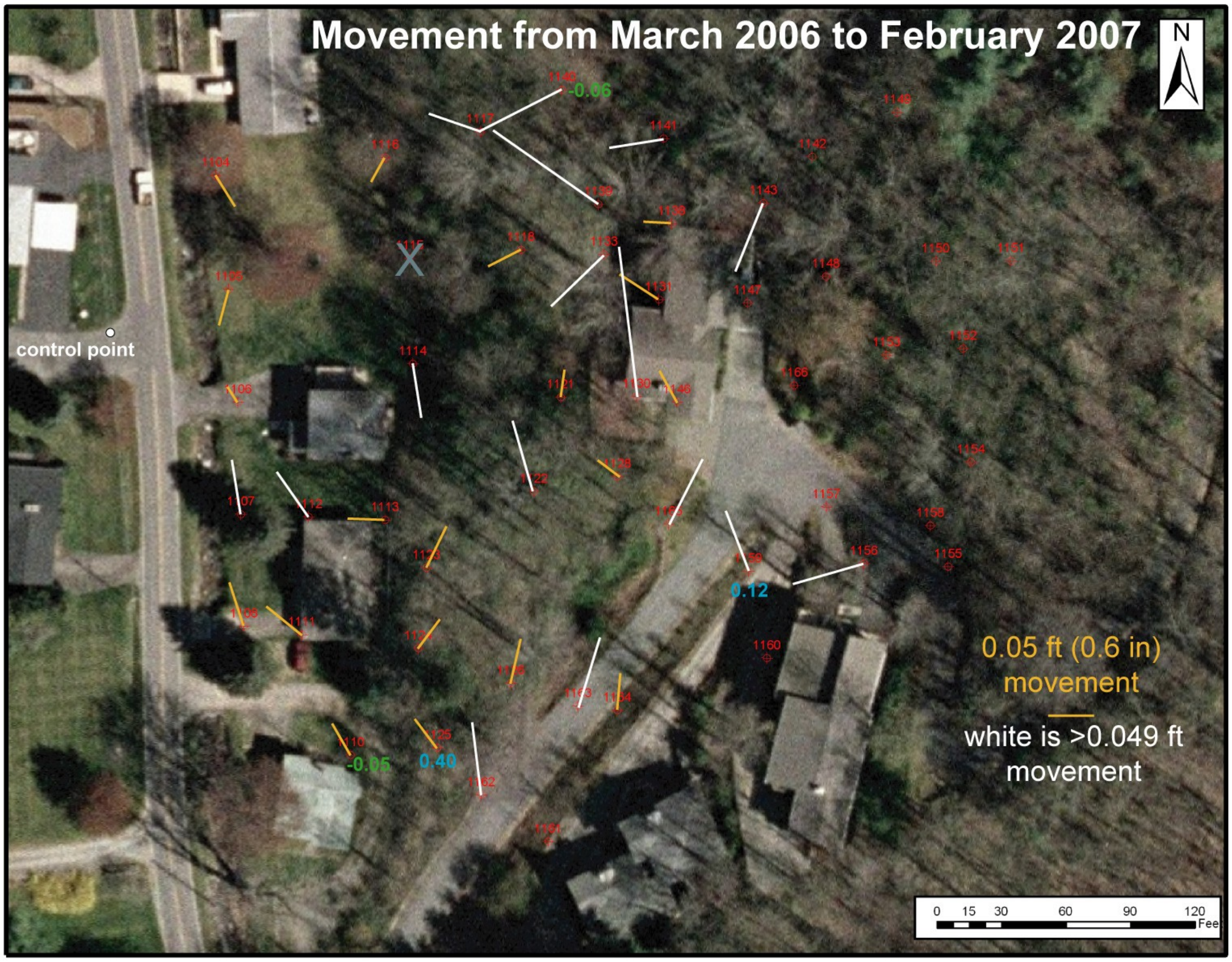
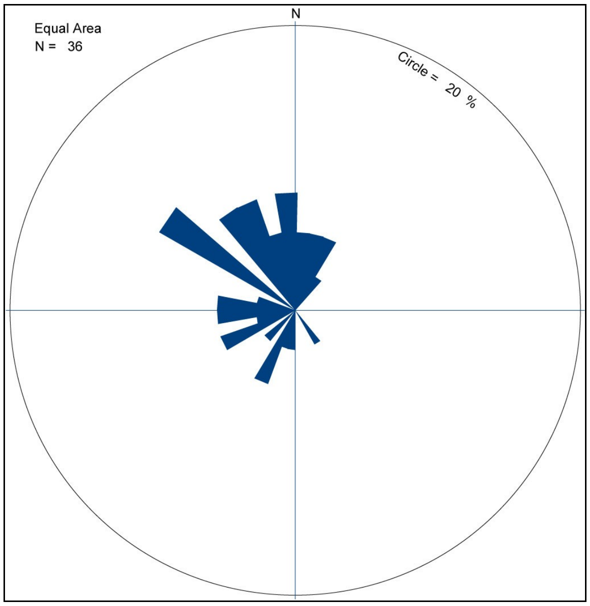


Figure 19

Figure 20 is showing Rose Diagrams, which are like bar graphs in 360 degrees. Each wedge shows the number of movements in a certain direction. The blue diagram shows all horizontal movements. The red diagram shows all significant movements. Most trend towards the N-NW. (Alpha) December, 2006, North Carolina Geological Survey



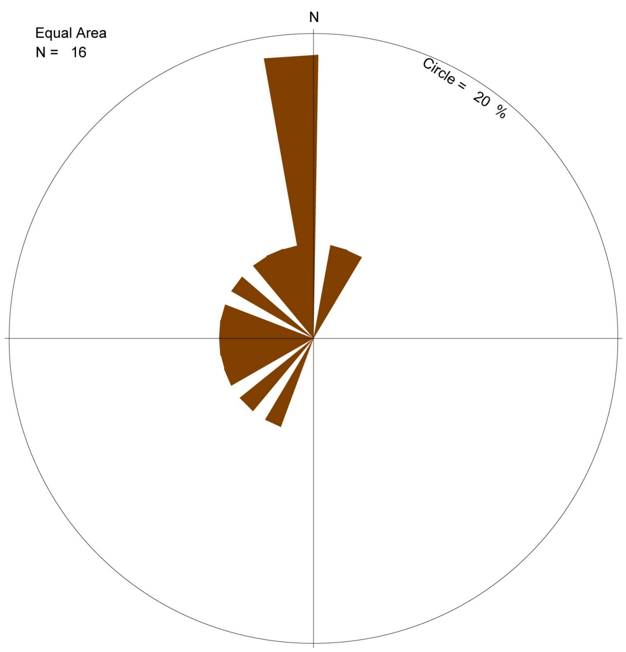
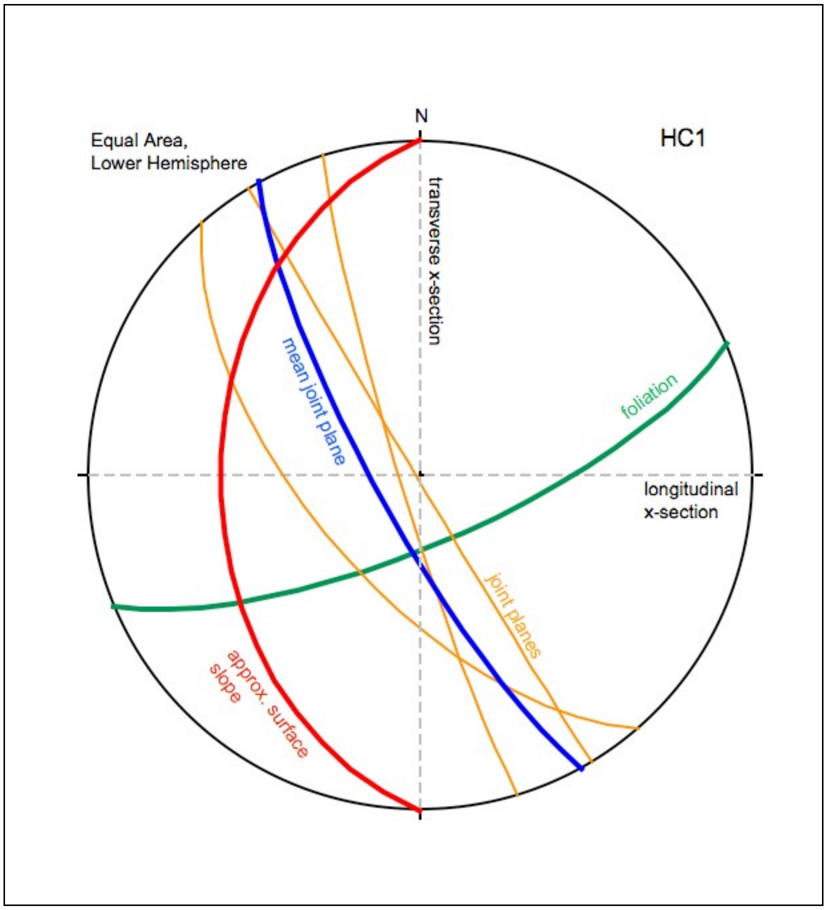


Figure 20

The strike and dip of joints and foliations of outcrops were taken on a hike up the Hunter's Crossing property. Stereonets were then completed using the information gathered from the hike. The stereonets provide information on the dip direction of the foliations, joints, and the slope surface. Figure 21 are the stereonets that were calculated. There are candidates for weak surfaces in the bedrock that could contribute to slope instability. The most abundant joint sets seem to dip W-SW, which dip in the same direction as the Hunters Crossing land surface. Foliation dip would not contribute to slope instability unless it is forming part of a “chute”. Chutes provide a surface for sediment and water to travel through, making it unstable. (Alpha) December, 2006, North

Carolina Geological Survey



N
Equal Area,
Lower Hemisphere
HC1
transverse x-section
longitudinal
x-section
mean joint plane
foliation
joint planes
approx. surface
slope

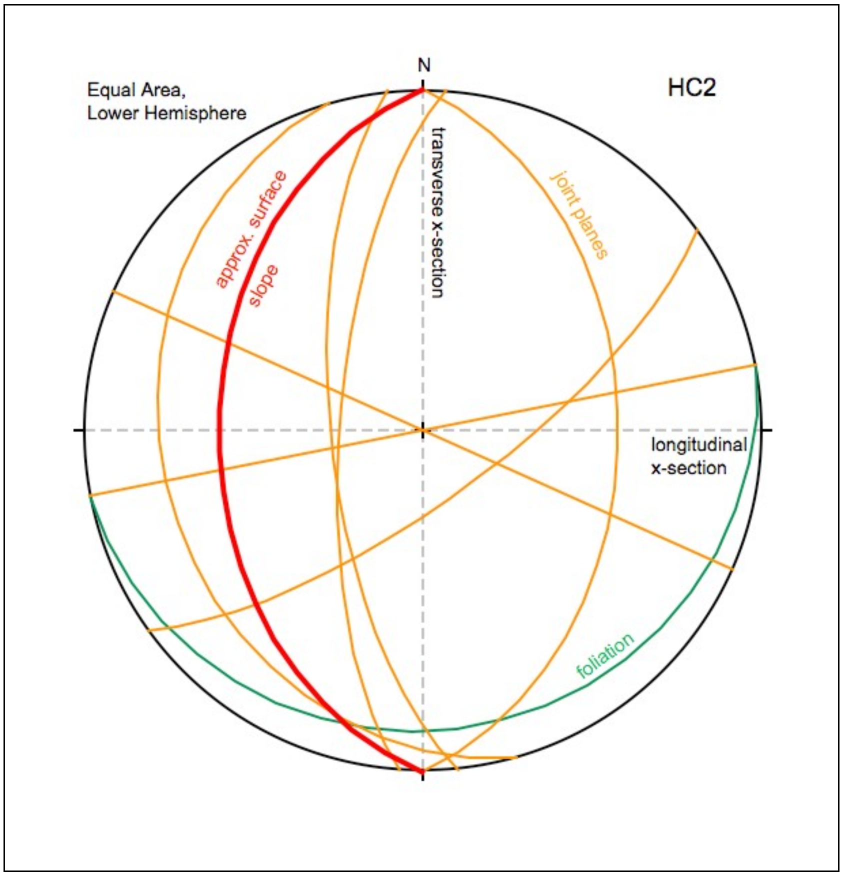


Figure 21

A lithologic description of the Hunter's Crossing area is given in figure 22. It is made up of mainly migmatitic biotite gneiss. Migmatitic biotite gneiss is medium to dark gray, consisting of dark-colored layers of medium-to coarse-grained inequigranular hornblende, garnet, biotite, quartz, plagioclase, biotite schist, and light colored, medium-to coarse-grained, granoblastic, biotite, quartz, feldspar rich layers. Stromatic migmatitic layering ranges from 1-70cm. Contains lens and layers of medium-grained amphibolite, garnet amphibolite, and biotite granitic gneiss. Layering is often intricately folded and may have a wavy appearance. This type of lithology is common for the Western North Carolina Area. The red circles denote the Hunter's Crossing area with respect to Western North Carolina. (Alpha) December, 2006, North Carolina Geological Survey

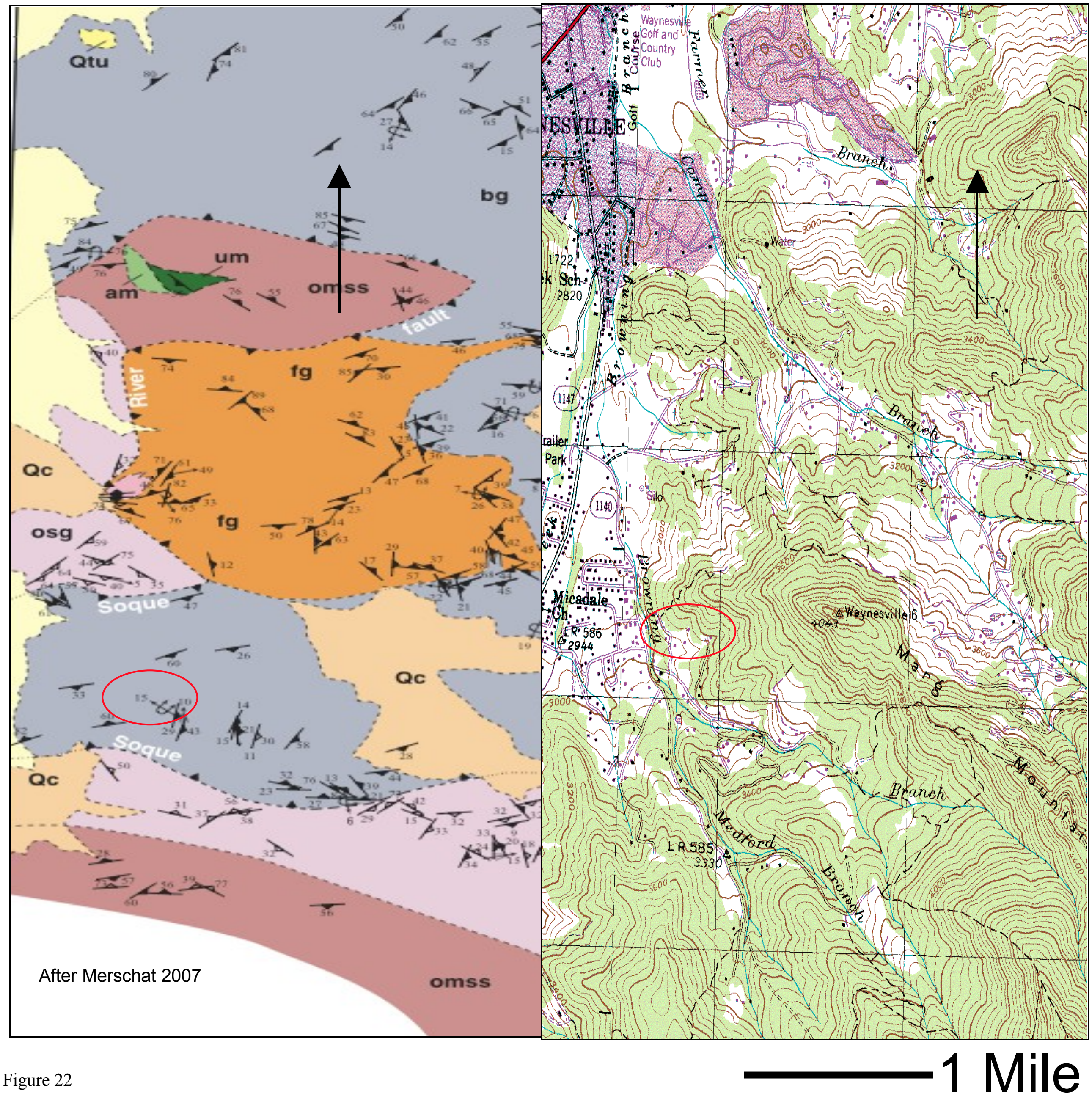


Figure 22

Figure 23 shows a representation of the joint and foliation intersections as if one was looking upslope to the north. Only one intersection could possibly be a chute, and that is the second intersection in the HC2 measurements. (Alpha) December, 2006, North Carolina Geological Survey

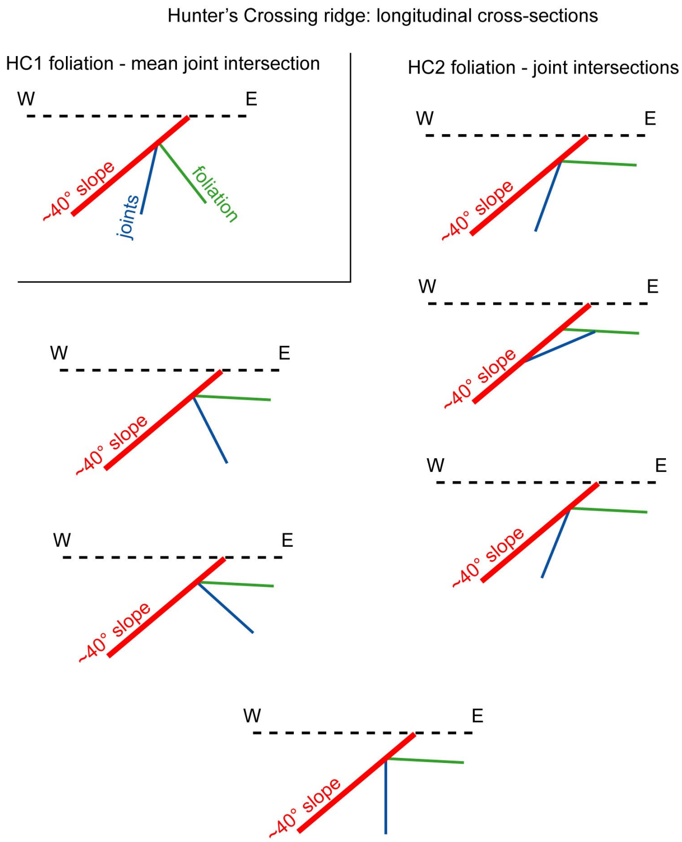


Figure 23

The analysis of the sediment size done by Alpha was done at 28-50ft deep and was almost 75% sandy materials. The cores taken by the capstone researchers was taken at a depth of 1-4ft and was nearly 82% sandy materials. The sediment analyzed by Alpha was all saprolite, while the first three feet of sediment analyzed by the capstone researchers was sediment, and then saprolite after about 3 feet. This is an extremely high amount of sand to be on the slope of a mountain, and is unstable to build on. This is an unusual feature of the area. The unconformity at around 35 feet of the non-micaceous silty sand is the only possibly failure surface that has been identified. There have been other "big slow movers" analyzed in North Carolina, and all show the same sandy sediment. Figure 24 shows a representation of Alpha's results and the capstone researchers' results. (Alpha) December, 2006, North Carolina Geological Survey

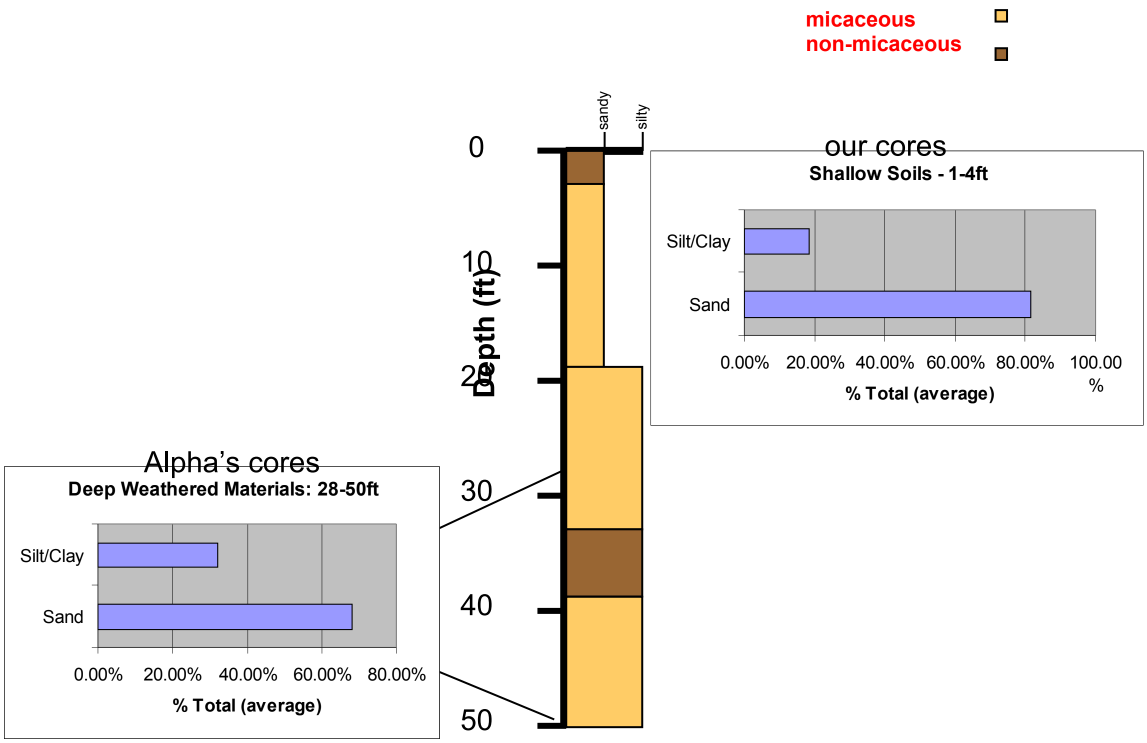


Figure 24

The area shows a relatively normal precipitation patter, except in September of 2004 when hurricanes Ivan and Frances hit the area. The permeability of the sediment was measured, which was 1.1x10^-3 cm/sec, which is comparable to sand-sized sediments. Figure 25 shows a picture of the installation of the permeameter which measured the sediment permeability. (Alpha) December, 2006, North Carolina Geological Survey

Figure 25

Summarizing the results that the capstone researchers got are that the slope is still moving and there is evidence for decades of movement due to presence of curved trees. The slide is larger than was previously thought by Alpha and the NCGS because the slide is expanding ~N-S and the scarps are extending. There are some potential bedrock failure surfaces that lean down slope, and the sediment is very sandy, which leads to instability. Some potential bedrock flow paths lean down slope, which could provide chutes for sediment and water to travel down. The sediment permeability was relatively fast due to its sandy nature, and the rain gauge data was normal for the duration of the study. The previous total station survey is questionable due to the fact that not all stakes could be seen from the control point, and the well depth was insufficient because it did not hit the groundwater table or bedrock.

The interpretations are that there are thick sandy layers greater than 50 feet which would cause the slope to be less stable because sand is more permeable, which increases the pore water pressure during storm events. The bedrock is permeable due to the foliations and joints on it, which could be possible water paths. The net movement is downhill, but the slide is expanding outward, possibly due to a bedrock buttress at the toe of the slope, which would cause the slide to expand outwards because it can no longer go forwards, much like an iceberg would do.

Some future work that should be done is getting the tree ages by doing tree cores and analyzing the tree rings. Well drilling to determine the sediment moisture, take samples and analyze them, and to monitor the water table. There needs to be continued monitoring of the crack monitors and scarps, and there needs to be a switch from total station surveying to GPS surveying. There also needs to be continued rain gauge data to determine the amounts of local precipitation and there possible affects on the slope. (Alpha) December, 2006, North Carolina Geological Survey

References

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