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Investigating Bedrock Controls on Erosional Retreat of the Blue Ridge Escarpment, Old Fort, North Carolina

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Abstract:

The Blue Ridge Escarpment is a steep topographic boundary that in North Carolina separates the Blue Ridge Mountains from the Piedmont. Due to its steep topography, landslides are a common occurrence along it and result in erosional retreat of the escarpment. In order to better assist during landslide events, the North Carolina Geological Survey (NCGS) has been working on mapping landslides across western North Carolina. To assist the NCGS, this project mapped landslides around the escarpment near Old Fort and evaluated the risk based on bedrock structures. Field work occurred from the Spring of 2023 to the early Spring of 2024. Orientations of faults, foliations, and joint fractures were collected in the field. Landslides were identified in the field and from high-resolution LiDAR data. Bedrock structures were plotted on stereonets to assess their contributions to landslides. The foliations dominantly dip toward the SE. The orientation of the joints are a bit more sporadic, however; the majority strike NW/SE, consistent with regional jointing due to the Mesozoic rifting of Pangea. The E/W striking joints are likely associated with the Swannanoa Lineament. The data shows that planar failures along the foliation planes are the most common cause of landslides. While planar failures are more common in this case, there are two areas in Old Fort that have an impending wedge failure between the foliation and joints. In conclusion, this study shows that due to the potential for landslides by planar failure,

slopes that dip in the same direction as the foliation are particularly at risk. Furthermore, joints associated with the Swannanoa Lineament play a role in erosional retreat of the escarpment.

Introduction

Between the years of 1990 to 2016, the North Carolina Geological Survey (NCGS) was active to respond to requests from the government agencies, the public, and consultants about landslide events (Wooten, 2017). The NCGS main purpose is to aid in landslide events in order to protect North Carolina residents, and further the state's knowledge on potential hazards and risks. In 2011, the NCGS landslide mapping division no longer would receive funding, which halted the program by 2016. After a series of devastating and deadly landslides, the state legislature ruled to add more funding, thus allowing the revitalization of the landslide mapping division (Wooten, 2017).

This project was designed to map landslides around the Blue Ridge escarpment (BRE) near Old Fort, North Carolina and evaluated the risk based on bedrock structures (Fig. 1). The escarpment separates the Blue Ridge from the low-relief Piedmont and Coastal Plain. The curvature of the escarpment marks an asymmetric divide between the Atlantic and Gulf of Mexico drainages. The BRE has retreated more in this area than the surrounding portions of the escarpment (Spotila, 2004). The BRE has a steep topography and does not coincide with the outcrop of a resistant lithology. Figure 1 shows this topography along with the lineaments near the BRE.

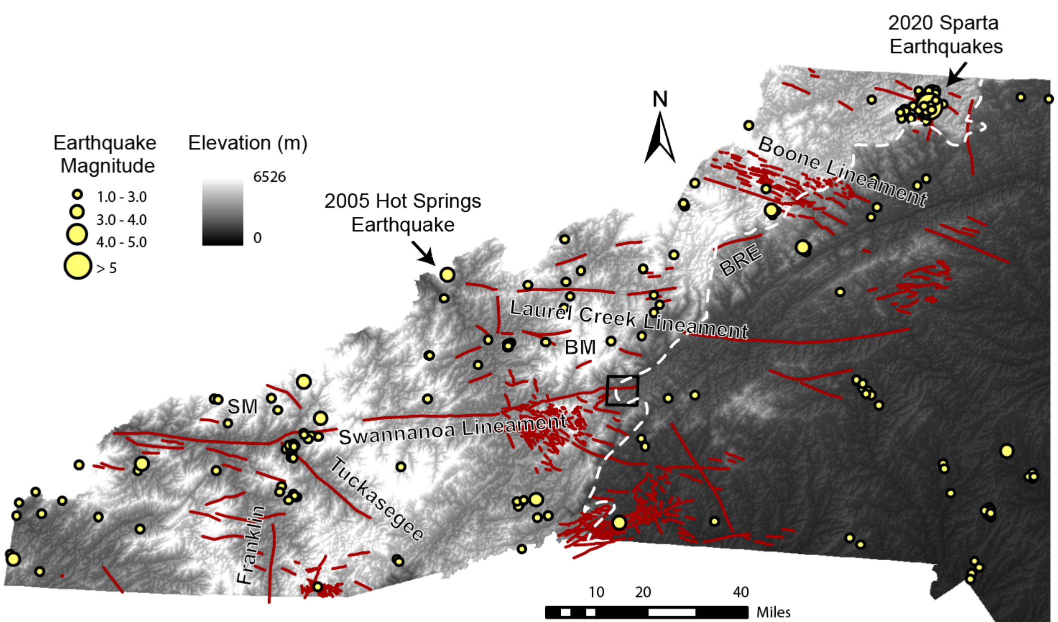

Figure 1. Map of Western North Carolina displaying the earthquakes that are near lineaments. (Langille, 2022)

The bedrock units on either side of the escarpment offer equal resistance to erosion, and contacts between units cut across at varying angles (Prince, 2010). The city of Old Fort is nestled between Asheville and Marion. Old Fort is on the eastern end of the Swannanoa Lineament and is believed to have increased landslide risk due to the fractures associated with the lineament. This field area was chosen due to the Swannanoa lineament, steep terrain, and because it includes a major transportation corridor.

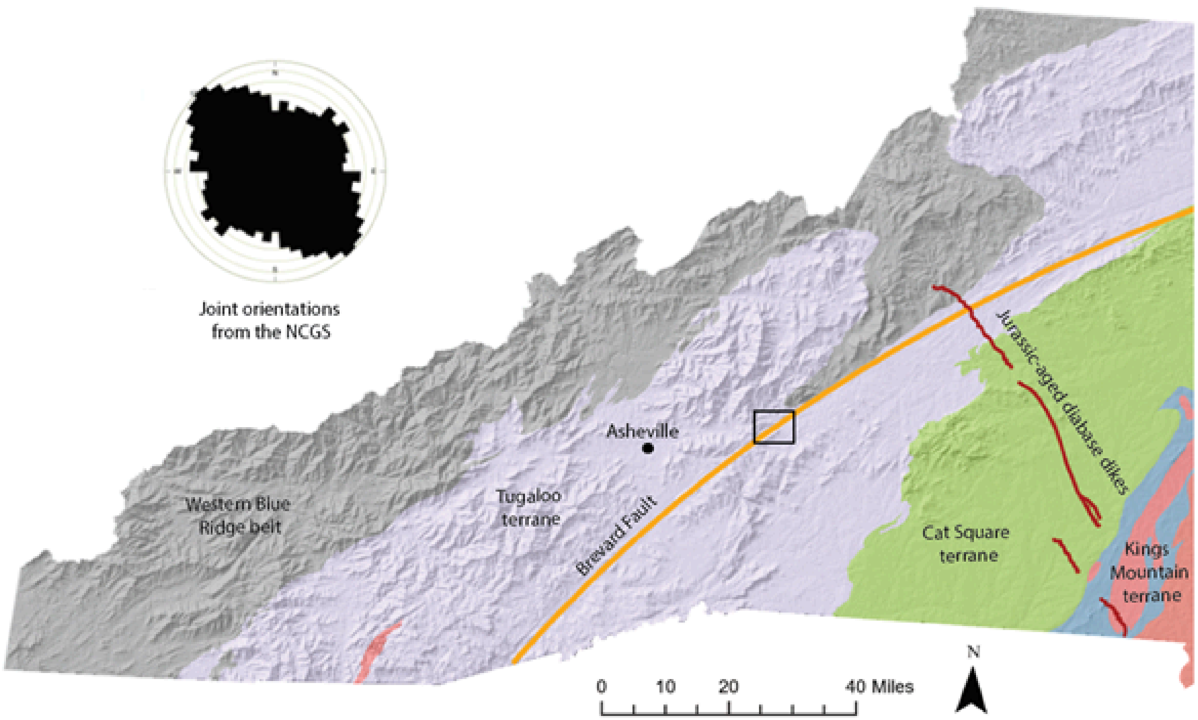

Figure 2. Map of Western North Carolina with a rose diagram reflecting the joint orientations from the NCGS. The field area is in the black box.

Background

The Swannanoa Lineament is known for its linear zone of E/W striking faults and fractures. The Swannanoa lineament starts in the west at Fontana Lake and ends at Lake Hickory, NC (Hill, 2013). It is the result of uplift during the Cenozoic Era (beginning 66 million years ago to present). The continuation of erosion and uplift can be seen in western North Carolina, especially in the area of Old Fort (Hill, 2013). During the Jurassic Period (201.3 million years ago-145 million years ago), Pangea rifted apart which caused the formation of the Atlantic Ocean (150 million years ago). Magma intruded into the crust along fractures and faults forming dike swarms. In the case of the Jurassic-aged diabase dikes, the diabase dikes (Fig. 2) are composed of igneous rocks called diabase, which are dark in color and fine-grained (Peach, 2018).

The field area is part of the Tugaloo terrane (Fig. 2). The Brevard fault zone provides the mylonite along with mixed gneiss units in this field area. These gneiss units are made up of the Tallulah Falls biotite gneiss, Ordovician Henderson Gneiss, and felsic gneiss. The Brevard fault zone strikes NE-SW and extends from Virginia to Alabama. It is a dextral strike slip fault that was active during the Acadian Orogeny (416 to 359.2 million years ago), and reactivated during the Alleghanian Orogeny (299 to 251 million years ago) (Hatcher et al., 2007). The fault zone is characterized by ductile behavior, hence the presence of the mylonitic and phyllonitic rocks that can be found near the fault (Vauchez, 1987).

In addition to constraining the mechanisms that caused landslides in the field area, foliation and joint orientation measurements were used to constrain the cause of the joints in the field area, either associated with rifting of Pangea and/or the Swannanoa Lineament. This data provides constraints on the mechanisms that have contributed to retreat of the escarpment.

Methods

Field Data

The data collected was mostly concentrated in the Pisgah National Forest near major roadways. A total of 37 data points were obtained, showing the orientations of faults, foliations, and joint fractures. Landslides were identified in the field and from high-resolution LiDAR data in ArcGIS (https://sdd.nc.gov/). Geologic data was documented using a GPS enabled iPad through the FieldMove app as well as manually with a Brunton compass.

Geographic Information System (GIS)

Geographic Information System (GIS) is a system used to capture, store, analyze, manage, and present spatial or geographical data. Data collected was imported into ArcGIS for analysis. The slope and aspect tools were used to characterize the orientation of landslides for slope stability analysis.

Slope Stability

The collected field data was plotted on stereonets using the Visible Geology website (app.visiblegeology.com/profile.html). For analyzing slope stability, stereonets are the most effective way. This is because they show the direction of the joints, slopes, and planes' dips, and show where they interact.

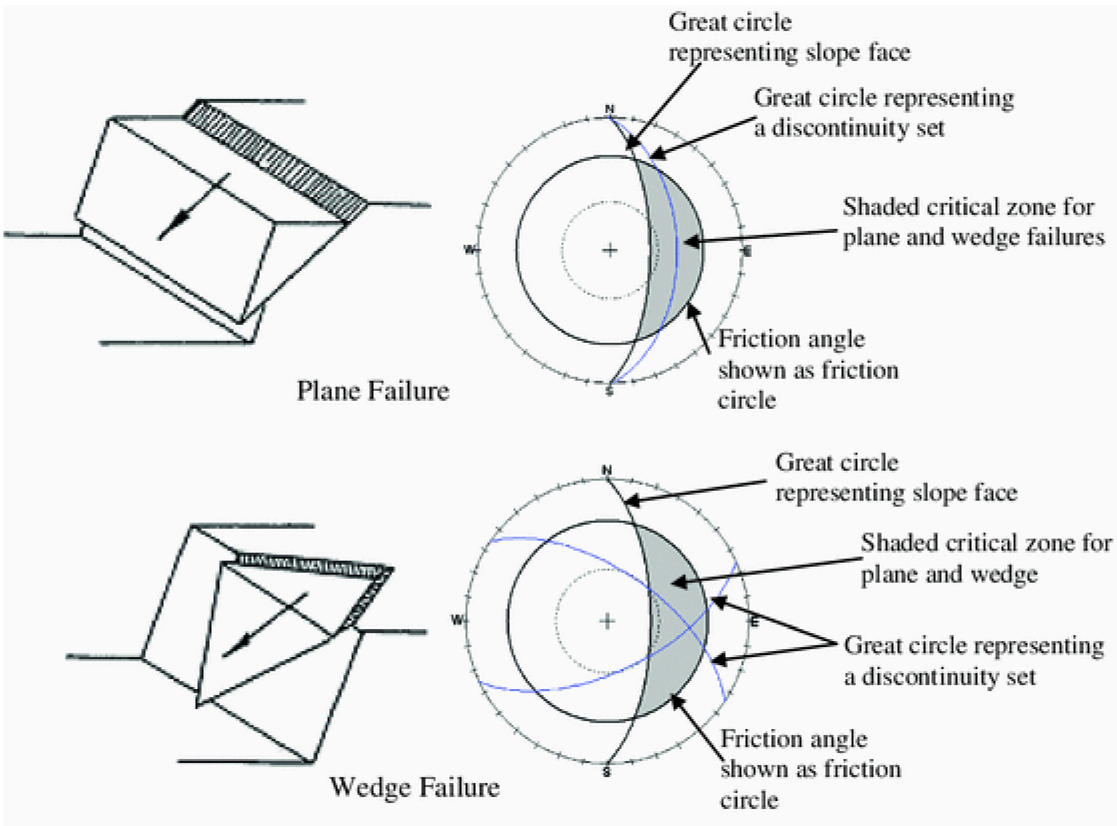

Figure 3. Planar failure and wedge failure as shown on stereonets (Hoek, 2010).

Methodology for assessing slope stability from Latham et al. (2009) was followed. For a planar failure to occur, it must have the failure plane dipping in the same direction of the slope, dips less than the slope, strikes within 20° of slope strike, and dips greater than the friction angle (Fig. 3). On a stereonet, this would look like the friction angle crossing through the shaded critical area. Wedge failure occurs when two failure planes intersect within the shaded area (Fig. 3).

Results

The foliations dominantly dip toward the SE (Figs. 4 and 5). The orientation of the joints are a bit more sporadic. However, there are two sets of joints, a dominant set striking NW/SE and a second striking SW, consistent with Cattanach et al. (2019) (Figs.4 and 6). There were 24 landslides identified in the research area, and were found predominantly in the Alligator formation which is north of the Brevard Fault (Fig. 4). Most of the landslides occur on SE facing slopes, in the same direction as the foliation dip. This means that planar failures along the foliation plane are the most common causes of landslides in this area (Fig. 7).

The percentage of the landslides that showed planar failure is 91.67% (Fig 7). It is important to note that there are two areas in Old Fort that had wedge as opposed to planar failure. Figure 8 shows an example of a landslide that occurred by a wedge failure along joint fractures. The stereonet shows that the two measurements of data cross the shaded critical area. Looking at the map, the wedge failure is clear to see due to the large impression that the landslide left.

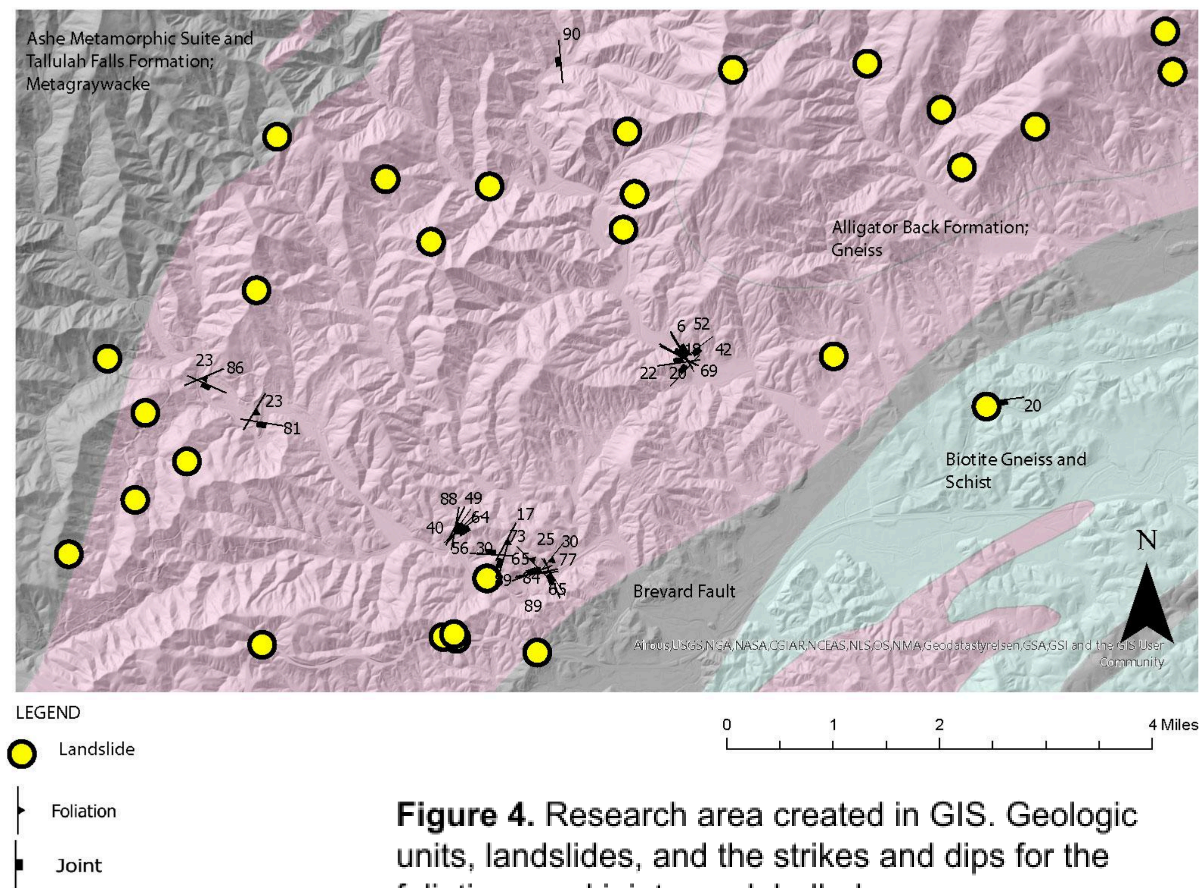

Figure 4. Research area created in GIS. Geologic units, landslides, and the strikes and dips for the foliations and joints are labelled.

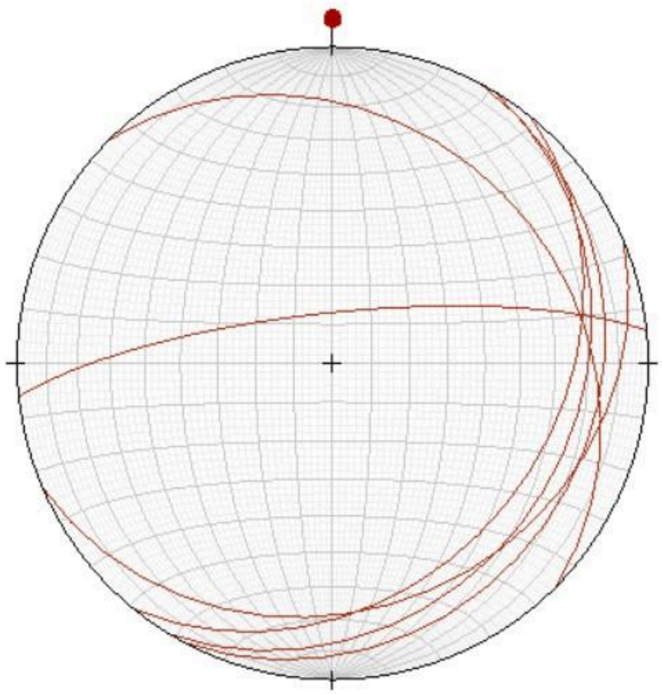

Figure 5. Stereonet of foliation orientations.

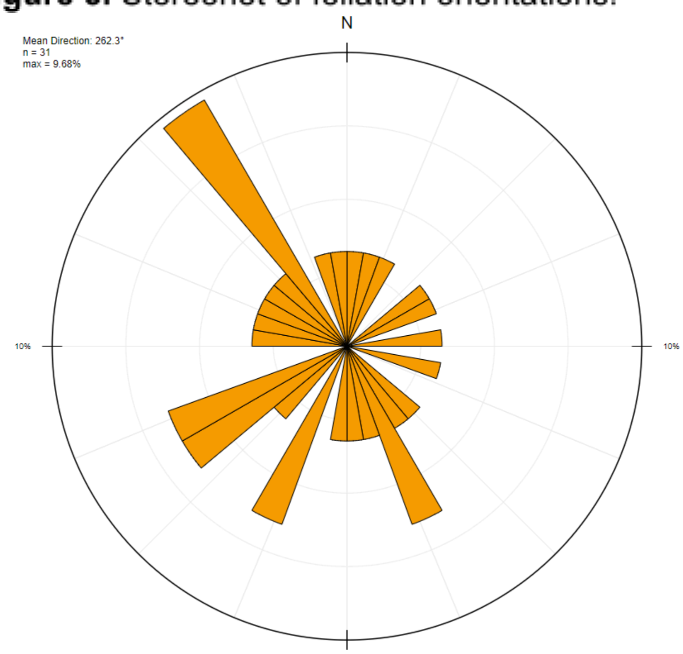

Figure 6. Rose diagram of joint and fault orientations.

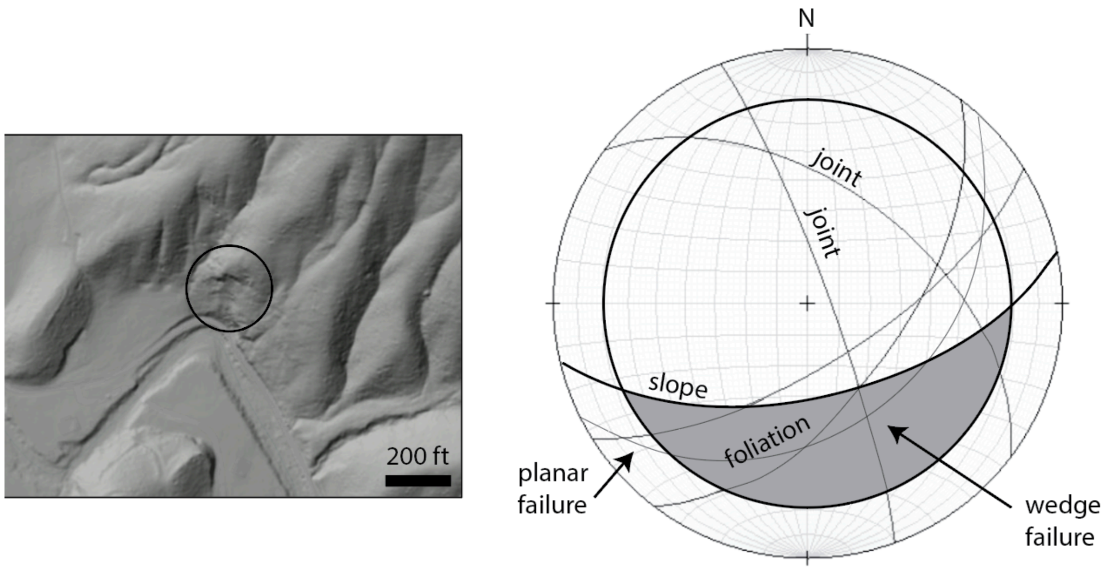

Figure 7. Slope stability stereonet for landslide A. This landslide is located 82.1727424°W 35.6343752°N

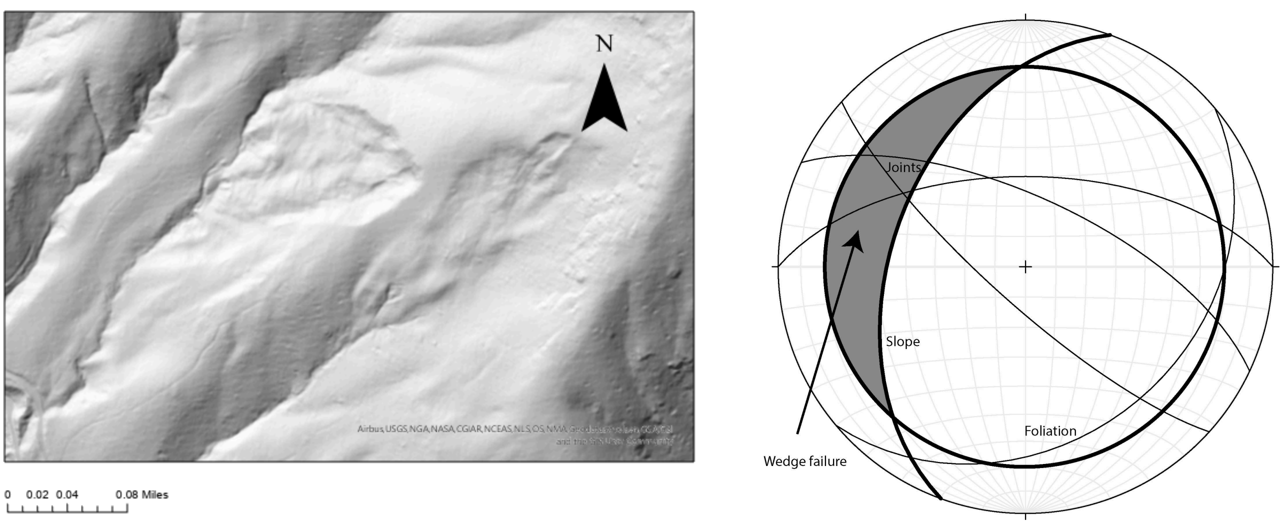

Figure 8. Figure 8. Slope stability for landslide B. This landslide is located 82.1727424°W 35.6343752°N

Discussion

The data show that planar failures along the foliation planes are the most common cause of landslides. Results of this study show that foliations throughout most of the field area dip toward the SE so slopes at risk are those that also face toward the SE. Areas in the field area that have a slope greater than 20° and dip in the same direction as the foliation were calculated to show all areas as at risk for planar failure (Fig. 9).

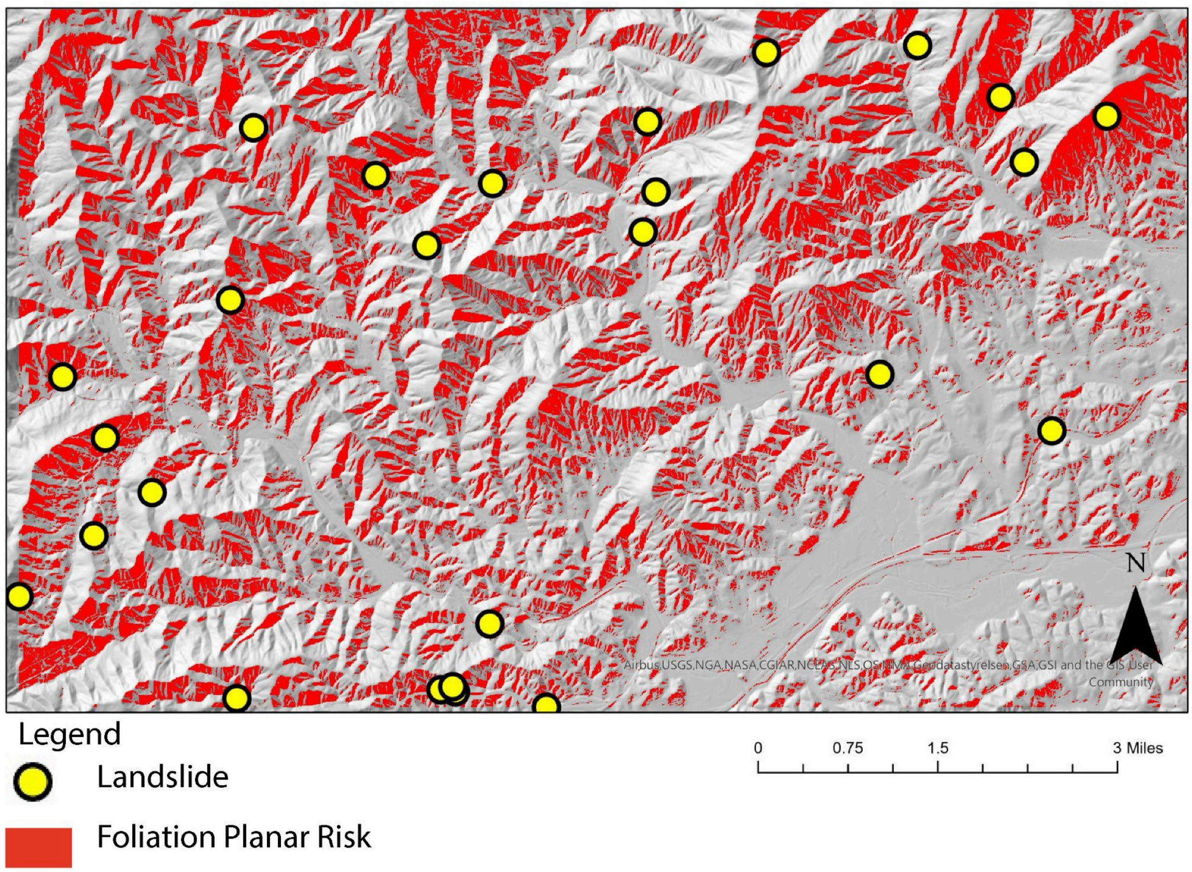

Figure 9. Foliation planar risk map with landslides labelled.

While planar failures are more common in this case, there are two landslides in Old Fort that did not occur in the areas of foliation planar failure risk. Slope stability plots show that failure occurred via wedge failure along joints, indicating that the joints also contribute to erosional retreat of the escarpment. The dominant set of joints that strike NW/SE are in the same orientation as the extension that occurred during the Mesozoic rifting of Pangea (Figs. 2 and 6). This suggests that rifting is the source of these joints. The E/W striking joints are hypothesized to likely be associated with the Swannanoa Lineament (Figs. 1 and 6). The combination of regional joints with those of the Swannanoa Lineament can be argued as to why the Blue Ridge Escarpment is curving and eroding at a faster rate here.

Conclusions

In conclusion, this study shows that due to the potential for landslides by planar failure, slopes that dip in the same direction as the foliation are particularly at risk. With the combination of the Jurassic-aged joints and the Swannanoa Lineament, the area of Old Fort is at high risk for landslides. The fractures found in this area correlate with the main causes of the erosion rate. Planar failure is the most common cause of landslides in Old Fort, though there are two locations within Old Fort that have an impending wedge failure between joints and foliation. The LiDAR maps supports this as well.

Acknowledgments

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