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Assessing the Prevalance of Joint-Controlled Mass Wasting in the Southern Appalachian Mountains, U.S.A.

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ASSESSING THE PREVALENCE OF JOINT-CONTROLLED MASS WASTING IN THE SOUTHERN APPALACHIAN MOUNTAINS, U.S.A.

A Master's Thesis

Presented to

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In Partial Fulfillment

Of the Requirements for the Degree

Master of Science, Geography and Geology

By

Madeline Konopinski

July 2021

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ABSTRACT

Landslides are common hazards that produce devastating effects worldwide. Within the United States, the Appalachian Mountains are identified as an area of moderate to high susceptibility and incidence for landslides (Mirus et al., 2020; Wieczorek and Morgan, 2008). Given the presence of active seismic zones (eastern Tennessee and Giles County seismic zones) and variable rainfall due to seasonal storms (hurricanes) throughout the Appalachians, ancient earthquake activity or intense rainfall may trigger mass wasting events. Regional bedrock joints may further control the susceptibility of landslides to develop in specific locations during trigger events by providing a pre-existing weakness in the substrate. This relationship is demonstrated by three large rock block slides in the Appalachian Valley and Ridge province downslope of ridges where bedrock units are oriented parallel to regional fractures. To investigate the distribution of joint orientations and landslide occurrence throughout the southern and central Appalachians, I present 3,000 structural measurements of joints collected throughout the southern Valley and Ridge province. The discordance between joint orientations and local strike of bedrock units is used to (a) identify higher- and lower-risk mass wasting zones, (b) focus searches for unmapped, ancient landslides using high resolution digital elevation models, including light detection and ranging (LiDAR) based data and (c) to determine if joint orientations are influenced by regional basement structures. From these techniques, two mass wasting features were identified 60 miles southwest of the Sinking Creek Mountain landslides along the same ridge, within the Giles County seismic zone.

KEYWORDS: Appalachians, landslides, joints, seismic activity, basement structures

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I dedicate this thesis to my grandpa.

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INTRODUCTION

On average, 25-50 fatalities and billions of dollars in destruction occur annually due to landslides (Mirus et al., 2020). In 1980, the average yearly cost of damage caused by landslides was more than $1 billion (Fleming and Taylor, 1980). Recently, the United States Geological Survey (USGS) has estimated the annual cost of damage caused by landslides has increased to between $2 and $4 billion (AGI, 2021), and landslide hazards have been identified in all 50 states of the U.S. (Mirus et al., 2020). The USGS has labeled the Pacific Northwest, Rocky Mountains, and Appalachian Mountains as areas with the highest concentration of landslide occurrences and highest susceptibility for landslides (Wieczorek and Morgan, 2008). Within the Appalachian Mountains, the Valley and Ridge province has been identified as an area with moderate susceptibility and incidence with ~25% of the region labeled as high susceptibility and incidence (Wieczorek and Morgan, 2008) (Figure 1).

The Valley and Ridge province is one of four main physiographic provinces that make up the Appalachian Mountains. From east to west, they are the Piedmont, Blue Ridge of the Piedmont, Valley and Ridge, and Appalachian Plateau (Hatcher, 2005; Rast 1989) (Figure 2). The Valley and Ridge province extends from southeastern New York to northeastern Alabama and is characterized by subparallel linear valleys and ridges that trend northeast to southwest. Within the Valley and Ridge province, a study of landslides in northeastern Alabama has revealed large rock block slides on Colvin Mountain located downslope of areas where the strike of the ridge and joint orientation sets become sub-parallel to parallel (McKay and Jackson, 2019).

These landslides have a combined size of ~52,000,000 m^3 (McKay and Jackson, 2019) and have been identified as joint controlled with no evidence of fluvial undercutting, precipitation induced failures, or seismic activity. Another cluster of large landslides was identified in southwestern Virginia along the dip slope of Sinking Creek Mountain with a combined size of ~100,000,000 m^3, with Schultz (1986) suggesting they detach along bedding and joint planes (Schultz, 1986). Both landslide occurrences are located within the Valley and Ridge province and are near active seismic zones but are located ~400 miles apart.

Therefore, I hypothesize that joint controlled landslides may be a common characteristic of the southern Valley and Ridge province, the propagation of joint orientations may be controlled by regional basement structures, and joint controlled landslides can be identified based on the workflow in Table 1. Joint orientation sets and the strike of bedrock units are presented throughout the Valley and Ridge province from New Castle, Virginia to Birmingham, Alabama. Structure data was used to create landslide susceptibility maps and joint orientation maps. LiDAR-based DEM data (U.S. Geological Survey, 2020) is utilized to identify previously unmapped mass wasting deposits in high susceptibility areas. Joint orientation maps were used to determine if Iapetus Ocean rifting basement structures are influencing the orientation at which joints are propagating.

Table 1. The table displays the Excel and ArcMap workflows for 6 of the 19 figures and how the different color schemes were created.

Figure	Workflow	Additional Information
Precipitation Map	ArcMap: Conversion Tool → To Raster → ASCII to Raster Tool Data Management Tools → Raster → Raster Dataset → Mosaic to New Raster Spatial Analyst Tool → Map Algebra → Raster Calculator	ASCII to Raster: Output data type → FLOAT Mosaic to New Raster: Pixel type → 32-bit-FLOAT, number of bands: 1 Raster Calculator: "raster"/1000
Data Station	ArcMap: Display XY Data → X Field = Easting → Y Field = Northing → Click Edit → Projected Coordinate Systems → UTM → NAD 1983 → NAD 1983 UTM Zone 16N → OK → OK Display XY Data → X Field = Easting → Y Field = Northing → Click Edit → Projected Coordinate Systems → UTM → NAD 1983 → NAD 1983 UTM Zone 17N → OK→ OK Right click each layer → Data → Export → Export: All features → Output feature class → navigate to desired geodatabase ArcToolbox → Data Management Tools → Raster → Raster Dataset → Mosaic to New Raster → Input all rasters → choose geodatabase output → name → number of bands = 1 → OK	DEM creation: Pixel Type needs to be the same as the Tif files DEM: hillshade with a z factor of 10

Table 1 continued. The table displays the Excel and ArcMap workflows for 6 of the 19 figures and how the different color schemes were created.

Figure	Workflow	Additional Information
Joint Orientation Map	Excel: Strike measurement – 180º = difference =IF([difference]<0, [revert to the original number], [keep the number the same]) ArcMap: Spatial Analyst Tools → Interpolation → Nearest neighbor	Input point feature → Joint layer Z value field → Difference
Susceptibility Map	Excel: Converted data: strike measurements – joint strike measurements → ldifferencel ArcMap: Layer → Properties → Quantities → Graduated Colors → 3 categories	
Landslide DEMs	ArcMap: Data Management Tools → Raster → Raster Dataset → Mosaic to New Raster	Pixel type must match the original LiDAR pixel type Number of bands: 1
Landslide Curvature	ArcMap: Spatial Analyst Tool → Surface → Curvature	
Color Schemes	ArcMap: Customize → Style Manager → folder being used → Color Ramps → right-click → New → Present Color Ramp	

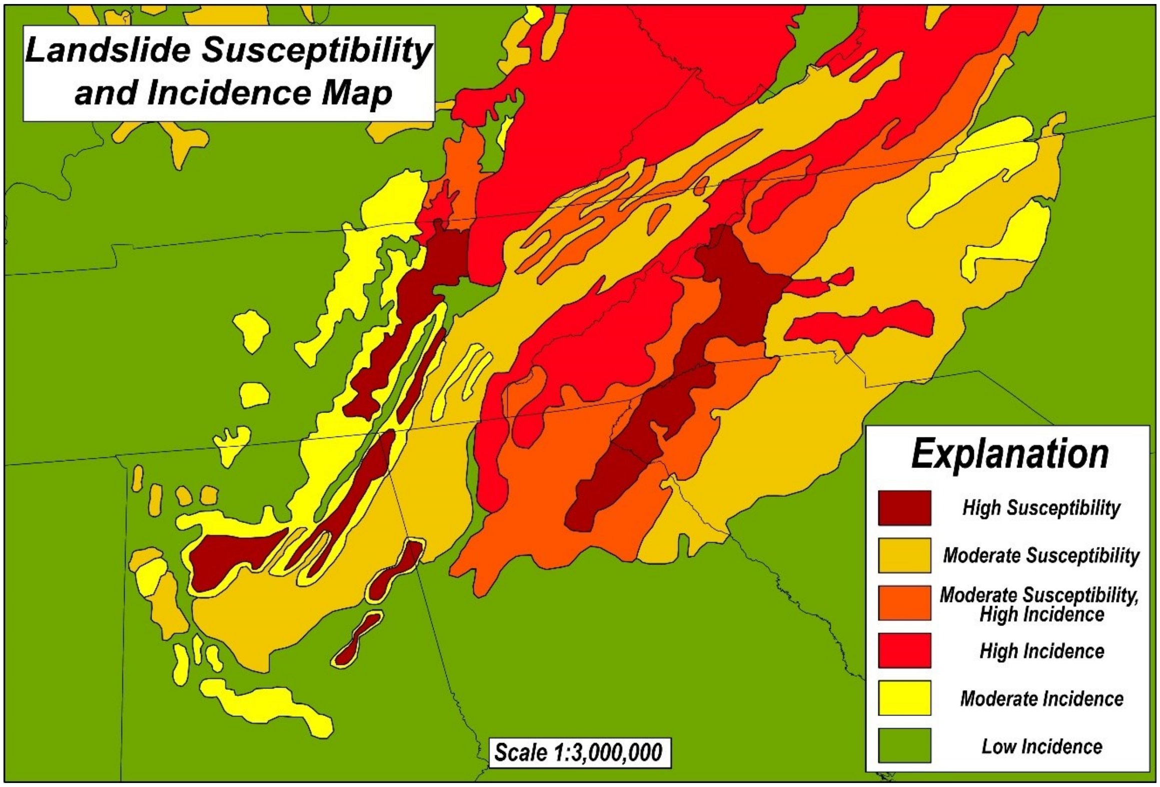

Figure 1. Landslide susceptibility and incidence map for the southern Appalachian Mountains modified from Mirus et al., 2020; Wieczorek and Morgan, 2008. Most of the Valley and Ridge province is defined as being moderate susceptibility with portions labeled as moderate incidence, moderate susceptibility and high incidence and high susceptibility.

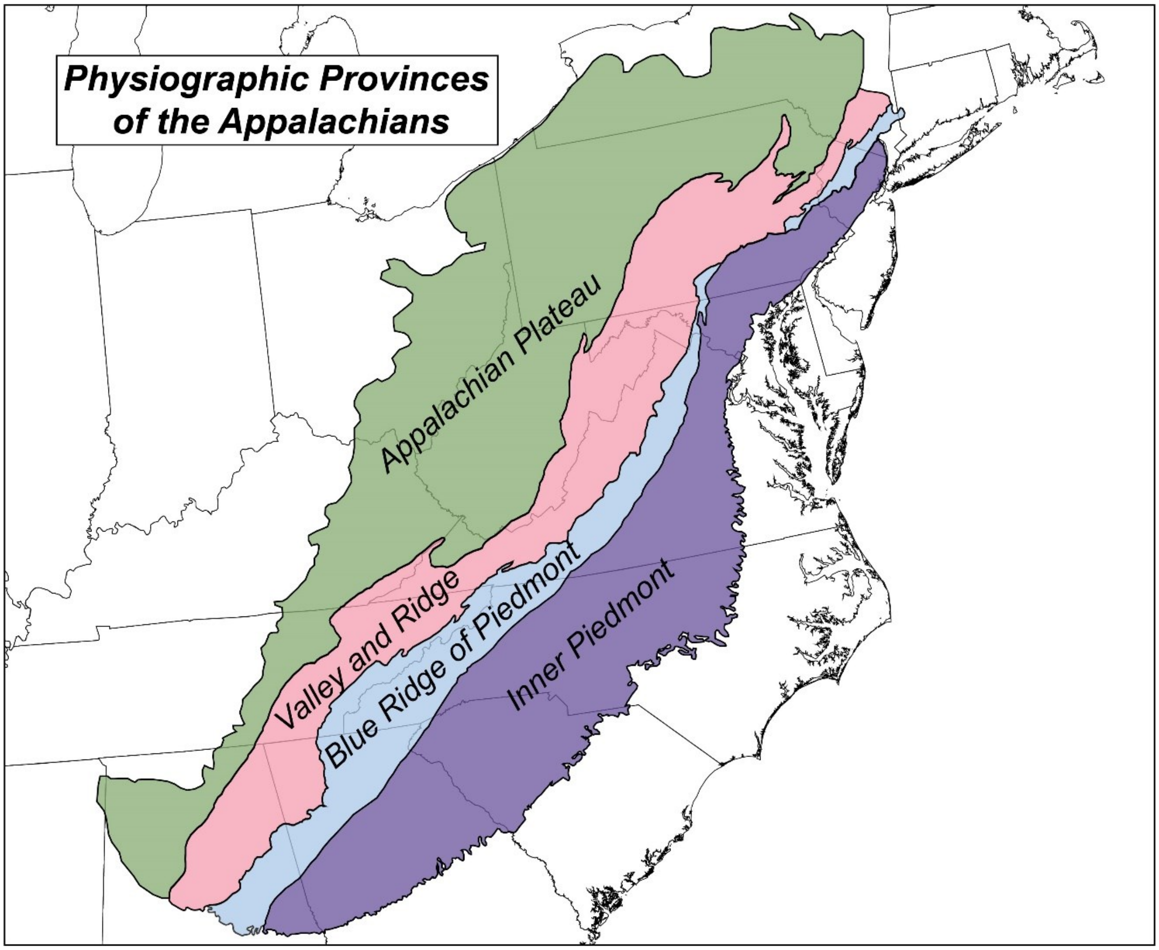

Figure 2. The Appalachian Mountains are composed of four main physiological provinces: Appalachian Plateau, Valley and Ridge, Blue Ridge of the Piedmont, and the Inner Piedmont (adapted from Sinha et al., 2012).

BACKGROUND

Causes of Mass Wasting in the Eastern U.S.

Most of the historical landslides that have been documented within the Valley and Ridge province were triggered by precipitation events (Kirschbaum et al., 2015; Kirschbaum et al., 2010). Precipitation is the most common trigger for landslides (Schuster and Wieczorek, 2002; Yeh and Lee, 2013; Raghuvanshi, 2017) followed by seismic activity (Korup, 2007). Recent research has identified discontinuities as another potential control of large mass wasting events (McKay et al., 2016), but research is limited within the Appalachians.

Precipitation. The intensity and duration of a precipitation event are the key factors that trigger landslides (Cuomo and Della Sala, 2013). Intense rainfall over a short period of time, and moderate rainfall over a long period of time increase the likelihood of landslide occurrences (Schuster and Wieczorek, 2002). In areas where the soil is normally unsaturated, slope failures are linked to heavy rainfall and infiltration (Yeh and Lee, 2013). When heavy rainfall and infiltration occur, the pore-fluid pressure increases (Terlien, 1998) which in turn decreases the shear strength of the soil (Yeh and Lee, 2013). The depth to which the water infiltrates the soil impacts the likelihood of a slope failure and the type of failure (Yeh and Lee, 2013). Typically, the direct infiltration of rainfall with a maximum depth of 2 m triggers shallow landslides (Terlien, 1998; Cuomo and Della Salla, 2013) and areas that receive less than 8-10 inches of rain have fewer identified landslides (Radburch-Hall et al., 1982).

Based on a 1,000 year, 48-hour precipitation event (Figure 3) (Bonnin et al., 2006; Perica et al., 2013), ~70% of the central and southern Appalachians receive 14 inches of rain or less. Northeastern Tennessee, southwestern Virginia, and West Virginia receive 6-10 inches of rain,

receiving the least amount of precipitation for the region. The Great Smokey Mountains region receives the most amount of rainfall due to a rain-shadow effect and large storm events that occur in this region.

Between November 3rd and 5th 1985, Tropical Storm Juan collided with other low-pressure systems (Jacobson et al., 1989; Cenderelli and Kite, 1998) and resulted in ~12 inches of rain over the Wills Mountain anticline area located on the border of Pendleton County, West Virginia and Highland County, Virginia (Wieczorek et al., 2009). The precipitation event was identified to be an 80–300-year frequency storm event (Jacobson, 1993; Jacobson et al., 1993; Cenderelli and Kite, 1998). The storm triggered more than 3,000 landslides (Jacobson et al., 1989; Jacobson et al., 1993; Wieczorek et al., 2009). Most of the triggered landslides were identified as slides, slide flows, slumps, and slump flows (Jacobson et al., 1993). The majority of the failures were planar slides that were shallow, most being less than 2 m thick, that had minor rotational movement (Wieczorek et al., 2009).

The North Fork Mountain in the southeastern limb of the Wills Mountain anticline (Jacobson et al., 1993) produced the largest debris flows that occurred during the storm event (Cenderelli and Kite, 1998) (Figure 4). The largest failure has a length of 2,848 m, involving 13,900 m^3 of material (Wieczorek et al., 2009; Cenderelli and Kite, 1998) and was mainly composed of sandstone residuum and colluvium (Wieczorek et al., 2009).

Seismic activity. Seismic activity is another trigger for landslides. The cycling of loading and unloading on rocks during an earthquake depends on a multitude of factors: magnitude, focal depth, and the frequency of the cycling (Sidle and Ochiai, 2006). The seismic waves produced from earthquake activity cause the ground to accelerate horizontally (Sidle and Ochiai, 2006; Raghuvanshi, 2017) and can result in slope failures on over-steepened slopes along

discontinuities (Sidle and Ochiai, 2006, Highland and Bobrowsky, 2008). Less is known about seismically induced mass wasting compared to precipitation, because seismically triggered landslides are less common and more difficult to predict (Sidle and Ochiai, 2006). Within the eastern United States, the New Madrid seismic zone and the east Tennessee seismic zone are the two most active seismic zones and have historically produced devastating earthquakes (Steltenpohl et al., 2010; Warrell et al., 2017). Within the Valley and Ridge province of the Appalachian Mountains, the east Tennessee seismic zone and the Giles County seismic zone are prominent seismic zones.

New Madrid Seismic Zone. The New Madrid seismic zone is located along the Mississippi River between Kentucky, Missouri, Tennessee, and Arkansas and is the most active seismic zone in the central eastern U.S. (Baldwin et al., 2005). The New Madrid seismic zone roughly lies in the center of the Mississippi embayment (Baldwin et al., 2005), where Late Cretaceous coastal marine sediments have accumulated on top of basement structures (Jibson and Keefer, 1993).

The Reelfoot rift is an intracratonic rift that formed (Jibson and Keefer, 1993) during the late Precambrian to early Paleozoic (Braile et al., 1982) and lies below the New Madrid seismic zone (Jibson and Keefer, 1993; Hildenbrand and Hendricks, 1995; Csontos et al., 2008). The Reelfoot rift formed during the breakup of Rodinia (Csontos et al., 2008) and the opening of the Iapetus Ocean (Hildenbrand and Hendricks, 1995). During the opening of the Iapetus Ocean, a triple junction formed in southwestern Arkansas and two of the failed arms were the Reelfoot rift and the Oklahoma aulacogen (Hildenbrand and Hendricks, 1995). Reelfoot rifting began along normal faults, but the rift structures are suggested to have formed as strike-slip faults (Csontos et al., 2008).

Reactivation of the Reelfoot rift faults during the assemblage of Pangea is suggested to be the source of seismicity within the New Madrid seismic zone (Csontos et al., 2008; Braile et al., 1982) as most epicenters produced within the New Madrid seismic zone are bounded in the Reelfoot rift grabens (Braile et al., 1982). In 1811-1812, the New Madrid seismic zone has produced devasting earthquakes with an estimated moment magnitude of M_W = 7.0-7.5 (Guccione, 2005; Li et al., 2005) are suggested to have been key triggers for at least three large landslides within the Mississippi embayment (Guccione, 2005). In total, 221 landslides suggested to be triggered by the earthquakes were mapped along the bluffs of the Mississippi alluvial plain in western Kentucky and Tennessee (Jibson and Keefer, 1988; Jibson and Keefer, 1993). Three landslide types were identified along the bluffs: old coherent slides, earth flows, and young rotational slumps (Jibson and Keefer, 1988). Old coherent slides are defined as rotational slides and translational block slides that stay intact (Jibson and Keefer, 1993). To trigger block slides and Earth flows within the New Madrid seismic zone, a minimum magnitude of m_b = 5.9 was required and a magnitude of m_b = 5.3, respectively (Jibson and Keefer, 1993).

East Tennessee Seismic Zone. The second most active seismic zone in the eastern U.S. is the east Tennessee seismic zone (Dunn and Chapman, 2006; Steltenpohl et al., 2010; Hatcher et al., 2012; Warrell et al., 2017) that extends for ~300 km from southeastern Kentucky and western Virginia to northeastern Alabama within the Appalachian Mountains (Chapman et al., 1997; Dunn and Chapman, 2006; Powell and Thomas, 2016) (Figure 5). The east Tennessee seismic zone is interpreted as an ancient intraplate seismic zone (Powell et al, 2014) presumably located in basement structures (Steltenpohl et al., 2010; Levandowski and Powell, 2019).

The hypothesized origin of the east Tennessee seismic zone is further supported by the New York-Alabama and Clingman magnetic lineaments acting as boundaries to the northwest

and southeast respectively (Steltenpohl et al., 2010). Most of the earthquakes produced by the east Tennessee seismic zone, 80-90%, have occurred between the two magnetic lineaments (Steltenpohl et al., 2010). It has been proposed that the New York-Alabama lineament represents a boundary between two crustal blocks (Kelly et al., 2017). The boundary is interpreted to be a right-lateral strike-slip fault (Steltenpohl et al., 2010) that is not related to the Appalachian orogeny (Brandmayr and Vlhovic, 2016), but instead related to an intra-Grenville suture (Thomas, 2006) during the creation of Rodinia (Powell and Thomas, 2016).

Hypocenter depths of 5-26 km (Chapman et al., 1997; Dunn and Chapman, 2006; Brandmayr and Vlhovic, 2016; Warrell et al., 2017) further suggest that earthquakes produced by the east Tennessee seismic zone are within Precambrian crystalline basement blocks beneath the Valley and Ridge province (Powell et al., 2014; Brandmayr and Vlhovic, 2016). Based on focal mechanisms, the seismicity within the east Tennessee seismic zone is suggested to be produced by primarily steeply dipping, strike-slip faults (Hatcher et al., 2012; Kelly et al., 2017).

Historically, the east Tennessee seismic zone has produced earthquakes with a magnitude of less than 5 (Powell et al., 2014). The largest earthquake produced by the east Tennessee seismic zone was Richter magnitude of 5.1 in Irondale, Alabama in 1916 (U.S. Geological Survey, 2021). The second largest earthquakes produced by the zone were in Maryville, Tennessee in 1973 and Fort Payne, Alabama in 2003, both with a moment magnitude of 4.6 (Dunn and Chapman, 2006; Powell et al., 2014; Brandmayr and Vlhovic, 2016). Even though an earthquake with a magnitude greater than 5.1 has not been recorded, paleoseismic data suggest that the east Tennessee seismic zone has the capability of producing an earthquake with a magnitude of ~7.5 (Hatcher et al., 2012; Levandowski and Powell, 2019). Research conducted in Dandridge, Tennessee identified earthquake features that suggest an occurrence of a late

Quaternary aged earthquake with a $M_w \geq 6.5 \pm 0.2$, with a 95% confidence interval, produced by the east Tennessee seismic zone (Warrell et al., 2017).

Giles County Seismic Zone. The Giles County seismic zone is ~40 km long and is located in southwestern Virginia (Bollinger and Wheeler, 1988), extending from New Castle, Virginia to Bristol, Tennessee (Figure 5). The seismicity generated from the Giles County seismic zone is interpreted to be in basement rocks below the Valley and Ridge province thrust sheets (Munsey and Bollinger, 1985; Kelly et al., 2017), as the earthquakes produced in the area are occurring at depths of 7-20 km (Munsey and Bollinger, 1985). It has been proposed that the Giles County seismic zone was created from the reactivation of an Iapetus normal fault due to a compressional event (Bollinger and Wheeler, 1988). The faults below the Giles County seismic zone may be moving is a right-lateral strike-slip motion with some areas displaying reverse motion (Munsey and Bollinger, 1985). The faults are most likely striking NE in the southwestern portion and NW in the northeastern portion (Munsey and Bollinger, 1985).

In 1897, the second largest earthquake recorded at that time in the southeastern U.S. and the first earthquake to be linked to the Giles County zone was produced (Bollinger and Wheeler, 1988). The 1897 earthquake is estimated be a moment magnitude of 5.5 (Kelly et al., 2017). The estimated maximum magnitude that can be produced by the Giles County seismic zone is a 6.8 (Bollinger, et al., 1992), but an earthquake of that magnitude has not been documented. Large quaternary landslides, including rock block slides and rock slumps (Schultz and Southworth, 1989), have been linked to the Giles County seismic zone (Schultz and Southworth, 1989; Kelly et al., 2017). Sinking Creek Mountain is located near the northeastern portion of the Giles County seismic zone and some of the largest landslides occurred along the dip slope of the ridge (Schultz, 1986).

Discontinuities. Failures can initiate along planes of weakness known as discontinuities. Common discontinuities are faults, bedding planes, joints (Shang et al., 2018), foliations, cleavage, and schistosity (Wyllie and Mah, 2004). Joints are one of the most abundant type of geologic structure and can be found in all types of rocks (Davis et al., 2012). The propagation of joints within a structure occurs when the tensile strength of a rock is exceeded from deformation (Wyllie and Mah, 2004, Davis et al., 2012), and they typically form perpendicular to the bedding plane (Engelder, 2004; Davis et al., 2012). Discontinuities such as joints can increase the weakness of a structure and can increase the chance of a failure occurring (Raghuvanshi, 2017).

One of the main types of failures controlled by discontinuities is a plane failure. Plane failures are characterized by the sliding of the failure mass along a single surface that is similar to a plane (Norrish and Wyllie, 1996). Plane failures occur in areas where the strike of the discontinuity is parallel to the face of the rock (Wyllie and Mah, 2004; Sharma et al., 1995).

Colvin Mountain is an example of joint-related landslides located within the Valley and Ridge province. Colvin Mountain is an east-west trending ridge located within the foreland thrust belt in Etowah County, Alabama (McKay, 2016). The ridge extends for 100 km trending ~045°-055° and then turns ~040° to the southeast, extending for another 18 km (McKay and Jackson, 2019). The ridge is underlain by the Helena thrust sheet and formed by the exhumation of the thrust sheet (McKay et al., 2016).

Recent structural research on Colvin Mountain has recorded a syntectonic joint set of 075°-255° (McKay et al., 2016). The strike of the mountain shifts to the SE from the NE and the ridge becomes orientated to ~070°, becoming subparallel to parallel with the joint orientations. These sections of the ridge are located on the upslope of three large landslides (Figure 6). The slides have a combined size of ~52,000,000 m^3 (McKay and Jackson, 2019). Other areas along

the ridge, where joint and bedding strike orientations were not subparallel to parallel, were observed to have few to no large volume mass wasting events, including smaller blocks of colluvium (McKay et al., 2016).

Summary of Regional Appalachian Geology and Tectonics

In eastern North America, the Appalachian Mountains extend ~3000 km from Newfoundland to beneath the Coastal Plains of Alabama (Hatcher, 2005) and reside on top of Grenville basement rocks (Thomas, 2006). Three Paleozoic orogenies formed the Appalachian Mountains: The Ordovician Taconic orogeny, the Devonian-Mississippian Acadian-Neoacadian orogeny, and the Pennsylvanian-Permian Alleghenian orogeny (Hatcher, 2005; Merschat et al., 2005; Thomas, 2006).

The Appalachian Mountains represent a full Wilson cycle beginning after the breakup of Rodinia and ending with the creation of Pangea (Hatcher, 2010). The supercontinent Rodinia was formed during the Grenville orogeny between 900-1300 Ma (Park et al., 2010; Thomas, 2006), which occurred from multiple continent-continent collisions (Park et al., 2010). Rodinia began to rift at ~750 Ma was broken into three separate continents: East Gondwana, West Gondwana, and Laurentia (Faill, 1997), forming the Iapetus Ocean between Laurentia and West Gondwana (Cawood et al., 2001), initiating the Appalachian orogeny (Williams and Hatcher, 1982). The Iapetan rift margin is characterized by northeast-striking rift segments that are offset by transform faults that strike northwest to southeast (Thomas, 2006) (Figure 7).

At ~470 Ma, the Taconic orogeny began from the obduction of multiple terranes and microcontients (Stowell et al., 2019), closing the Iapetus Ocean (Thomas, 2006; Hatcher, 2010). The Acadian-Neoacadian orogeny (~410 Ma- ~345 Ma) (Hatcher, 2005; Stowell et al., 2019) is

the second orogenic event caused by the north-to-south closure of the Rheic Ocean (Hatcher, 2005) from the collision of small terranes and microcontinents with the eastern margin of Laurentia (Rast, 1989; Park et al., 2010). During the Taconic and Acadian-Neoacadian, sandstones, shales, and carbonates were deposited (Hatcher, 2005) within the Valley and Ridge Province (Figure 8). Sandstones, limestones, and shales deposited during the Taconic orogeny are currently located on the tops and sides of ridges of the southern Valley and Ridge province. The valleys of the Valley and Ridge province are predominatly composed of shales, mudstones, and siltstones deposited during the Acadian-Neoacadian orogeny (Figure 8).

The Alleghenian orogeny is the final orogenic event and was caused by the north-to-south collision between Gondwana and Laurentia (Secor et al., 1986), closing the Theic Ocean (Hatcher, 2005). Gondwanan crust was thrusted more than 330 km onto Laurentian (Hopper et al., 2017). The late Devonian to Permian compression created the fold and thrust belt that characterizes the Valley and Ridge province today (Hatcher, 1972; Evans and Battles, 1999; Hatcher, 2005). Throughout the Alleghenian orogeny, multistage deformation occurred (Bartholomew and Whitaker, 2010) and produced five stress fields that caused the propagation of discontinuities (Engelder and Whitaker, 2006).

During the beginning stages of the Alleghenian orogeny, the Appalachian-wide stress field was created from the oblique convergence of Gondwana and Laurentia (Engelder and Whitaker, 2006). The Appalachian-wide stress field persisted while Gondwana pushed closer against Laurentia in a dextral slip motion (Engelder and Whitaker, 2006; Lash and Engelder, 2007). During the active period of the Appalachian-wide stress field, the compression formed discontinuities with an orientation of 085° and a secondary set with an orientation of 355° (Bartholomew and Whitaker, 2010). After more than 10 m.y. of dextral slip, the Appalachian-

wide stress field was disrupted by a stress field that formed from the thrusting of basement decollements (Engelder and Whitaker, 2006) and ended in the late Mississippian (Bartholomew and Whitaker, 2010).

Following the Appalachian wide stress field, the Princeton event, produced discontinuities with a dominant orientation of 055º and a secondary set at 145º (Bartholomew and Whitaker, 2010). The third stress field was formed by a main central Appalachian deformation event that occurred in the late Mississippian (Bartholomew and Whitaker, 2010). The event produced discontinuities striking 035º with a secondary set striking 120º (Bartholomew and Whitaker, 2010). The fourth Alleghenian event had the most widespread impact and was the main southern Appalachian deformation event, producing a set of discontinuities oriented 070º with a minor set trending 160º (Bartholomew and Whitaker, 2010). The final Alleghenian event is defined as a late southern Appalachian deformation event with a predominate discontinuity set oriented 095º and a second set oriented 010º (Bartholomew and Whitaker, 2010).

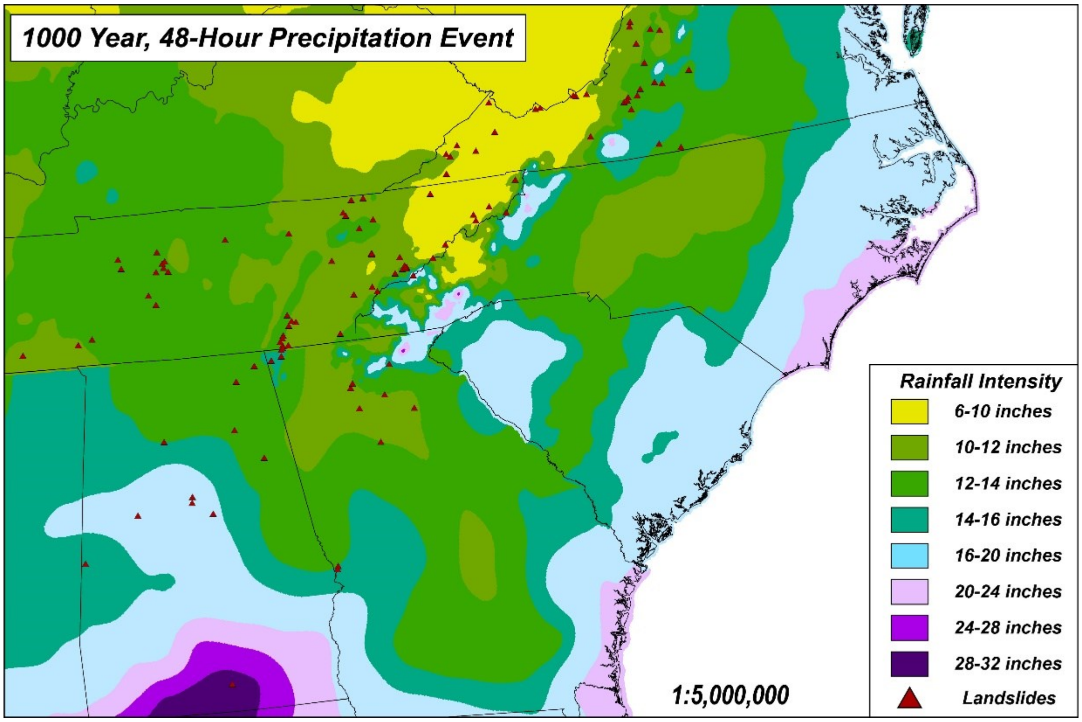

Figure 3. 1000-year, 48-hour precipitation event for the central and southern Appalachians. Precipitation data collected from the NOAA Precipitation Frequency Database (Bonnin et al., 2006 and Perica et al., 2013). Documented landslides, collected from the NASA Global Landslide Catalog (Kirschbaum et al., 2015 and Kischbaum et al., 2010). Table 1 shows the workflow for the creation of this map.

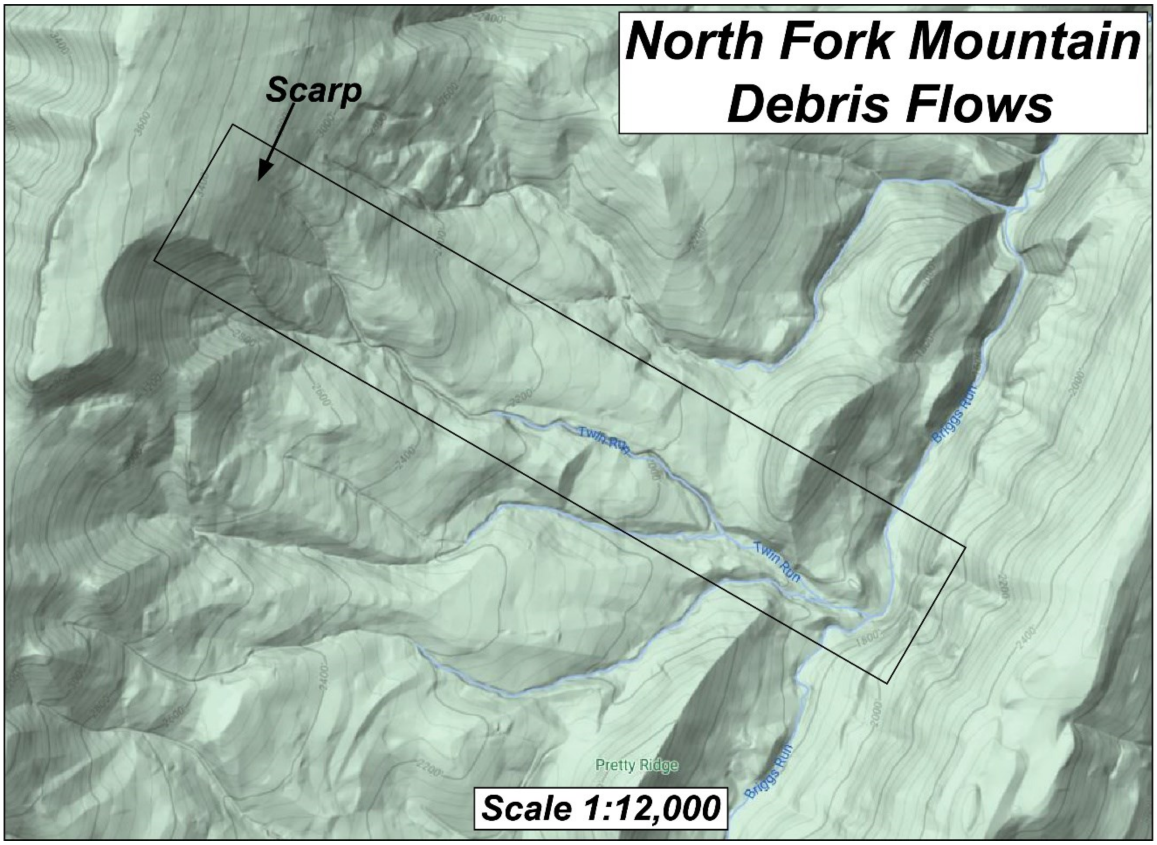

Figure 4. The debris on Twin Run, North Fork Mountain, West Virginia (Cenderelli and Kite, 1998) is outlined by the black rectangle (Kite et al., 2019). Imagery from Google Maps (Google Maps, 2021).

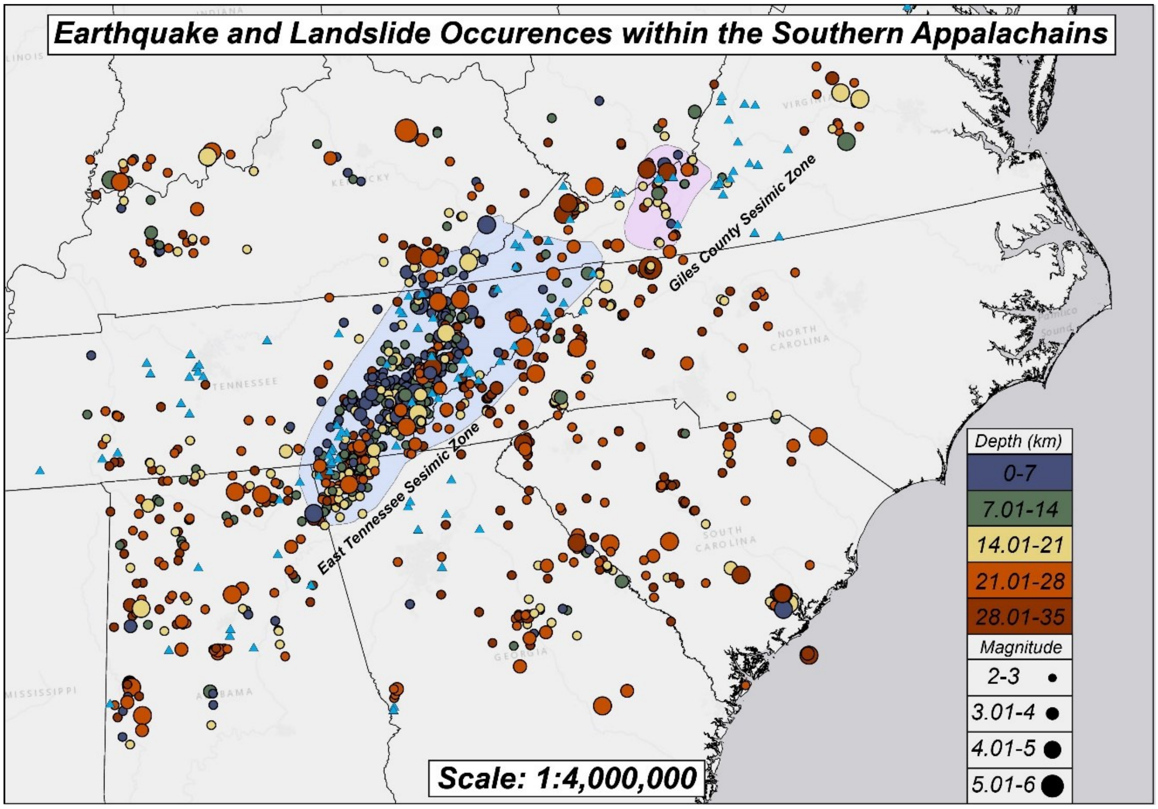

Figure 5. Documented earthquakes and landslides within the southern Appalachians. Earthquake data collected from the USGS Earthquake Search catalog (U.S. Geological Survey, 2021) and landslide data collected from the NASA Global Landslide Catalog (Kirschbaum et al., 2015; Kischbaum et al., 2010). Table 1 shows the workflow for this map.

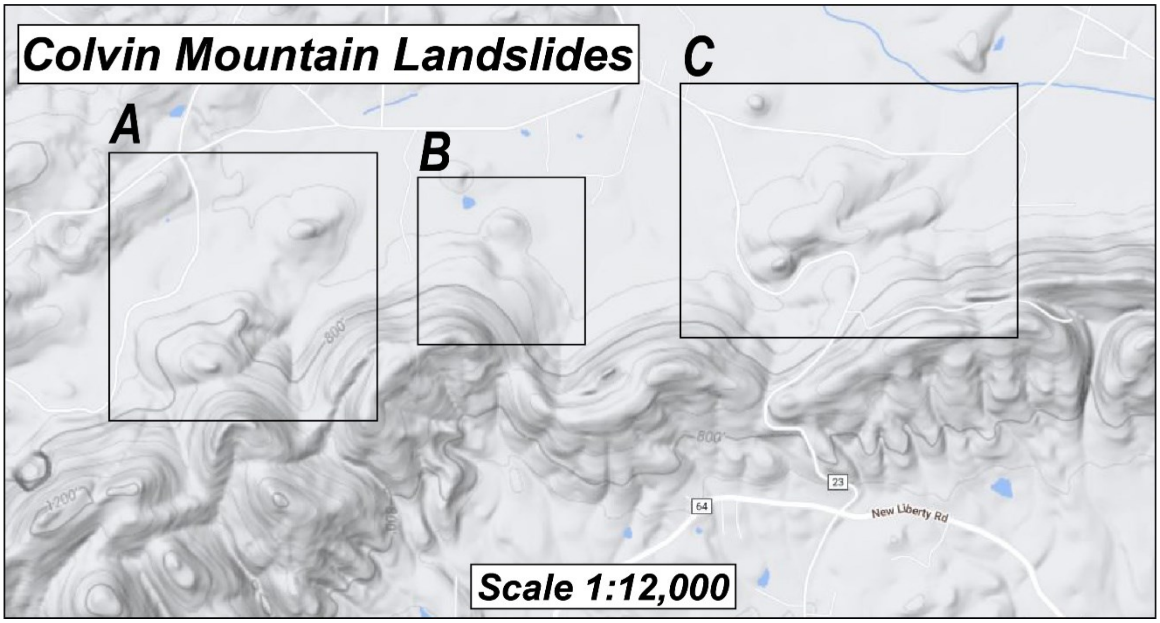

Figure 6. Three large landslides were identified on the northern slope of Colvin Mountain. A is the large western landslide, B is the smaller middle landslide, and C is the large eastern landslide (Google Maps, 2021).

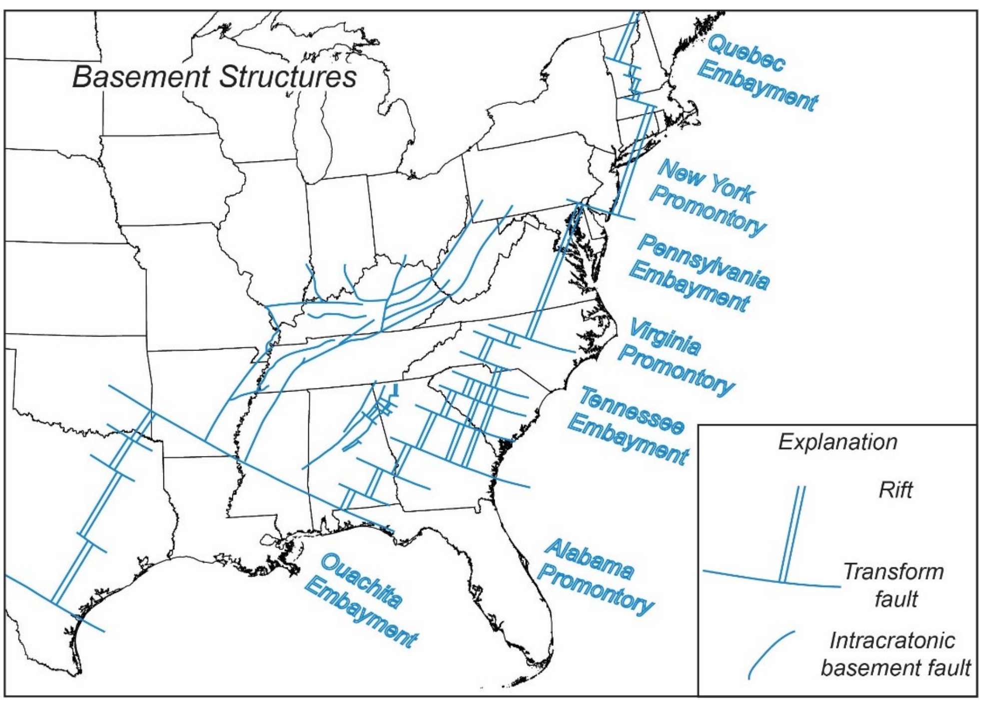

Figure 7. Prominent basement structures along the eastern Appalachian Mountains are northeast trending rifts connected by northwest trending transform faults (modified from Thomas, 2006).

Generalized Stratigarphy of the Valley and Ridge Province

Era	Period	Units
Phanerozoic	Penn.	Pottsville Formation - Light to dark grey nterbedded sandstone, shale, siltstone, conglomerate, and coal. Lower portion is thick-bedded and dominated by massive, conglomeratic sandstones.
	Mississippian	Parkwood Formation - Medium to dark grey shale interbedded with a light to medium, very fine to fine grained sandstone. Contains reddish and greenish mudstones and limestones.
		Pennington Formation - Grey shale interbedded with reddish and greenish mudstone, fine grained dolostone, limestone, sandstone, and shaly coal.
		Bangor Limestone - Medium grey bioclastic and oolitic limestone. Upper portion interbedded with reddish and greenish mudstone.
		Floyd Shale - Dark-grey shale with grey claystone interbedded. Thin sandstone, limestone, and chert beds are locally present.
		Hartselle Formation - Well-sorted, fine-grained, light-colored sandstone, interbedded with grey shale and locally oolitic and coarse-grained limestone.
		Pride Mountain Formation - Fissle medium to dark grey clay shale, interbedded with blockly red and green mudstones, clay shale, and shaly limestone, locally.
		Tuscumbia Limestone - Light to dark grey fossiliferous, micritic and partly oolitic limestone. Light grey and white chert nodules that are abundant locally.
		Fort Payne Chert - Light to dark grey limestone, finely crystalline to microcrystalline. Abundant with light grey chert beds and nodules. Dark shale or light grey fossiliferous limestone locally.
		Maury Formation - Greenish-gray to grayish-red sahle that is thinnly laminated and commonly contains phosphate nodules.
	Devonian	Chattanooga Shale - Black to brown organic, silty shale. Some areas contain fine-grained sandstone.
		Frog Mountain Sandstone - Light to dark grey fine to coarse grained sandstone that is locally pebbly. Unit contains interbedded dark-grey shale, dolomudstone, limestone, and fossiliferous chert.
	Silur.	Red Mountain Formation - Dark red-brown to green-grey siltstone, sandstone, and shale. Hematite beds are common along with thin limestone beds.
	Ordovician	Sequatchie Formation - Red and grey shaly limestone interbedded with green to red calcareous shale and siltstone.
		Colvin Mountain Sandstone - Light grey quartzose sandstone that is medium to coarse-grained and well-sorted.
		Greensport Formation - Dark red to dark yellow-orange shale, calcareous mudstone, limestone, siltstone, with some minor sandstone.
		Upper Chickamauga Group - Greenish-grey calcareous shale and a grey medium grained, fossiliferous limestone with shale in parts.
		Middle and Lower Chickamauga Group - Limestone units with shale and siltstone parts. Lower units composed of limestone, breccia, conglomerate, and quartz sandstone.
		Knox Group Undifferentiated - Light grey limestone, dolomitic limestone, and dolomite along with fine to medium grained sandstone and white, grey, and brown chert. Shale common in lower Knox with thin sandstone beds.
	Cambrian	Conasauga Formation - Mainly shale Northwest of Knoxville and Tazewell and mainly dolomitic with some shale southeast of Newport and Kingsport. Fine-grained limestone with interbedded shales common in southwestern portion.
		Rome Formation - Red, green, yellow shale and siltstone with fine-grained grey sandstone located in the middle and western portions.
		Shady Dolomite - Light grey dolomite with thin to medium bedded grey limestone.
		Chilhowee Group - Light to medium grey arkose, conglomerate, and discontinuous mudstone. Greenish -grey mudstone overlay the above units with minor amounts of siltstone and sandstone.

Figure 8. For the Valley and Ridge province, a generalized stratigraphic column was created based on previous maps and stratigraphic columns. The stratigraphy is based mainly on Alabama and Tennessee as most of the data were collected from these two states. Modified from Raymond et al., (1988), Szabo et al., (1988), and Hardeman (1966).

METHODS AND RESULTS

Field Work

Data collection included joint set orientations (Figure 9) and strike of regional ridges that extend from New Castle, Virginia to Birmingham, Alabama. Three ridges were followed throughout the region to determine if the joint features are only located on certain ridges, located on certain sides of ridges, or are common characteristic of the province. Approximately, every 20 miles a data station was constructed. At each data station, between 20 and 100 joints were measured, along with the strike of the ridge and lithology.

Joint Data Analysis

Methods. Throughout the Valley and Ridge province, 57 data stations were constructed (Figure 10) and 3051 joints were measured (Appendix: Joint Data). Rose diagrams were used to visualize the primary and second most prominent joint orientation sets for each data station. Rose diagrams were created in Stereonet (Allmendinger, 2020), using a bin size of 10° and were treated as axes to see the full strike of the joints (Table 2). The data stations were divided into eight sections, A-H, based on the location of Iapetan basement transform faults (Figure 11), to create a more regional study of the joint orientations compared to an individual analysis of each data station. The strike of the joints is used to determine the stress field and tectonic event that formed the joints. Using dip frequency histograms with bin sizes of 5°, the dip of the joints is used to determine the timing of joint propagation (Figure 12).

Results. The most prominent joint strike orientations of the region were 105°- 095°, and 345°. The joints in section A have a primary and secondary average strike of ~090° and ~104°,

respectively. Section G had a similar trend with a primary joint orientation of ~099° and a secondary joint orientation of ~063°. Section H has a primary joint orientation of ~049° and secondary joint orientation of ~087°. The primary joint orientation in section G trends parallel to the basement transform faults and the intracratonic basement faults of the Birmingham graben. The primary joint set of section H and the secondary joint sets for both sections, G and H, trend sub-parallel to parallel of the intracratonic basement faults located in northeastern Alabama (Figure 7).

The primary and secondary strike of the joints in section B is ~065° and ~145°, respectively. Section C has joints predominatly striking WNW. The primary and secondary joints in section D have a trend of ~105° and ~095°, respectively. The primary joint sets for sections E and F trend ~092° and ~98°, respectively. Section E has a secondary joint set striking ~093°, but section F has a secondary joint set striking ~080°.

Using the orientation and dip of the joints, timing and potential control for propagation can be determined (Engelder, 2004). If the dip of the joint is 80° or more, the joints formed after the rocks were deformed (Engelder, 2004). Joints dipping predominatly between 40°-80° indicate that propagation occurred during the folding events (Engelder, 2004). If the dip of the joint is 40° or less, the joints formed before the rocks were deformed and the dip orientation was altered through the deformation process (Engelder, 2004).

Based on Figure 12, most of the joints for the region dip between 40° -90°. The northern and southern most sections (Figure 12-A, G, and H) have joints that predominantly dip between 75°-90°. The north central sections, B, C, and D, have a wider variety of dip angles (Figure 12-B, C, and D) ranging between 40°-80°. The south-central sections (Figure 12-E and F), contain joints that mainly dip between 60°-90° with a handful of joints dipping between 25°-55°.

Bouguer Gravity Anomaly Data

Methods. A gravity anomaly map was created using Bouguer gravity data from the National Geospatial-Intelligence Agency and the program Oasis Montaj (Geosoft Incorporated, 2021). The gravity data was converted to UTM zone 17N and gridded using a minimum curvature, a 2 km spacing, and a sun angle of 45°. The basement faults (Thomas, 2006) were overlain on top of the gravity map to visualize the location of basement structures (Figure 13).

Results. Three distinct zones are identified by different gravity measurements: Birmingham, Gadsden to Chattanooga, and eastern Tennessee (Figure 13). The Birmingham area has a relatively uniform gravity anomaly of -40 to -30 mGal with a small area with higher anomaly readings concentrated around intracratonic basement faults. The Gadsden to Chattanooga area mainly has gravity readings between -40 and -30 with more positive readings concentrated around intracratonic basement faults. The eastern Tennessee area has predominantly negative gravity anomaly readings between -40 and -30. The area also contains a linear low gravity reading located just to the west of the Tennessee and North Carolina border. Iapetan rifts and transform faults are predominantly located in areas defined by gravity highs.

Joint Controlled Landslide Susceptibility Classification

Methods. Joint controlled landslide susceptibility maps (Figure 14) were created by finding the difference between the joint orientation and the strike of the bedding at each data station (Table 1). Landslide joint susceptibility maps (Figure 14) were created using three levels of susceptibility defined as the following: a joint and bedding plane difference of 0°-10° is high susceptibility, 10.01°-20° is moderate susceptibility, and >20° is low susceptibility (Table 1). Colvin Mountain joint data is included within the susceptibility maps to determine if the above

classification of susceptibility would hold as joint controlled landslides were identified downslope of areas where the joint and bedding orientations were parallel to sub-parallel.

The DEM created for the data station map was added to the susceptibility maps to show the topography of the region. Documented landslides from the NASA Global Landslide Catalog (Kirschbaum et al., 2010; Kirschbaum et al., 2015), along with outlines of the east Tennessee seismic zone and the Giles County seismic zone were overlain on the susceptibility maps to determine if there is any connection between high susceptibility stations and locations of known landslides and active seismic zones.

Results. From both susceptibility maps, 17 data stations were identified as areas of high landslide susceptibility and seven of those were identified from the primary joint susceptibility map (Figure 14). For the primary susceptibility map, all the high susceptibility data stations are located either in the northern portion, southern portion, or on the edges of the Valley and Ridge province. The secondary susceptibility map displays a similar trend with most of the high susceptibility data stations located either in the northern portion or on the very eastern edge of the Valley and Ridge province.

When the seismic zones are overlain on top of the susceptibility maps, three of the primary high susceptibility stations and seven of the secondary high susceptibility stations are located within the east Tennessee seismic zone and the Giles County seismic zone (Figure 15). Regarding documented landslides, most of the failures are occurring within the two seismic zones. Two of the primary high susceptibility joint stations are located within 20 mi of documented landslides and both are located near the Colvin Mountain landslides (Figure 15). From the secondary joint failure susceptibility map, five of the high susceptibility stations are

located within 15 mi of the documented landslides (Figure 15) with one of the data stations located almost directly on the documented landslide in southwestern Virginia.

Identified Mass Wasting Features

Methods. The primary joint susceptibility map was used to search for mass wasting features in high susceptibility areas. Original Product Resolution DEM data from the USGS 3DEP database was downloaded for areas surrounding data stations labeled as high susceptibility. For each data station, the DEMs were mosaiced together in ArcMap to create a cohesive topographic view of each area (Table 1). The DEMs were then processed using the curvature tool to identify concave areas that may represent mass wasting features (Table 1).

Results. Two mass wasting features were identified near station 5 in southwestern Virginia. A feature was identified on the dip slope just south of station 5 between stations 12 and 5 (Figure 16-D) from the high-resolution DEM (Figure 16-A). Using the curvature tool, the feature is more clearly defined (Figure 16-B). Other landslides were identified and mapped close to this feature (Figure 16-C). Along the same ridge further to the northeast, a previously mapped landslide was identified upslope of where station 5 is (Figure 17). All of the identified mass wasting features were found within ~60 mi of the Sinking Creek Mountain landslides (Figure 18).

Table 2. This table displays the workflow used to create the rose diagrams for each data station and the rose diagram with all the joint measurements within Stereonet.

Item	Workflow
Opening of excel spreadsheet	File → Import Text File → navigate to excel files → double click to open
Bin size	View → Inspector → Analyses → Bin size → 10º
Perimeter value	View → Inspector → Analyses → Value of perimeter → 80
Axes	View → Inspector → Analyses → Check "treat data as axes"

Figure 9. Joint data being collected from an outcrop in Tennessee by the author.

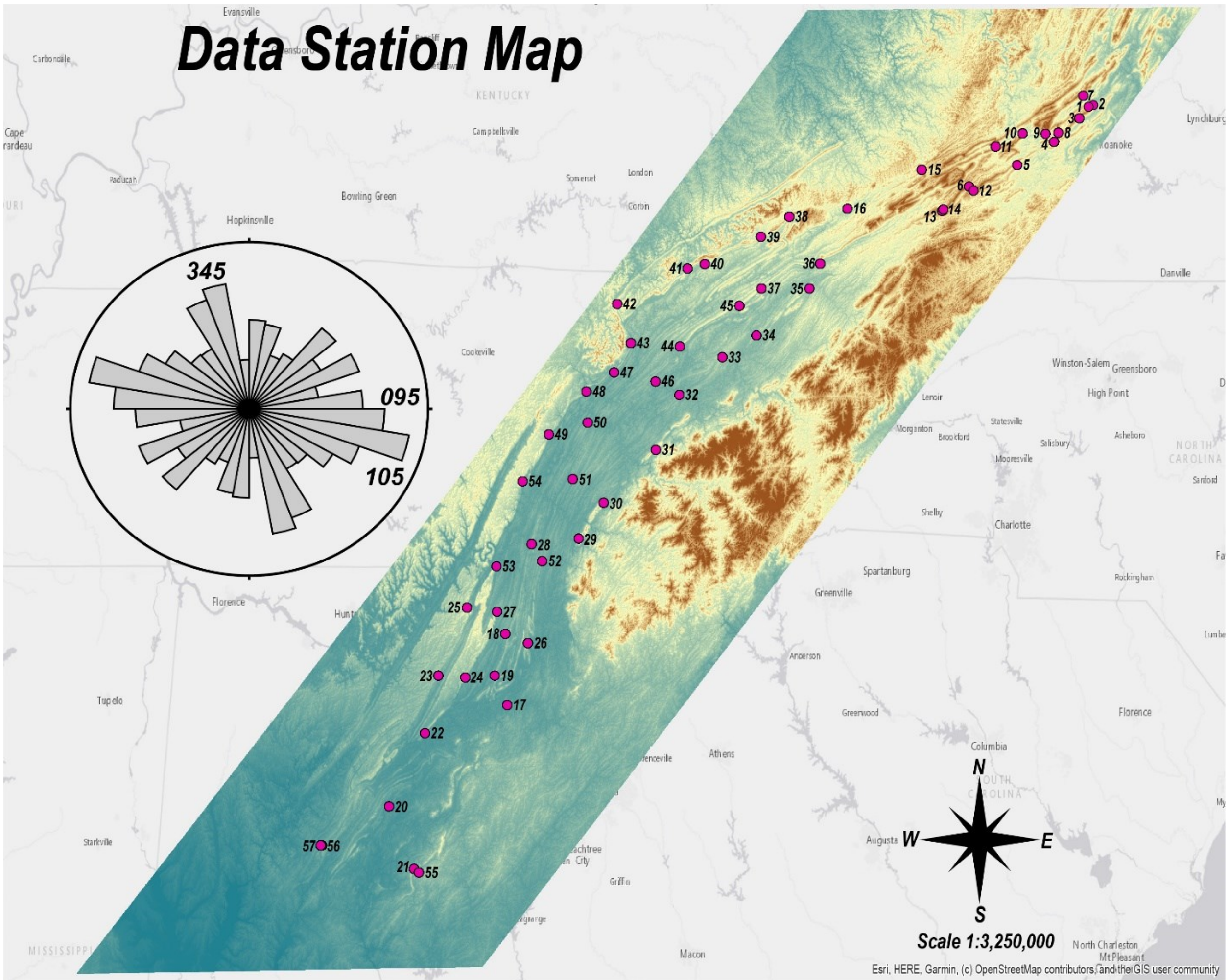

Figure 10. Joint data collected throughout the Valley and Ridge province from New Castle, Virginia to Birmingham, Alabama. Data stations are shown as pink circles with their corresponding station number (Table 1). Rose diagrams were created for each station's joint measurements (Table 2) but, a rose diagram displaying all of the joint measurements is presented here. A DEM of the research area was created using high resolution DEM data from the USGS 3DEP database (U.S. Geological Survey, 2020).

Joint Zones Defined by Basement Faults

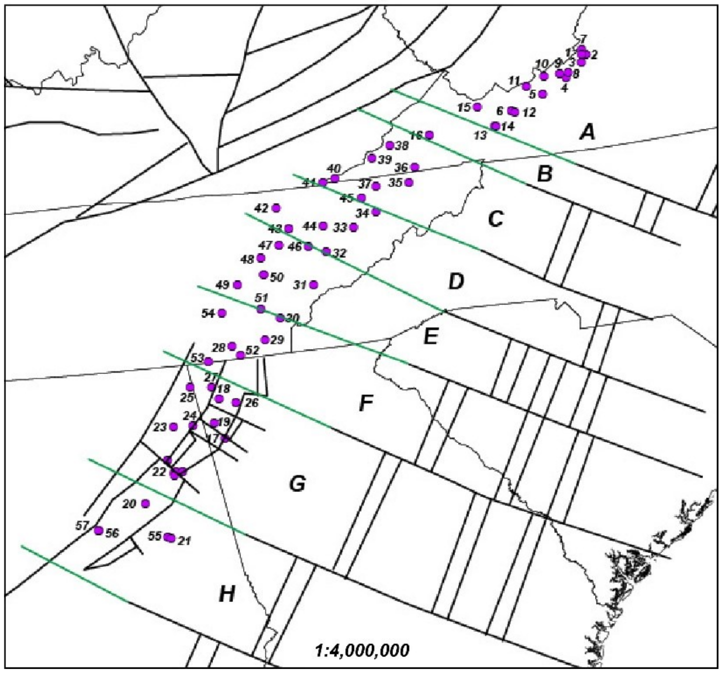

Figure 11. Data stations were divided into eight zones, A-H, based on the orientation of the Iapetan transform faults. Modified from Thomas, 2006.

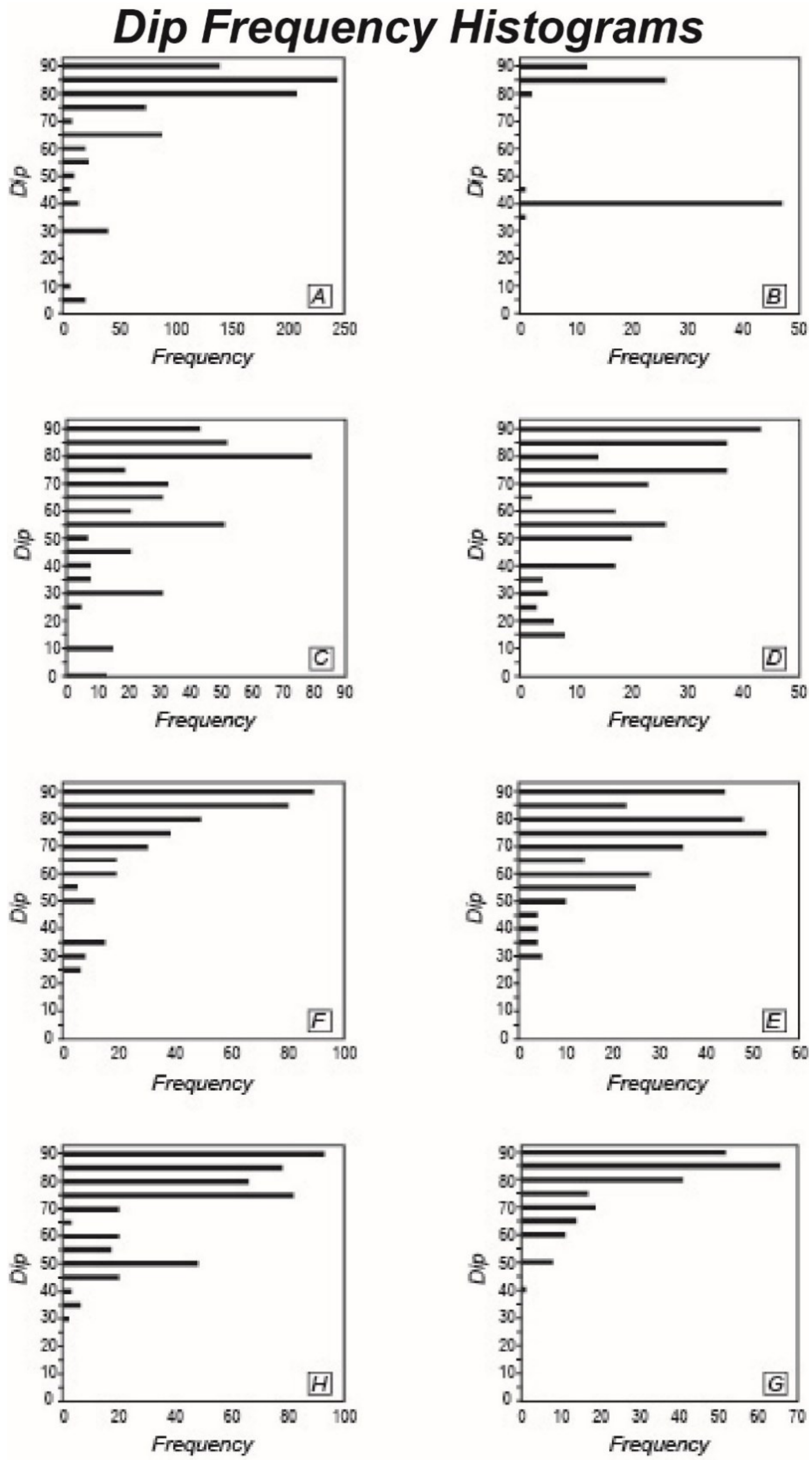

Figure 12. –The data stations were broken up into the following sections based on Figure 11 A: 1-15, B: 16, C: 35-41, 45, D: 32-34, 42-44, 46, E: 47-51, 31, F: 52-54, 28-30, G: 17-19, 22-27, and H: 20, 21, 55-57. The dip angles are located on the y-axis and the frequency is on the x-axis.

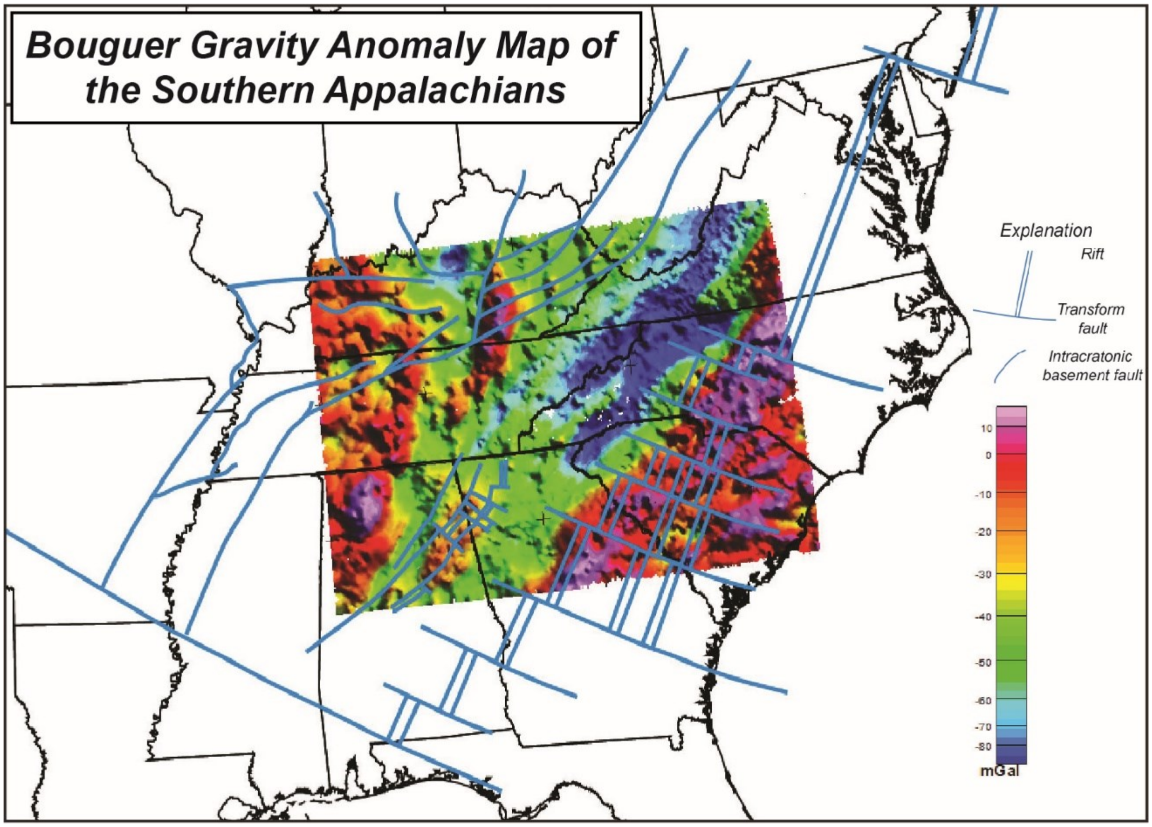

Figure 13. A gravity anomaly map was created for the southern Appalachians using data from the National Geospatial-Intelligence Agency. Basement faults (adapted from Thomas, 2006) are overlain on top of the gravity map in blue. Gravity map was created using the program Oasis Montaj (Geosoft Incorporated, 2021).

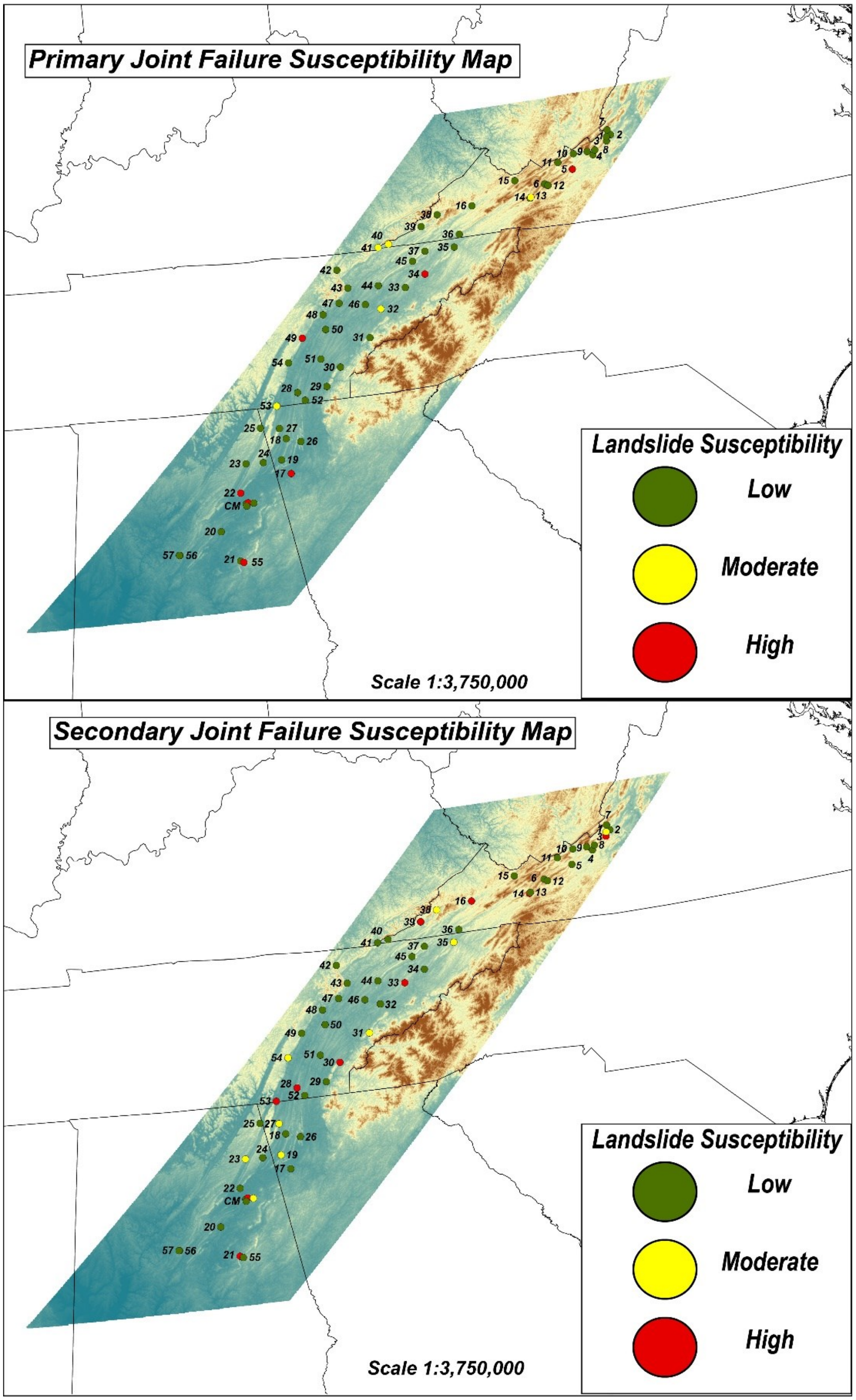

Figure 14. Susceptibility maps were created based on the difference between the average joint orientation and the strike of the ridge for each station. Table 1 and 2 show the workflow and color scheme for these maps, respectively.

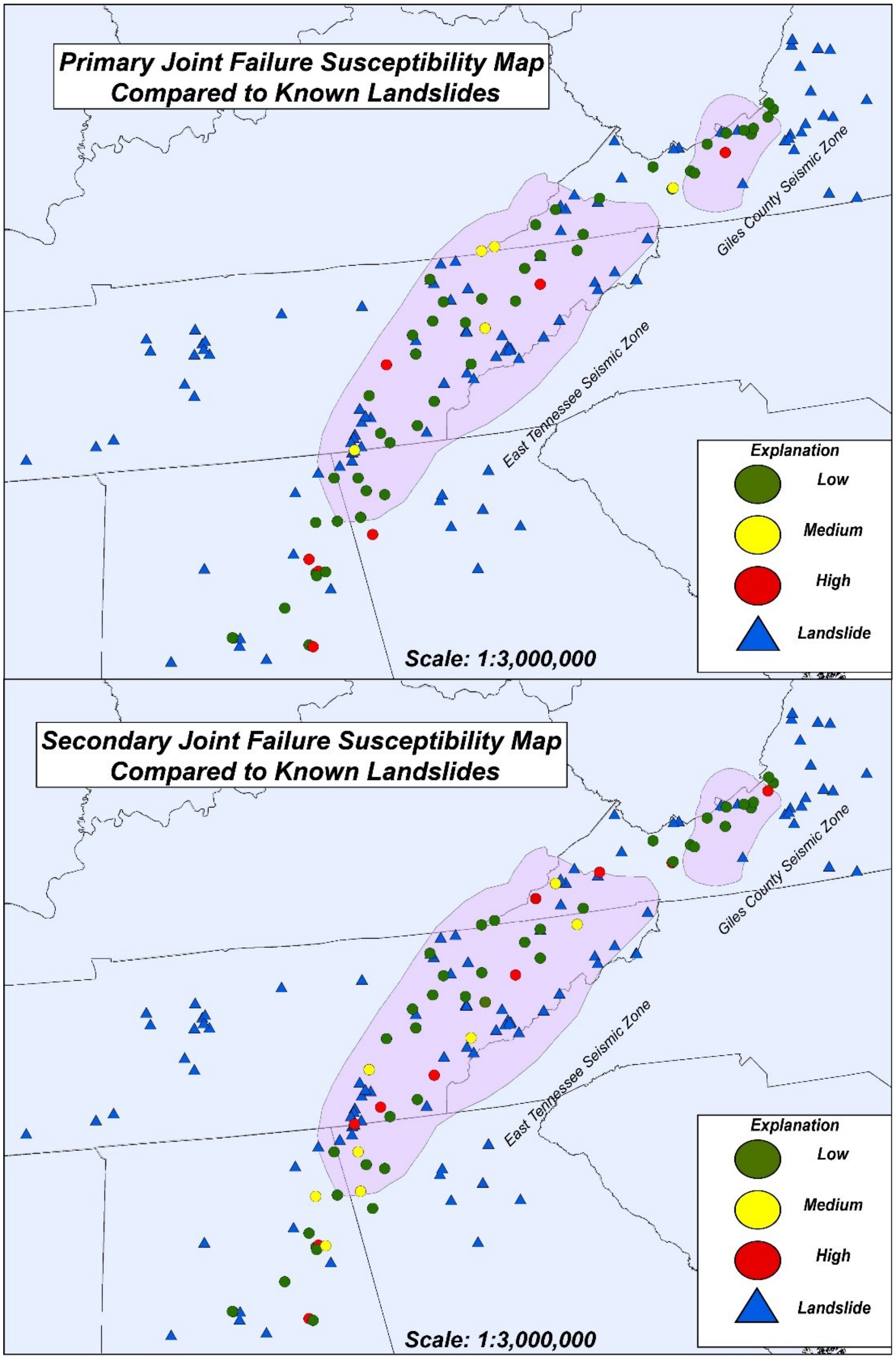

Figure 15. Documented landslides from the NASA Global Landslide Catalog (Kirschbaum et al., 2010; Kirschbaum et al., 2015) are symbolized as blue triangles and are overlain on top of the susceptibility maps. The east Tennessee seismic zone and the Giles County seismic zone were modified from U.S. Geological Survey, 2016 and Division of Geology and Mineral Resources, 2015 are also overlain onto both susceptibility maps.

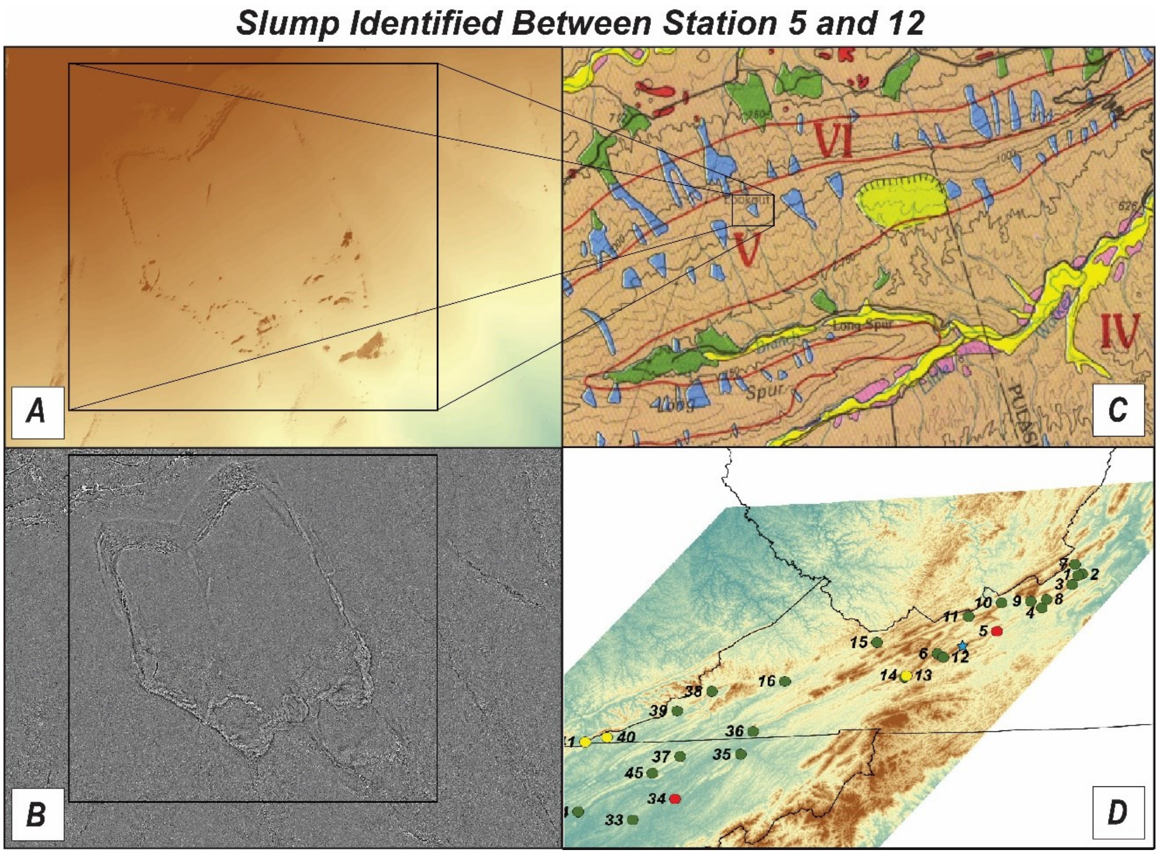

Figure 16. A large mass wasting event was initially identified using high resolution DEM data (A). The curvature tool was then used to construct a more defined image of the feature (B). Previous mappers identified the feature as colluvium and identified other landslides to the northeast along the same ridge (C). The feature is located on the dip slope of the ridge. The event is located between stations 5 and 12 and is represented by the blue star (D). Figure 17-C modified from Schultz et al., 1991. The workflow for A and B can be found in Table 1.

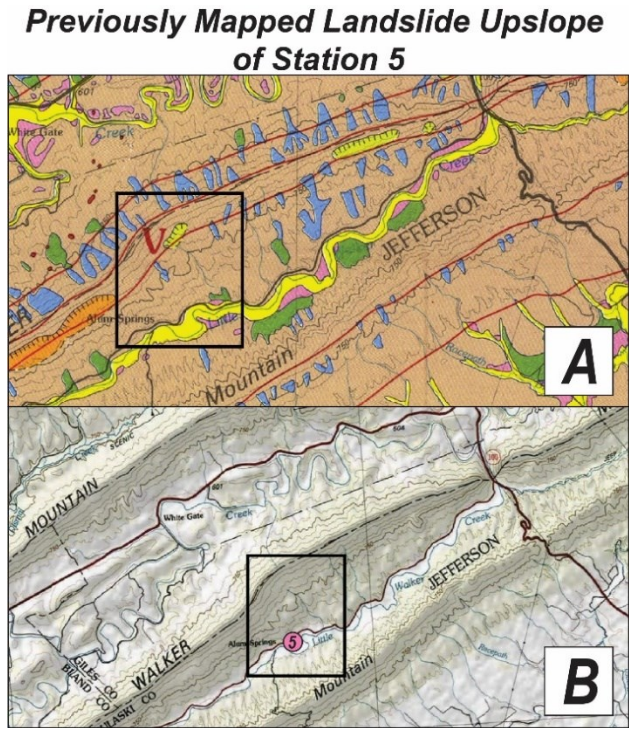

Figure 17. Previous mappers identified a small landslide (A) located upslope of station 5 (B). A modified from Schultz et al., 1991.

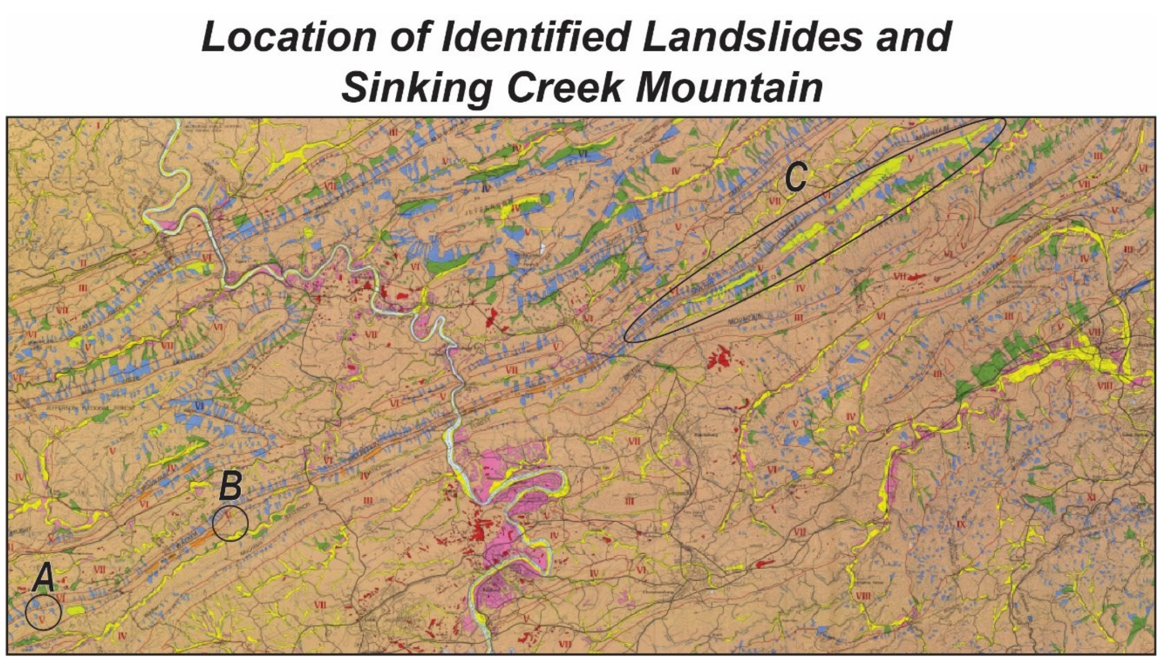

Figure 18. Landslides found between stations 5 and 12 (A) and the landslide documented at station 5 (B) are all within 60 miles along the same ridge as the Sinking Creek Mountain landslides (C). All the landslides are located on the dip slope of the ridge. Modified from Schultz et al., 1991.

DISCUSSION

Joint Timing and Propagation Mechanism

Basement faults formed from the creation of the Iapetus Ocean and the formation of five Alleghenian stress-fields may have largely influenced the orientation of joint propagation in the southern Appalachian Valley and Ridge Province. The regional basement structures, specifically the transform faults, and a large portion of the joint sets strike WNW to ESE with a few variations striking NE to SW (Figure 19). The primary and secondary joint orientations located in northeastern Alabama and northwestern Georgia predominantly strike at the same orientation as the intracratonic basement faults located within that region.

Based on the large range of dip angles for the north central sections (Figure 12- B, C, and D), it is interpreted that the joints formed during folding. The number of dips greater than 80^{o} may indicate jointing occurring at the very end of deformation. Both joint sets for section B, primary and secondary joint set of ~065^{o} and ~145^{o} respectively, have a similar joint orientation set as the fourth Alleghenian event as described by Bartholomew and Whitaker, (2010). The event is defined as the main southern Appalachian deformation event (Bartholomew and Whitaker, 2010) with a primary joint set trending 070^{o} and a secondary joint set trending 160^{o}.

Most of the joints in section C dip between 55^{o}-80^{o}, suggesting joints formed during folding. The primary and secondary joint orientations strike WNW-ESE, parallel to the Iapetus basement transform faults and a late southern Appalachian event which is defined as the last Alleghenian deformation event (Bartholomew and Whitaker, 2010). Two data stations in section C have primary and secondary joint sets trending NE-SW, similar to the Appalachian wide stress

field which formed before deformation began during the Alleghenian orogeny (Engelder and Whitaker, 2006), and may explain the handful of joints with dips less than 40º.

Section D has a similar dip variation as section C, suggesting that the majority of the joints formed during folding with outliers forming pre- and post-folding. Based on the primary and secondary joint orientation sets of 105º and 095º respectively, it can be interpreted that these joints formed during the last southern Appalachian event (Bartholomew and Whitaker, 2010) and may be influenced by the basement transform faults.

The joints in the south-central sections (Figure 12 E and F) are suggested to have formed either during or after deformation. Both the average primary joint set (~092º) and the average secondary joint set (~093º) for section E are striking at a similar orientation as the basement faults and the final southern Appalachian event, suggesting propagation during the creation this stress field. Section F has an average primary set striking sub-parallel with the basement faults at ~098º. The secondary joint set is striking sub-parallel with the main and final southern Appalachian events at ~080º. These are the final two stress fields of the Alleghenian orogeny (Bartholomew and Whitaker, 2010) and are suggested to be the mechanism for which joints propagated in section F.

The joints measured in the northern most and southern most sections of Figure 15 (A, G, and H) are suggested to have formed post-deformation based on the high dip angles. Based on predominatly NW striking joints (Figure 20), it can be interpreted that the basement faults influenced the propagation of these joints. Specifically, the Birmingham graben in Alabama and Georgia may largely be influencing both the primary and secondary joint sets in sections G and H based on the joint orientations in Figure 19. The less prominent NE striking joints of section A

may be linked to the Giles County seismic zone as the stress field had a maximum horizontal compression of ~065º (Bartholomew and Whitaker, 2010).

Landslides Identified in High-Risk Zones

Sections A, G, and H, have the highest susceptibility for landslides based on the joint failure susceptibility maps. These areas are located outside of the main east Tennessee seismic zone where large earthquakes are infrequent and large landslides and mass wasting features have been identified in these sections. Two mass wasting features were identified in section A, located within ~60 mi of the Sinking Creek Mountain landslides which are some of the largest landslides, combined size of 100,000,000 m^3, within the Appalachian Mountains (Schultz, 1989).

The first mass wasting event was identified between station 5 and 12 (Figure 16-A, B, and D), located on the dip slope of the ridge, and was originally identified as colluvium by previous researchers (Schultz et al., 1991) (Figure 16-C). Previous researchers (Schultz et al., 1991) mapped the feature as smaller than what was identified in this study. Other large landslides were identified in the surrounding area along the dip slope, and the previous misidentification of this event may be due to the lack of technology at the time of mapping.

Farther to the northeast of this slide, another small landslide (Figure 17) was identified upslope of station 5 by the same researchers. The landslide is located on the same ridge as the previous slides and is located on the dip slope. Based on the previous identification of large landslides near these high susceptibility areas, it can be inferred joints are acting as a control of mass wasting events, mainly within the northern and southern portions of the Valley and Ridge province. Landslides documented by NASA are scattered across the Valley and Ridge province

(Figure 15), but most of these landslides were triggered by precipitation events (Kirschbaum et al., 2010; Kirschbaum et al., 2015).

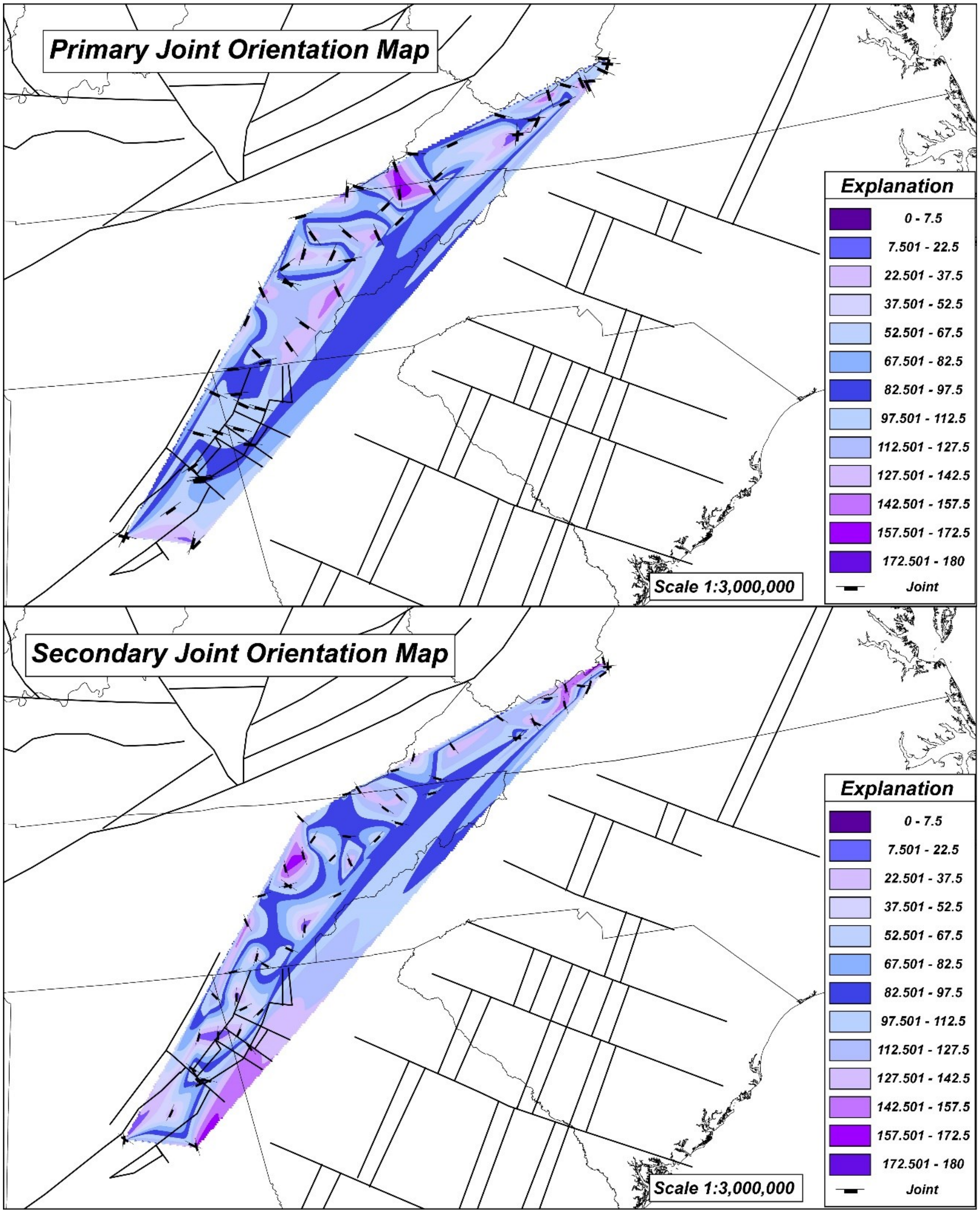

Figure 19. – Joint orientation maps were created to determine the regional strike of the region in relation to basement faults. The joint orientations were converted to the eastern quadrants. The stress maps were created using the nearest neighbor tool (Table 1) using a bin size of 15. Regional basement faults are overlain on top of the stress maps (modified from Thomas, 2006).

CONCLUSION

Joint orientation measurements were collected from New Castle, Virginia to Birmingham, Alabama to determine if the occurrence of joint-related landslides is prevalent throughout the Valley and Ridge province and if regional basement structures influence the orientation at which joints propagate. From the structural data, rose diagrams were constructed and the primary, and secondary joint orientations for each data station were determined. Regional stress maps and landslide susceptibility maps were created using the primary and secondary joint orientations. Areas identified as high-risk landslide zones were investigated for landslide features using high-resolution, LiDAR derived DEMs and mass wasting features were found in 3 of 7 high-risk zones in active seismic zones, demonstrating a tentative correlation between joint orientations and mass wasting susceptibility. The 3 mass wasting features were identified at the northern and southern most regions of the research area.

Regional stress maps were created to determine if basement structures had an influence over the orientation of joint propagation. Based on these maps, I interpret that the orientation of joints within the southern Valley and Ridge province are influenced by basement structures formed during the creation of the Iapetus rift margin during the breakup of Rodinia and the stress fields created during the collision of Laurentia and Gondwana. It can further be interpreted joint-controlled landslides are a common characteristic that is prevalent throughout the Valley and Ridge province with the highest-risk areas located in the very northern and southern portions. Joint controlled landslides have been identified in northeastern Alabama by previous researchers and mass wasting features have been identified in high-risk areas of southwestern Virginia from data collected in this study.

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APPENDIX

Joint Data

Joint				Bedding				
Station	Strike	Dip	Dip Direction	Strike	Dip	Dip Direction	Easting	Northing
1	205	80	SW	283	2	NW	572245	4147559
1	190	85	SW					
1	190	86	SW					
1	195	84	SW					
1	195	84	SW					
1	195	84	SW					
1	195	84	SW					
1	195	84	SW					
1	195	84	SW					
1	195	84	SW					
1	195	84	SW					
1	195	84	SW					
1	195	84	SW					
1	195	84	SW					
1	86	86	SSE					
1	81	86	SSE					
1	84	86	SSE					
1	84	86	SSE					
1	84	86	SSE					
1	84	86	SSE					
1	84	86	SSE					
1	84	86	SSE					
2	90	84	S	250	15	SE	575992	4149398
2	270	84	S					
2	272	85	S					
2	271	84	S					
2	271	84	S					
2	271	84	S					
2	271	84	S					
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2	271	84	S
2	271	84	S
2	271	84	S
2	271	84	S
2	271	84	S
2	271	84	S
2	182	65	W
2	176	65	WSW
2	175	65	WSW
2	178	65	WSW
2	178	65	WSW
2	178	65	WSW
2	178	65	WSW
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2	178	65	WSW					
2	178	65	WSW					
2	178	65	WSW					
2	178	65	WSW					
2	211	88	SE					
2	210	70	NW					
2	210	79	SE					
2	210	79	SE					
2	210	79	SE					
2	210	79	SE					
2	210	79	SE					
2	210	79	SE					
2	210	79	SE					
2	210	79	SE					
2	210	79	SE					
2	86	83	ENE					
3	31	82	SE	52	21	SE	565738	4140733
3	31	82	SE					
3	31	82	SE					
3	31	82	SE					
3	31	82	SE					
3	31	82	SE					
3	210	81	SE					
3	30	89	NW					
3	32	76	SE					
3	295	82	NE					
3	295	82	NE					
3	295	82	NE					
3	295	82	NE					
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3	295	82	NE					
3	295	82	NE					
3	295	82	NE					
3	300	76	NE					
3	293	85	NE					
3	293	84	NE					
3	262	67	NNE					
3	236	77	NW					
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3	244	77	NW					
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3	234	80	NW					
4	337	76	SW	63	52	SE	546273	4126579
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4	337	76	SW					
4	337	76	SW					
4	337	76	SW					
4	336	80	SW					
4	348	72	SW					
4	327	76	SW					
4	205	42	SE					
4	205	42	SE					
4	205	42	SE					
4	205	42	SE					
4	205	42	SE					
4	205	42	SE					
4	15	54	NW					
4	215	30	SE					
4	84	40	NW					
4	84	40	NW					
4	84	40	NW					
5	64	76.5	SE	250	23	SE	517832	4112733
5	64	76.5	SE					
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5	64	76.5	SE					
5	64	76.5	SE					
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5	64	76.5	SE					
5	64	76.5	SE					
5	64	76.5	SE					
5	63	71	SE					

5	65	82	SE					
5	164	82	SW					
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5	164	82	SW					
5	163	79	SW					
5	345	85	NE					
6	82	83	NW	215	5	SE	480470	4100164
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6	82	83	NW					
6	82	83	NW					
6	82	83	NW					
6	85	86	NNW					
6	80	81	NW					
6	154	81	NE					
6	154	81	NE					
6	154	81	NE					
6	154	81	NE					
6	154	81	NE					
6	154	81	NE					
6	154	81	NE					
6	154	83	NE					
6	154	79	NE					
6	294	85	NE					
7	340	77	NE	62	57	SE	568518	4154000
7	340	77	NE					
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7	340	77	NE
7	340	77	NE
7	340	77	NE
7	340	77	NE
7	348	75	ENE
7	340	75	SW
7	330	80	NE
7	272	64	NE
7	272	64	NE
7	272	64	NE
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7	272	64	NE
7	98	55	NE
7	276	68	NE
7	11	82	SE
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7	18	85	SE					
7	4	80	SE					
8	82	75	NW	228	45	SW	549620	4132019
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8	82	75	NW					
8	84	70	NW					
8	80	81	NW					
8	133	75	NW					
8	133	75	NW					
8	133	75	NW					
8	133	75	NW					
8	133	75	NW					
8	133	75	NW					
8	130	79	NE					
8	137	85	NE					
8	198	84	SE					
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