University of North Carolina Asheville
Journal of Undergraduate Research
Asheville, North Carolina
December 2021

Cenozoic Lineaments And Associated Fractures In The Spruce Pine 7.5-Minute Quadrangle, Western North Carolina: Interplay Between Bedrock Fabrics And Fractures Associated With Modern Uplift Of The Southern Appalachians.

Megan Palmer
Environmental Studies, Earth Science,
The University of North Carolina at Asheville
One University Heights
Asheville, North Carolina 28804 USA

Faculty Advisor: Dr. Jackie Langille

Abstract

There are multiple linear fracture systems (lineaments) exposed across western North Carolina that are associated with Cenozoic topographic rejuvenation of the Appalachian Mountains. These fracture systems are composed of joints and faults that strike obliquely to the rock units across the region. This obliquity along with previous constraints on the direction of fault motion, knickpoints along stream channels, and paleostress analysis suggests that these fracture systems are not associated with the Paleozoic assembly of Pangea, but are in fact likely much younger. One of these lineaments, the Laurel Creek Lineament, which extends from Hot Springs, NC east toward Spruce Pine, NC has not been previously mapped. An earthquake on fractures associated with this lineament in 2005 suggests it is still an active fault system. This study included geologic field mapping of rock units and fractures in the Spruce Pine 7.5-minute quadrangle to document fractures, fault offsets, and the direction of fault motion. Vertical joints and faults are exposed throughout the entirety of the quadrangle and dominantly strike toward 080/260°. However, these fractures are denser around the topographic lineament that extends through the town of Spruce Pine. The majority of the fractures found in Spruce Pine exhibited no offsets and offsets that were found were inches to meters in magnitude. Fault slickenlines and offset soil or rock units suggest that the north block moved up relative to the south block. Previous studies on the Boone Lineament, north of Spruce Pine, showed that the fracture system moved with the south side up. These data indicate that the block of crust between the Boone Lineament and the Laurel Creek Lineament has been uplifted by these fracture systems, resulting in the high topography around Grandfather Mountain which is within this uplifted block.

1. Introduction

1.1 Paleozoic Geologic History

Rocks exposed in the Appalachian Mountains record three mountain-building events known as orogenies, associated with the assembly of Pangea, giving it a unique and complicated history. Starting approximately ~450 million years ago, a chain of island arcs were accreted onto Laurentia. This is known as the Taconic orogeny. ~350 million years ago, the Neoacadian orogeny began in the southern Appalachians and resulted in the accretion of more crust onto Laurentia. The last orogeny to take place was the Alleghanian, where Gondwana collided with North America forming various faults ~330 million years ago, culminating in the Pangea supercontinent.[1] The Burnsville fault is an example of a Neoacadian fault in western North Carolina, known for being a high-grade dextral strike-slip fault zone.[2] This fault, and others that resulted from these orogenies strike dominantly NE-SW.[3]

Following the rifting of Pangea ~240 million years ago, the mountains have been considered to have low seismic activity without any uplift occurring. The mountains that remained have been slowly eroding away leading many people to believe these mountains are geologically dead.[4] However, geomorphological and structural evidence suggests that Cenozoic uplift has occurred along the belt of high topography within the Blue Ridge Mountains of western North Carolina and the Valley and Ridge of Virginia and is potentially due to delamination of the lower crust, resulting in rejuvenation of the topography.[5]

1.2 Cenozoic Lineaments

Throughout western North Carolina, there are various sets of linear topographic lows known as lineaments. These lineaments are fracture systems exposed on the surface in topography. These lineament systems have not been widely studied and more is required to fully understand their kinematic history and evaluate how they affect topography in the region. Hill (2013) found that the Swannanoa Lineament, which is exposed from Fontana Lake, east through Asheville and Swannanoa, contains abundant joints and faults that strike east-west, oblique to the structures that are attributed to the assembly of Pangea. Such lineaments bound blocks of crust that have their own spatial and temporal uplift history, rather than all uplifting uniformly. Blocks contain fracture zones that have some seismic activity (Figure 1).[5] In 2005, an earthquake occurred in Hot Springs, NC along the Laurel Creek Lineament which shows that this is an active fault. In 2020, Sparta, NC faced a 5.1 magnitude earthquake that also occurred along an east-west oriented lineament system.[6]

The Laurel Creek Lineament extends east from Hot Springs, NC to Spruce Pine, NC (Figure 2A). Near Spruce Pine, it cuts through medium to high-grade metamorphic rocks of the Ashe Metamorphic Suite, which originated as sediment on the Iapetus ocean floor prior to the Taconic orogeny.[7] While the topography suggests that the lineament extends through Spruce Pine, it has not been mapped there.

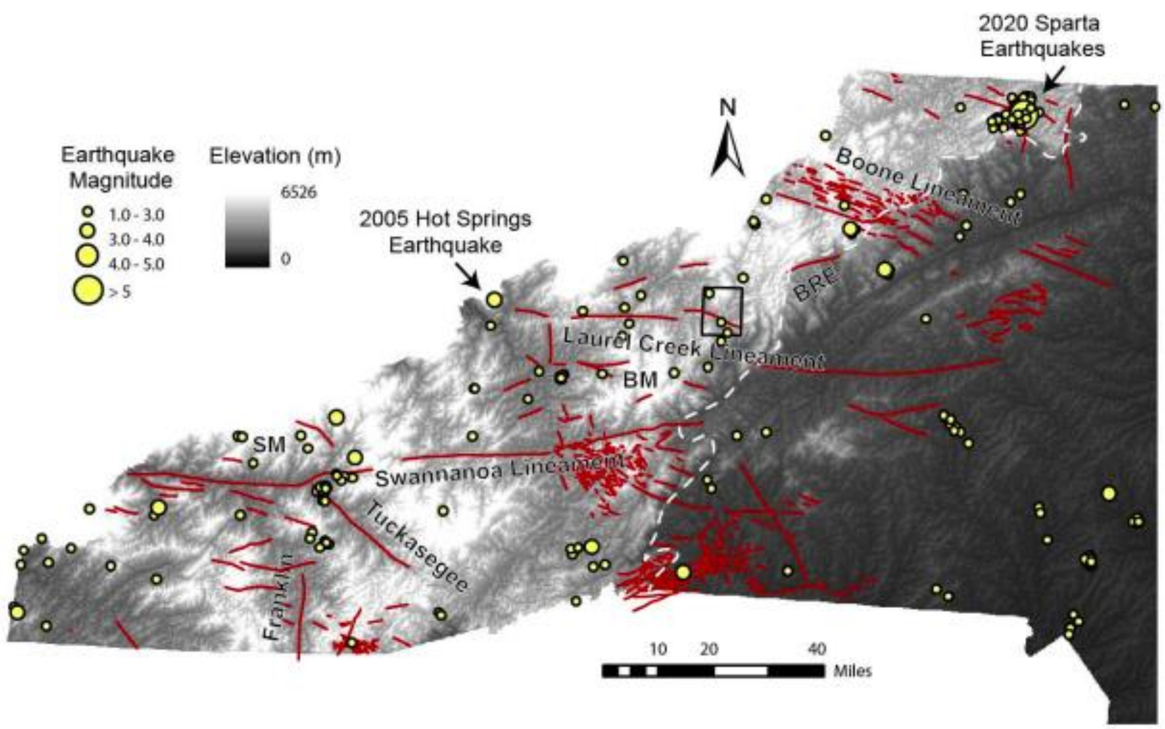

Figure 1. Lineaments and fractures in western North Carolina (red) with earthquakes from USGS. The black rectangle shows the Spruce Pine 7.5- minute quadrangle from this study[10].

1.3 Previous studies within the Spruce Pine Quadrangle

Brobst (1962) previously mapped the bedrock in the Spruce Pine Quadrangle at a 1:100,000 scale (Figure 2). Their map was completed at a larger scale, so they had fewer data points meaning there were loose constraints on bedrock.

This map did not include the section southeast of the Blue Ridge Parkway. The NCGS had previously completed a geologic map in 1944[8] mainly focused around the pegmatites. Borella (2000) mapped the Crabtree-Penland fault

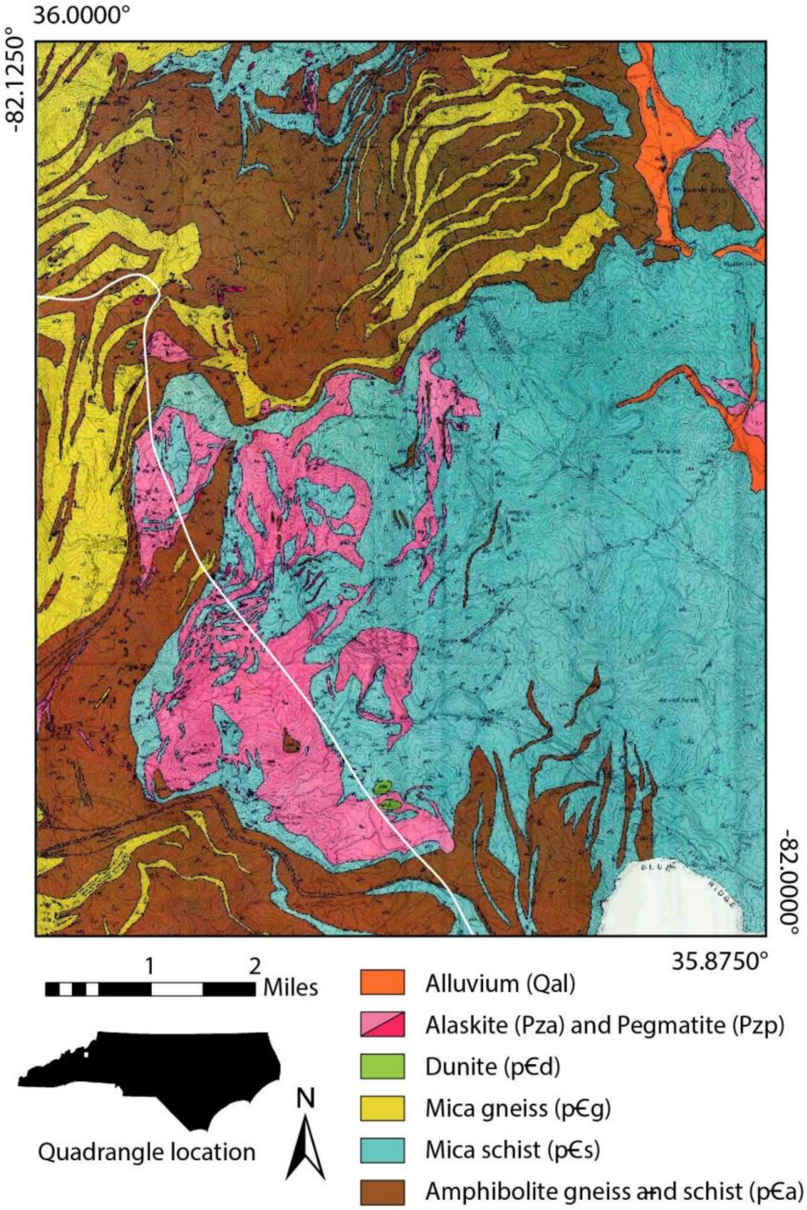

Figure 2: Previously published geologic map of the quadrangle was done by Brobst (1962).[11] White polygon outlines Crabtree-Penland fault done by Borella (2000).[9]

zone in the southwest portion of the quadrangle to document the cause of chloritized rocks of the AMS, which occur in mylonite. The mylonitic fault zone was constrained as late Alleghanian in age. Borella reported some NW-SE trending faults that all post-dated folding, but determined that the fractures were unrelated to the Alleghanian fault zone.[9] The Laurel Creek Lineament and associated fractures in the quadrangle have not been previously mapped.

1.4 Purpose of study

This study was conducted to test the hypothesis that the Laurel Creek Lineament extends through Spruce Pine as suggested by the topography. The goals were to map the lineament and related fractures within the Spruce Pine quadrangle, document fault offset, and constrain the direction of motion. This was done through geologic field mapping of joints, faults, and bedrock. Bedrock was mapped in addition to the lineament fractures to see if there are any map scale offsets. Additionally, lithology and fractures have some control on topographic features so evaluating whether the topography was controlled by fractures or rock type aided in identification of faults and fractures.

2. Methods

Rock type and structural data of foliations, joints, and faults in Spruce Pine were collected in the field with FieldMove on an IPad over six weeks in the summer of 2021. Every road or trail accessible was traversed. Rock outcrops were found along the trails, roads, and within private property when granted access. To aid in identifying the location of rock outcrops, 1-m per pixel resolution LiDAR elevation data was used. At all outcrops that could be accessed, the rock type and orientations of the foliation, fractures, faults, and fault striations were documented where exhibited in the rocks. GPS locations were logged for each location. Horizontal accuracies for the GPS unit were ~3 to 5 m. Rock contacts previously mapped by Borella and Brobst were remapped or more precisely constrained with the addition of more foliation data. This data was used to construct a geologic map at a 1:24,000 scale (Fig. 3). The map was overlaid on a USGS topographic base map. The mapping project mainly focused on documenting joints and faults and if there were any fault striations indicating slip direction.

3. Results

3.1 Rock Unit Descriptions

The units in the field area include granodiorite (Pzg) and pegmatite (Pzp) of the Silurian-Devonian Spruce Pine plutonic suite and the Ashe Metamorphic Suite (AMS). Pzg includes granodiorite which is medium to coarse-grained and dominantly composed of quartz, plagioclase feldspar, and muscovite. It also contains some garnet. Pzp consists of coarse to large-grained pegmatite dominantly made of quartz, plagioclase feldspar, and muscovite. The AMS includes aluminous mica schist (Zas), Spruce Pine schist (Zsps), Spruce Pine metagreywacke (Zspg), dunite (Zad), biotite gneiss (Zbg), mica gneiss (Zmg), chloridized rock of the AMS (Zacs), and amphibolite (Zaa). Zas is a light grey, medium coarse-grained rock with muscovite, quartz, feldspar, garnet with some kyanite, amphibole, and biotite. This schist is well foliated. Zsps is a light to dark grey, coarse-grained schist with muscovite, biotite, quartz, feldspar, and garnet. Shear textures such as S-C fabrics are distinctive of this unit. Zspg is light to dark grey, moderately foliated, and composed of quartz, feldspar, muscovite, biotite, and traces of garnet. Zbg is dark grey to black with fine-grained minerals consisting of biotite, quartz, feldspar, and some amphibole. Garnet is only found in some samples. Zmg is a light to dark grey, fine to medium-grained gneiss with muscovite, biotite, quartz, feldspar, and garnet. The meta-igneous rocks consist of amphibolite (Zaa) which is a dark grey to black rock composed of amphibole, quartz, and feldspar. Quartz and feldspar were sheared out into bands with traces of hornblende. Zacs occurs in AMS rocks rich in biotite that were retrogressed to chlorite during Alleghanian ductile shearing[12].

Zsps and Zspg were originally mapped together as Zsps.[11] In the field, Zspg had notably more quartz and was less foliated than Zsps. Due to its higher competence, Zspg contained more jointing. The two units are interlayered (Figure 4A) but Zsps is more prominent near Pzg. These units also had some Zaa interlayered with Zmg (Figure 4B).

3.2 Structural Observations

The Laurel Creek Lineament which crosses through Spruce Pine is an east-west running lineament that can be seen throughout the quadrangle by joints and faults. Jointing was documented throughout the field area, but it was more noticeable in more competent units like Zaa, Zspg, and Pzg. Fractures are dominantly oriented east-west. Four faults had evidence of north side up faulting. Figure 5A shows an example of one of the faults documented in the field and exhibits a 19 inch offset within saprolitic Zsps. Fault slicks and offset rock units indicate the north block moved up along a high angle dip-slip fault. This fault strikes 270°. Tension gashes and a smaller fracture were also observed near the fault with a 1 cm offset (Figure 5B).

Much of the jointing observed occurred in the more competent rock units; Pzg, Zspg, and Zaa. Figure 6A shows jointing within Pzg in a quarry. Quartz and feldspar are some of the more competent minerals in the rocks within the field area and make up most of Pzg which fractures because it is more competent. In comparison, Zsps does not show fracturing as much due to the abundant mica which flexes and makes it less likely to break. In the same quarry, fault slicks were found within Zsps trending 265°. Figure 6B shows striations on fractures which parallel foliation.

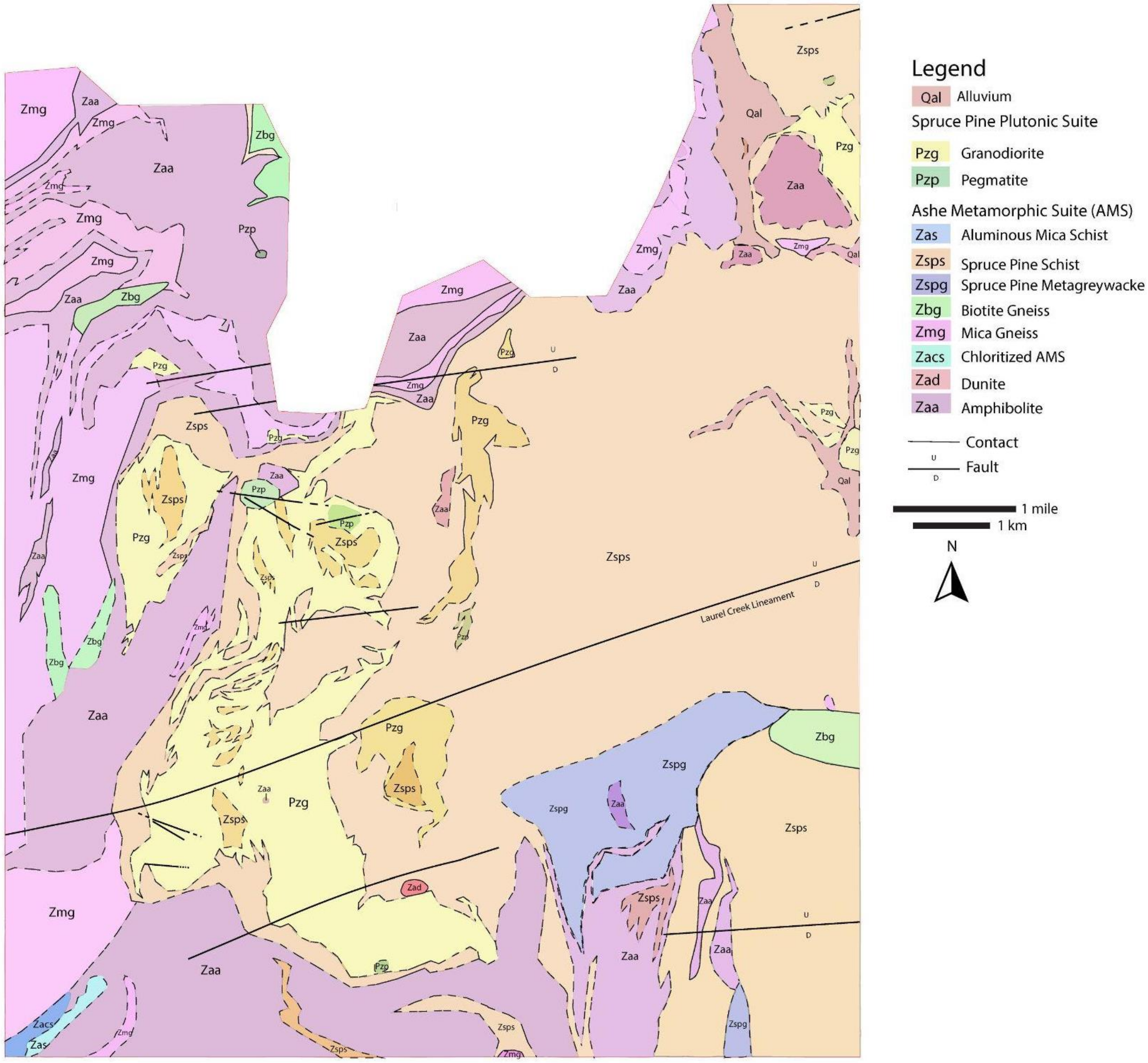

Figure 3. Updated geologic map of Spruce Pine 7.5- minute quadrangle based on this study.

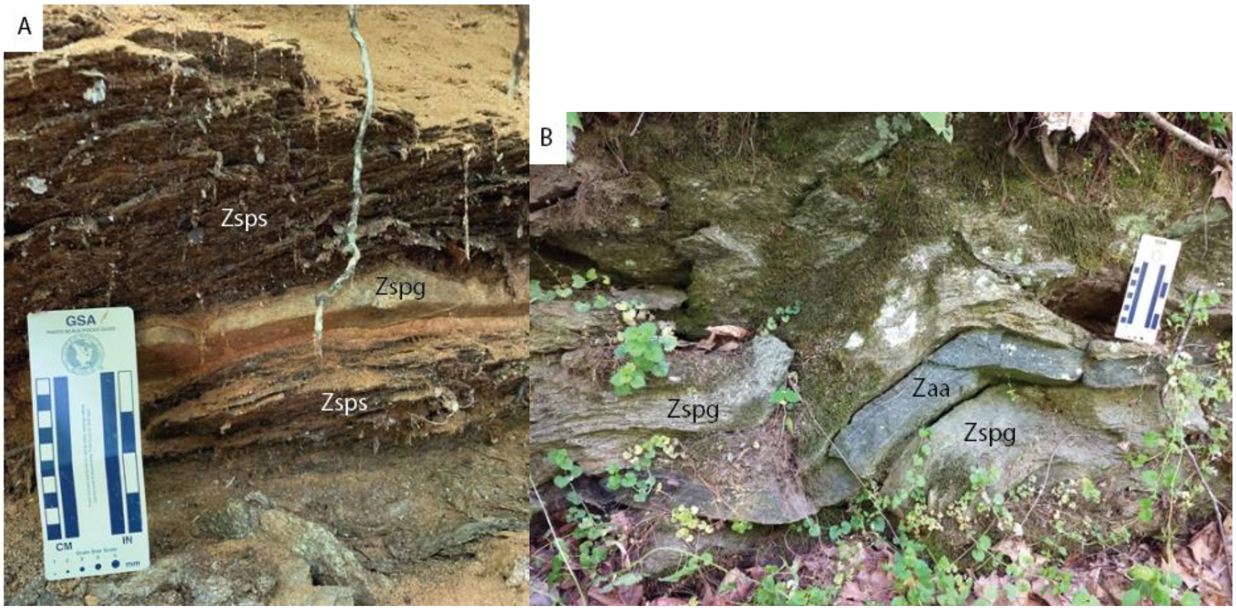

Figure 4 : (A) Relationship between Zsps and Zspg. (B) Folding of interlayered Zsps, Zspg, and Zaa.

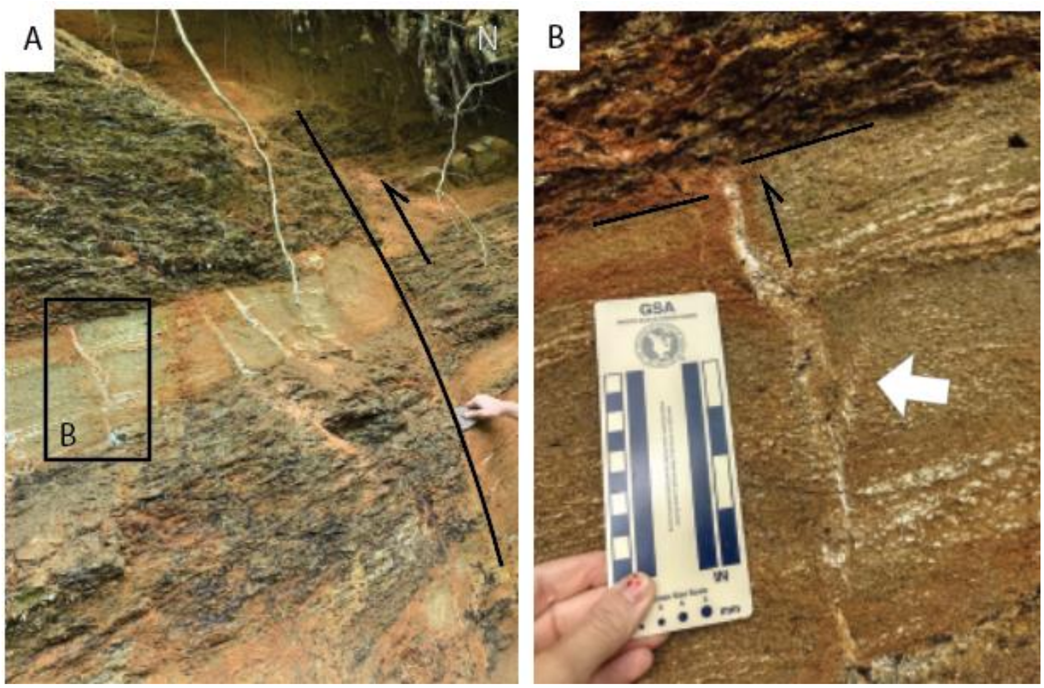

Figure 5: (A) Steep reverse fault with 19 inches of offset with north block up. (B) Tension gashes (white arrow) and ~ 1 cm north side up offset.

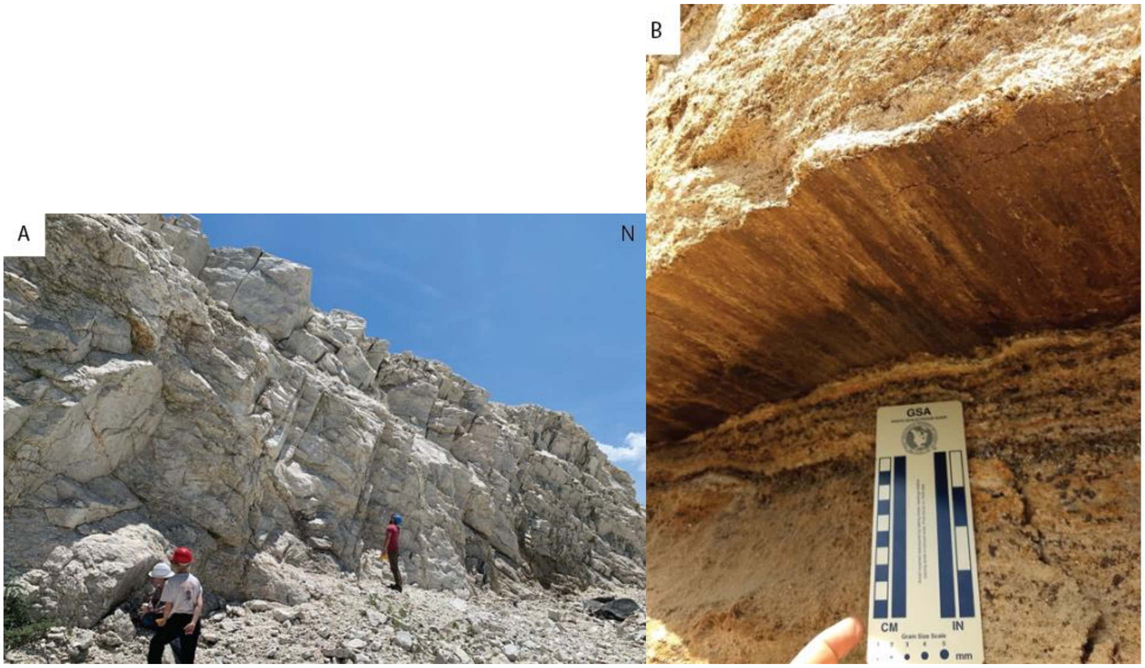

Figure 6: (A) East-west orientation of joints in the Pzg unit in Sullins Quarry. (B) Fault slicks trending 265 degrees plunging 18 degrees with east-west direction sliding in Sullins Quarry.

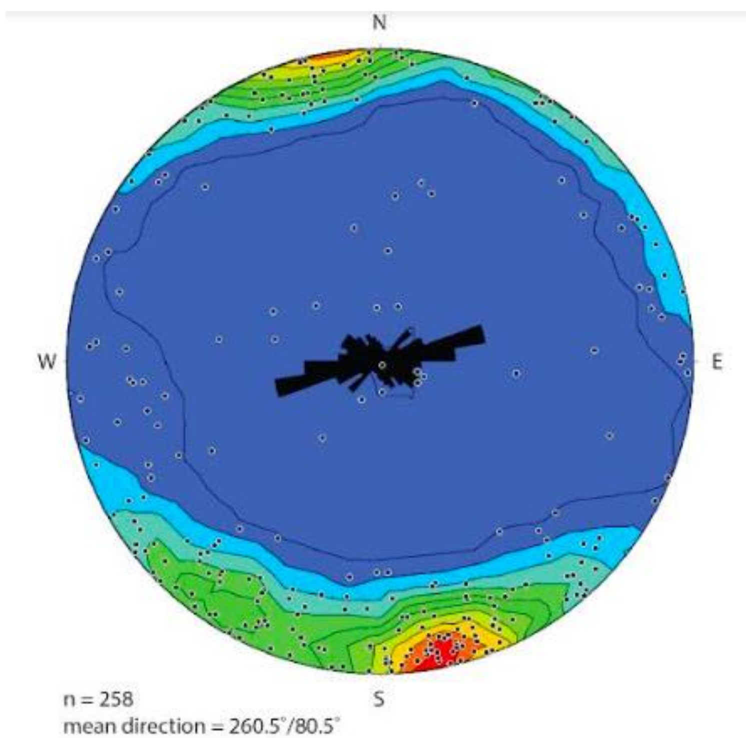

Figure 7. Orientations of joints and faults plotted as poles on a stereonet, red with highest densities and blue with lowest densities. A maximum density of 350° and 170° shows a dominant joint orientation of 080° and 260°. The black bars are a rose diagram of the joint strikes, also demonstrating this trend.

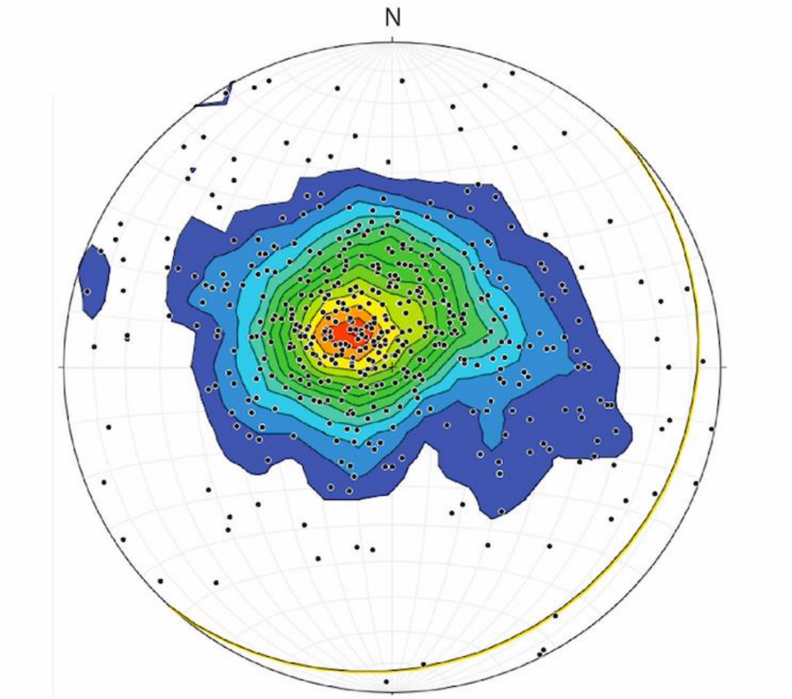

Figure 8. Orientation of foliation plotted as poles on a stereonet. The red shows where the points are densely concentrated, and the best-fit plane to that orientation is the yellow curved line.

258 orientation measurements were taken from joints and faults in the quadrangle. Poles to the planes were plotted on a stereonet and represented on a rose diagram (Figure 7). These data show that the dominant orientation of the joints and faults was toward 260° or 080°. Poles to the foliation planes were also plotted on a stereonet to interpret the dominant orientation (Figure 8). These data show that the dominant foliation orientation is 043° with a dip of 11° toward the SE.

4. Discussion

The Laurel Creek Lineament is within a the group of lineaments in western North Carolina responsible for the Cenozoic rejuvenation of the southern Appalachian Mountains. The lineaments are perpendicular to the Appalachian Mountains with an east-west orientation. Orogenic fault systems are relatively NE-SW oriented while lineaments are oriented east-west suggesting that the stresses that produced the lineament fractures is not the same stress that caused the faults during the assembly of Pangea[5]. Spruce Pine specifically contains various sets of joints, more densely located around the lineament with a mean strike orientation of 260° or 080°, parallel to the Laurel Creek Lineament (Figure 1 and 7). The dominant foliation orientation was 043°/11° dipping toward 133° (Figure 8). The fractures being parallel to the Laurel Creek Lineament support that these are associated with the lineament. The orientations of the fractures are oblique to the foliations, supporting the interpretation that the jointing is not associated with the older Paleozoic orogenies that produced the foliation and is younger.

Topographic uplift throughout the Cenozoic occurred by shifting of crustal blocks bound by the lineaments (Figure 1). The Boone fault, within the Boone Lineament, moved with the south side up[5]. Findings from this study suggest that the Laurel Creek Lineament moved with the north side up. This suggests that the crustal block between this lineament and the Boone Lineament uplifted by motion on these two lineaments. The higher topography of this block (Figure 1), which includes Grandfather Mountain, supports this interpretation.

Further studies along the Laurel Creek Lineament would be useful to understand earthquake and slope stability hazards associated with fractures. Additional studies that constrain when the lineament initiated is also needed to place this lineament in a chronologic history of the other lineaments.

5. Conclusion

This study within the 7.5-minute quadrangle of Spruce Pine determined that joints and faults associated with the Laurel Creek Lineament extend into this quadrangle. Joints and faults dominantly strike toward 080°/260°, parallel to the topographic lineament. Faults contained fault slicks that exhibited north side up motion with offsets ranging between cm to meter scale. These findings add to previous constraints on the Boone and Swannanoa Lineament and suggest lineaments are younger fracture systems with association to fault motion affecting the southern Appalachian Mountains. Additional work to constrain timing and direction of fault motion on the other lineaments will provide a spatial and temporal history of the evolution of uplift in the southern Appalachians.

6. Acknowledgements

The author wishes to express appreciation to Dr. Jackie Langille, the University of North Carolina at Asheville, Bart Cattanach and Jesse Hill from the NCGS, and to Jeremy Jurgevich and Chloe Green who assisted while conducting geologic mapping. This manuscript is submitted for publication with the understanding that the United States Government is authorized to reproduce and distribute reprints for governmental use. Supported by the U.S. Geological Survey, EDMAP Program, under assistance Award No. G21AC10439. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

7. References

1. Hatcher, R.D Jr., The Appalachian Origin: A brief summary, Department of Earth and Planetary Sciences and science alliance center of excellence, University of Tennessee, Knoxville, Tennessee 37996-1410, USA (2010): 1-14.
2. Trupe, C., Stewart K., Adams M., Waters, C., Miller B., and Hewitt L., The Burnsville Fault: Evidence for the timing and kinematics of southern Appalachian Acadian dextral transform tectonics: Geological Society of America Bulletin, V. 11 (2003).
3. Hill, S., Jesse, 2013, Zoned uplift of western North Carolina bounded by topographic lineaments, University of North Carolina Chapel Hill. https://doi.org/10/17615/16nt-xf06.
4. Clark, H.B., Sandra, 2001 Birth of the Mountains. The Geologic Story of the Southern Appalachian Mountains: U.S. Geological Survey, 16-20 p.
5. Hill, S., Jesse, 2018, Post-orogenic uplift, young faults, and mantle reorganization in the Appalachians, University of North Carolina Chapel Hill. https://doi.org/10.17615/rnrd-0d82.
6. Figueiredo, M., Paula et. al., 2020, Surface Deformation associated with the MW 5.1 Sparta, NC earthquake, Geological Society of America conference.
7. Abbott, Richard N. (1984), Raymond, Loren A., The Ashe Metamorphic Suite, northwest North Carolina: Metamorphism and observations on geologic histories, American Journal of Science, v. 284, p. 350-375.
8. Olson, J.C., 1944, Geologic maps of the Spruce Pine area and the Bandana area, Spruce Pine District, North Carolina: North Carolina Geological Survey, Bulletin 43, scale 1:1,320.
9. Borella, W., Josh, 2000, The Crabtree-Penland Fault zone: Investigating a new control on the macroscopic brittle-ductile transformation through mapping and related structural studies, University of North Carolina Chapel Hill.
10. Langille, J.M., 2021, Cenozoic lineaments and associated fractures within the Spruce Pine 7.5-minute quadrangle, western North Carolina: Interplay between bedrock fabrics and fractures associated with a modern uplift of the southern Appalachians, USGS EDMAP proposal.

11. Brobst, D.A., 1962, Geology of Spruce Pine district, Avery, Mitchell, and Yancey counties, North Carolina: U.S. Geological Survey, Bulletin B-1122-A, scale 1:24.000.