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# Knickpoint elevations within the Spruce Pine 7.5-minute quadrangle, NC: Implications for Miocene uplift of the Blue Ridge Province

Chloe Green
Earth Science
The University of North Carolina at Asheville
One University Heights
Asheville, North Carolina 28804 USA

Faculty Advisor: Dr. Jackie Langille

## Abstract

East-west-, southeast-northwest-, and north-south-trending lineaments within the Blue Ridge Province of Western North Carolina separate crustal blocks that record differential uplift throughout the Miocene. East-west oriented lineaments include, from north to south, the Boone, Laurel Creek, and Swannanoa lineaments. Relict topography and retreating knickpoints within stream channels that drain into these lineaments suggest the block between the Laurel Creek and Swannanoa lineaments uplifted first, followed by the block south of the Swannanoa Lineament, with the block south of the Boone lineament uplifting most recently. Previous research on the Laurel Creek Lineament, which extends from Hot Springs, NC east toward Spruce Pine, NC demonstrated that fractures within this lineament formed from a vertical maximum compressional stress consistent with the focal mechanism from a 2005 earthquake. This lineament parallels jointing found throughout the Spruce Pine 7.5-minute quadrangle, which dominantly strike toward 260°. Uplift-related knickpoints and other disequilibrium features have not been constrained on the block north of this lineament. This study utilized 1-m resolution LiDAR for the Spruce Pine 7.5-minute quadrangle to evaluate streams that drain into the lineament and place the blocks bounded by it into a chronological framework of uplift. Stream profiles were created for seven major stream systems: Little Bear Creek, Bear Creek, Graveyard Creek, Gouges Creek, Pyatt Creek, Jones Creek, and Beaver Creek. Twenty-four knickpoints discordant with lithologic contacts and anthropogenic disturbances were identified on streams flowing south into the lineament. The elevations of these knickpoints ranged from 780 to 1070 m, averaging 867 m (s.d. 70 m). A strong cluster (60%) of these knickpoints was found between 807 m to 874 m. This strong cluster in elevation is independent of lithology. Streams that flow north into the lineament do not exhibit disequilibrium. These data are consistent with previous research that suggests the block south of the Laurel Creek Lineament records an earlier uplift history and shows that the block north of this lineament likely uplifted concurrently with movement along the Boone Lineament.

## 1. Introduction

Southern Appalachian mountains have a complex geological history. The gentle slopes of the Blue Ridge mountain chain today are the remnants of a once Himalayan-scale belt that endured multiple Wilson cycles and three different Paleozoic orogenies.[3] As continents collide, mountain belts rise high, simultaneously forming deep roots under thickened lithosphere. Eventually, even the tallest belts collapse into rugged terrain, followed by rolling hills, and eventually plains once again.[3] The last major collisional event experienced by the Southeastern United States ended around 270 Ma. Tectonic forcing conversed as this region entered a phase of continental rifting around 200 Ma, the rifting of Pangea, which led to widespread volcanism and the opening of the Atlantic Ocean basin.[1,3] The Appalachian mountains' location on the interior of the North American plate away from the active plate margin presumes a generally inactive geologic area dominated by the passive processes of erosion and sedimentation, however, throughout the region of Western North Carolina disequilibrium features, active landscape characteristics, modern seismic activity, and enigmatic fracture zones point to active settings in this region, in the absence of tectonic forcing.[2,5]

Distinct topographic disequilibrium features, including retreating knickpoints along river profiles, have been linked with linear topographic lows (known as lineaments) indicative of zonal uplift in Western North Carolina. Uplift-related knickpoints and other disequilibrium features, which provide insight to the chronological framework of blocks bound by these lineaments, have not yet been constrained on the block north of the Laurel Creek Lineament. This study seeks to conduct the research required to evaluate the streams contained by the Spruce Pine 7.5-minute quadrangle that drains into the Laurel Creek lineament and place the blocks bounded by it into a chronological framework.

## 2. **Unexplained Structures and Mantle Rejuvenation**

The progression of topographic decay in post-orogenic mountain ranges is poorly understood and largely debated. We know relatively little about the processes that can occur post rifting in a passive margin setting, yet are presented substantial evidence of tectonic activism in this region. Evidence of an uplift found through this region suggests the topography of Southern Appalachians exists as a dynamic landscape, although the mechanisms of this perceived uplift remain enigmatic. Two main hypotheses seek to uncover the processes driving landscape evolution in the Southern Appalachians and explain their current state.[2] One explanation is that topography exists in an unsettled dynamic equilibrium primarily dependent on the variable erodibility of rock units throughout the regional fabric.[2] The other explanation is that topographic rejuvenation has advanced throughout the ancient mountain range, driven by climate change or mantle forcing.[2]

Gallen et al. explored the competing hypotheses of dynamic equilibrium and topographic rejuvenation by analyzing the Cullasaja River basin of North Carolina.[2] This research found the relict landscape above the Cullasaja River (which eventually drains into the Swannanoa lineament) has increased by >150% since the Miocene.[2] They also explored the existence of "transient knickpoints," key indicators of uplift, that independently incise the relict topography.[2] The authors propose that these indications of uplift, topographic rejuvenation, and the rise of relict topography are due to the delamination of the lithospheric mantle under the Southeastern United States.[2] They eliminate climate change as the driving mechanism, as the timing is not consistent with the records of topographic rejuvenation found within the basin.[2]

Recent studies suggest lithospheric foundering as the driving mechanism for active seismicity, uplifting, and young intraplate volcanism. Biryol et. al used teleseismic body wave tomography to image the upper mantle beneath the Southeastern United States in order to investigate the potential for delamination of the lower lithosphere**.**[1] This research followed the relatively thick lithospheric mantle of the North American plate and documented an abrupt thinning of the mantle beneath the Paleozoic Appalachian orogeny.[1] The tomographic model presented by Biryol et. al reveals a heterogeneous upper mantle beneath the Southeastern United States with significant lithospheric variations.[1] Based on these observations and evidence of fast seismic velocity patterns indicative of ongoing lithospheric foundering, this study suggests foundering in the lithospheric mantle as the mechanism for modern variable tectonism occurring across the region.[1] Furthermore, this research addressed the structural topography of the Southern Appalachian as both the product of complex interactions between the existing tectonic and geological fabric of the region and the active dynamic attributes of the region.[1]

Geomorphic research further supports the mechanism of mantle rejuvenation by delamination. Hill exhibited that 15-25 km of delaminated eclogitic root underneath the Southeastern region would result in uplift by 450-750m.[4] These values are consistent with uplift measurements previously found in geomorphic studies.[4] Furthermore, Hill presented geomorphic maps that show how the geomorphology of Western North Carolina is not solely correspondent to its lithology, providing examples where rugged topography exists free of influence from the underlying bedrock.[4] This opposes a system of dynamic equilibrium by differential erosion as the primary driver. Hill and other geologists propose mantle rejuvenation as the main driver of the Southern Appalachian topography we currently observe today, claiming it may also be the source of topographic lineaments that crosscut the belt, parallel young faults, and are clustered by earthquake epicenters.[1,2,3,4,5]

3. **Lineament Block Theory**

Although little is understood about the post-orogenic processes that occur within plate interiors under a passive margin, Western North Carolina contains a series of low-lying linear features called lineaments, which record a system of post-orogenic fracturing and uplift. The lineaments trend east-west, southeast-northwest, and north-south throughout the Western North Carolina Blue Ridge Province. East-west oriented lineaments found in the Western North Carolina region include, from north to south, the Boone, Laurel Creek, and Swannanoa lineaments. The regional bedrock fabric of the southern Appalachian orogenic belt trends SW-NE. The orientation of the lineaments crosscut the regional fabric, which reveals they are younger than the main orogenic belt, although the approximate age of their formation remains enigmatic.[5,4]

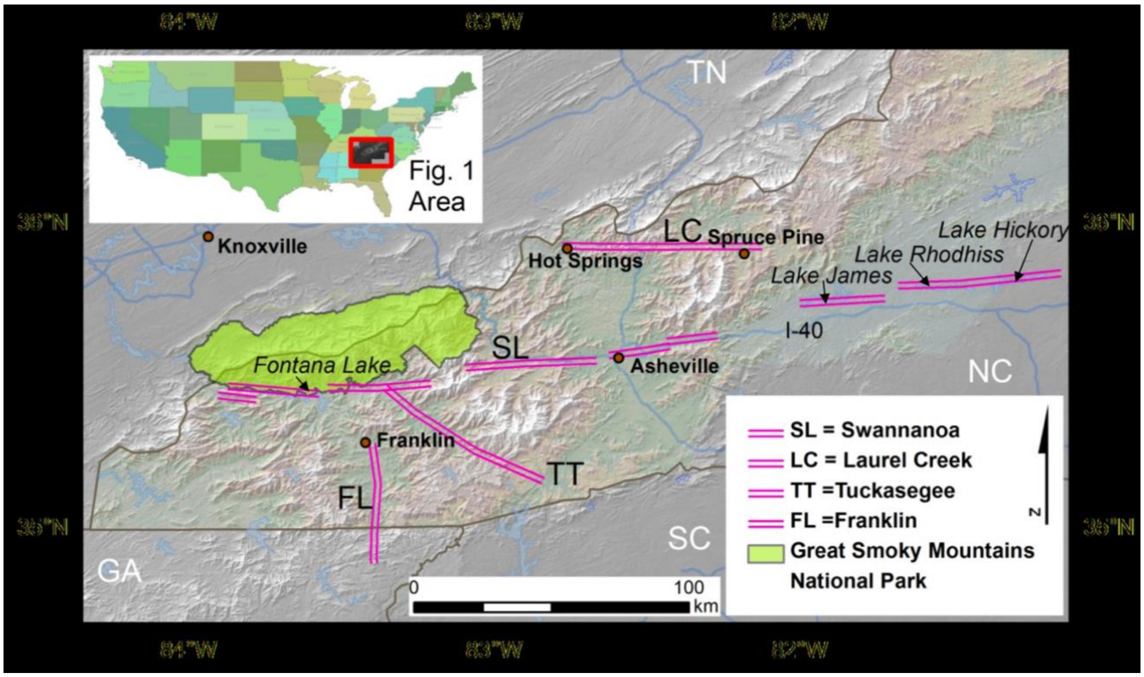


Figure 1. Western North Carolina topographic lineaments
Image from Hill (2013).

Hill suggests that the lineaments developed as borderlines between large crustatial blocks that uplifted sequentially sometime in the Miocene.[3] Rather than synchronous uplift occurring uniformly along the crust, differential uplift occurred on a chronological basis as separate zones constrained by the lineaments.[3] Records of this differential uplift, such as disequilibrium features, can be observed throughout the region, as relic topography experienced regional displacement. Furthermore, the Miceone creation of these lineaments birthed a series of relatively young fracture and seismic zones, potentially active today.

Evidence of active seismicity found throughout this region as well as modern fracture systems is inconsistent with passive margin settings. Across the Western North Carolina region, modern joints and faults have been recorded as striking obliquely to the regional fabric, in alignment with cross-cutting orientations of the lineaments. The alignment of these modern fracture systems suggests their origin is lineament-related and not orogenic. Furthermore, modern earthquake epicenters cluster along the lineaments revealing sites of active intraplate seismicity contingent upon the same post-orogenic fracture systems constrained by the lineaments.

Substantial evidence of topographic aberrations and disequilibrium features record post-orogenic uplift that has displaced the region's relict topography. Previous studies have linked these geomorphic uplift features to the lineaments, suggesting that past uplifting events triggered a wave of disequilibrium throughout the region. Observing these features helps us better understand the dynamic topography of the Southern Appalachians as a response to the regional uplift that occurred in the Miocene.[2] Disequilibrium features also offer clues to understanding the timing uplift occurred and aid in placing constraints on the chronological order the blocks contained by the lineaments were uplifted.

Streams draining into lineaments can offer insight into when uplift occurred. Stream profiles are scanned for topographic aberrations known as knickpoints.[2] Knickpoints interrupt the smooth concavity of a typical steam profile with the appearance of steep, stepping-stairs. Knickpoint form in response to uplift-related base-level drops.[2] When base-level suddenly drops within a stream, a wave of erosion follows as steep knickpoints, which propagate upstream towards the headwaters until they erode away.[4] While fracture-related, tectonically-driven, knickpoints are useful indicators of uplift, lithologically-controlled knickpoints influenced by the unequal erosion of underlying rock contacts are merely products of the regional fabric of the Appalachians and must be eliminated from studies concerned with lineament-related uplift. Bedrock heterogeneities can quickly be eliminated by overlaying a lithologic map over the located knickpoints in question.[4] Transient knickpoints generated by lineament-parallel fractures migrate along river profiles as independent waves that actively incise regional bedrock and relict topography, whereas lithologically controlled knickpoints remain stationary.[2] Backtracking the migration of transient knickpoints can aid in estimating the timing and magnitude of uplift that has previously occurred.[4] The chronological sequence of uplift for the blocks between the major lineaments can be derived from knickpoints that drain into these lineaments, as the mechanism of knickpoint formation is linked to its corresponding lineament.[4]

## 4. East-West Oriented Lineaments

East-west oriented lineaments found in the Western North Carolina region include, from north to south, the Boone, Laurel Creek, and Swannanoa lineaments. Knickpoint data collected from stream profiles in Western North Carolina showed the block between the Swannanoa and Laurel Creek lineaments had no preserved knickpoints, indicating they have all eroded away.[3] Hill proposes this block records the oldest uplift, occurring in the early Miocene.[3] Hill continued to use knickpoint data to place the block south of the Swannanoa and west of the Franklin lineament as the second oldest, uplifting in the mid-Miocene.[3] Finally, the youngest two blocks, the block south of the Swannanoa lineament and east of the Franklin lineament and the block south of the Boone lineament (north of the Laurel Creek lineament), appear to have uplifted synchronously in the late Miocene, as evidence shows these blocks have higher elevation and knickpoints lower downstream.[3]

The USGS has recorded at least a dozen earthquakes near the Swannanoa and Laurel Creek lineaments since 1979.[3] Earthquakes occurring along fractures parallel to these lineaments such as the 2020 Sparta earthquake and 2005 Hot Springs earthquake suggest modern lineament-related seismic activity.[5] Previous research on the Laurel Creek Lineament, which extends from Hot Springs, NC east toward Spruce Pine, NC found fractures within the lineament formed from a “near-vertical” principal stress, consistent with the focal mechanism from the 2005 earthquake.[3,5]

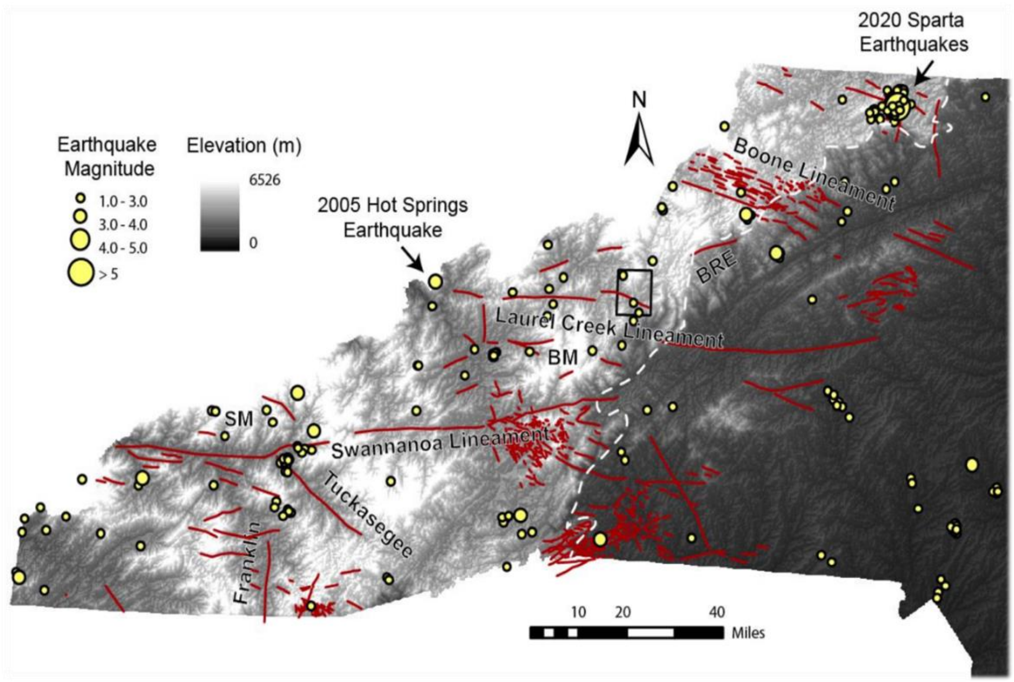


Figure 2. Western North Carolina topographic lineaments and associated fractures.
Earthquakes from 1970-2020 provided by the USGS. Spruce Pine 7.5-minute quadrangle is enclosed in the black rectangle. Lineament data provided by the NCGS. Image from Langille et al. (2021).

## 5. The Spruce Pine 7.5-minute quadrangle

The eastern portion of the Laurel Creek lineament is contained within the Spruce Pine 7.5-minute quadrangle of Western North Carolina (Fig. 3). Palmer found that jointing throughout the quadrangle dominantly strikes toward 260°,

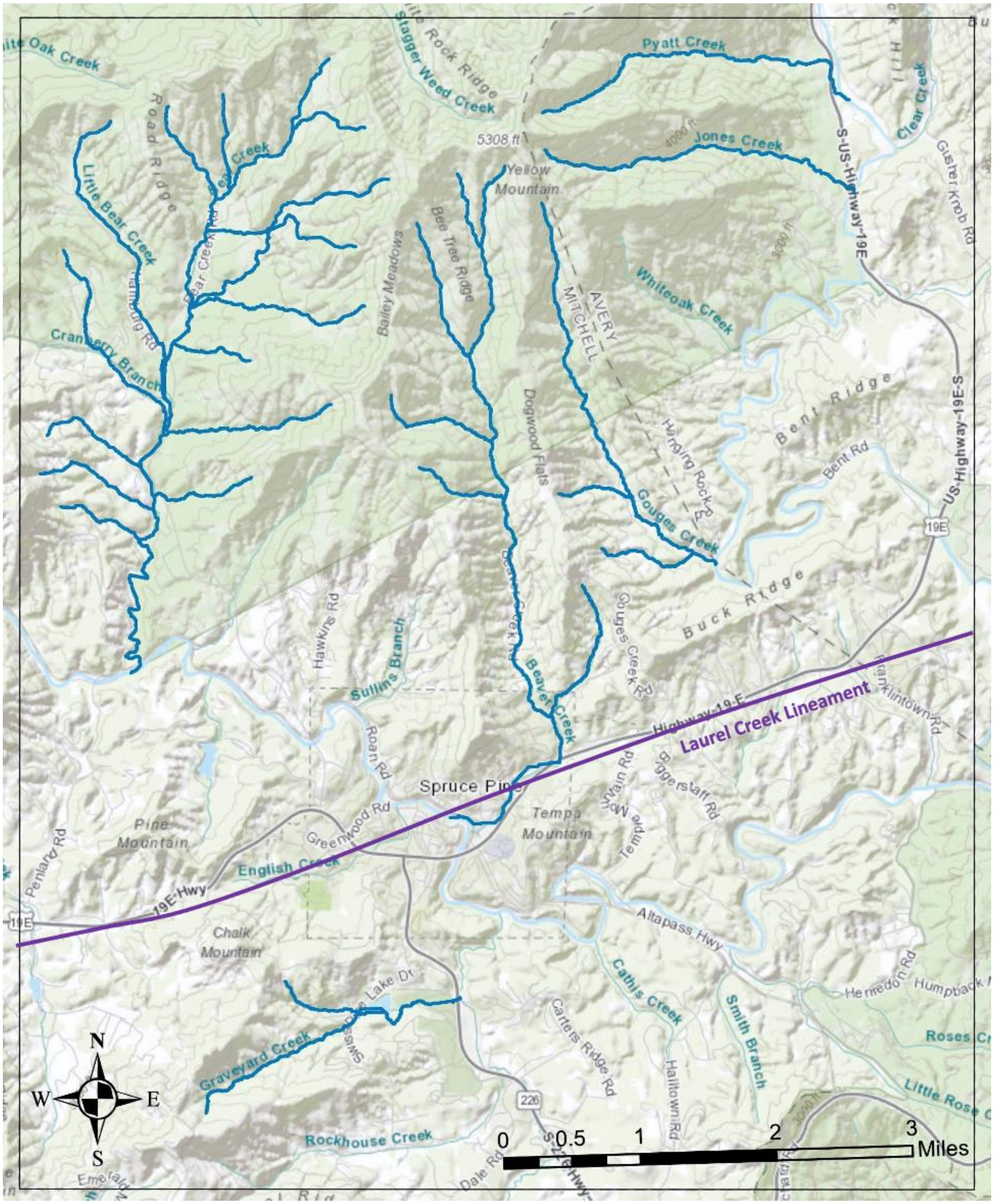


Figure 3. Spruce Pine 7.5-minute quadrangle of Western North Carolina along the eastern portion of the Laurel Creek topographic lineament (shown in purple). Stream systems that drain into the lineament selected for this study are shown in blue.

parallel with the Laurel Creek lineament.[6] Furthermore, fracturing was found to cluster more densely around the Laurel Creek Lineament.[6] This suggests that the block north of the Laurel Creek lineament moved up relative to the south block.[6] This corresponds with previous studies on the Boone Lineament, which indicate fault motion as the south blocks up.[3]

While fracture-based evidence throughout the quadrangle has been successfully accessed, streams contained by the Spruce Pine 7.5-minute quadrangle draining into the Laurel Creek lineament have yet to be evaluated for disequilibrium. This study, therefore, seeks to evaluate the streams contained by the Spruce Pine 7.5-minute quadrangle that drains into the Laurel Creek lineament in order to place the north and south block bounded by it into a chronological framework.

## 6. Methodology

This study utilized 1-m resolution LiDAR for the Spruce Pine 7.5-minute quadrangle to evaluate streams that drain into the lineament and place the blocks bounded by it into a chronological framework. Stream profiles were created for seven major stream systems: Little Bear Creek, Bear Creek, Graveyard Creek, Gouges Creek, Pyatt Creek, Jones Creek, and Beaver Creek (Figs. 4-10). Stream profiles were created using GIS, then exported into excel for analysis. The elevations of significant aberrations along the profiles were extracted from the graphs.

These knickpoints were then confirmed as fracture-related and non-lithologic by examining the locations of the knickpoints on a geologic map. Knickpoints observed with close proximity to lithologic contacts, either from the geologic map or in the field, were removed from the data set. Knickpoints involved with anthropogenic factors were removed from the data set. Data from remaining the knickpoints was inserted into a frequency histogram including all vertical knickpoint elevations (Fig. 11).

## 7. Results

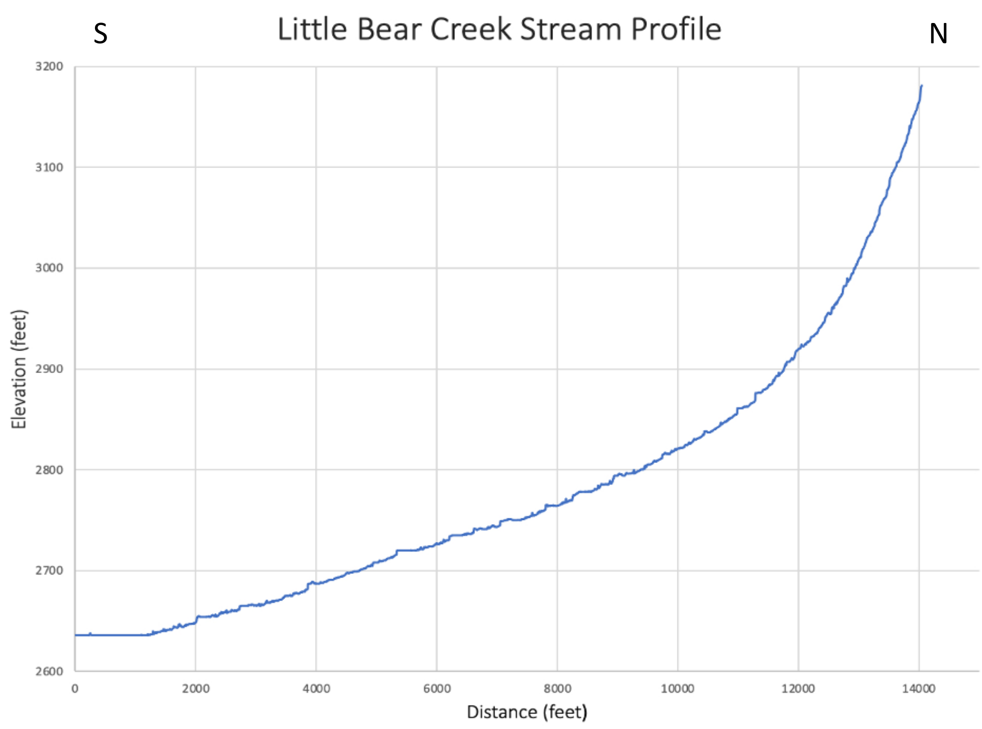


Figure 4. Little Bear Creek stream profile

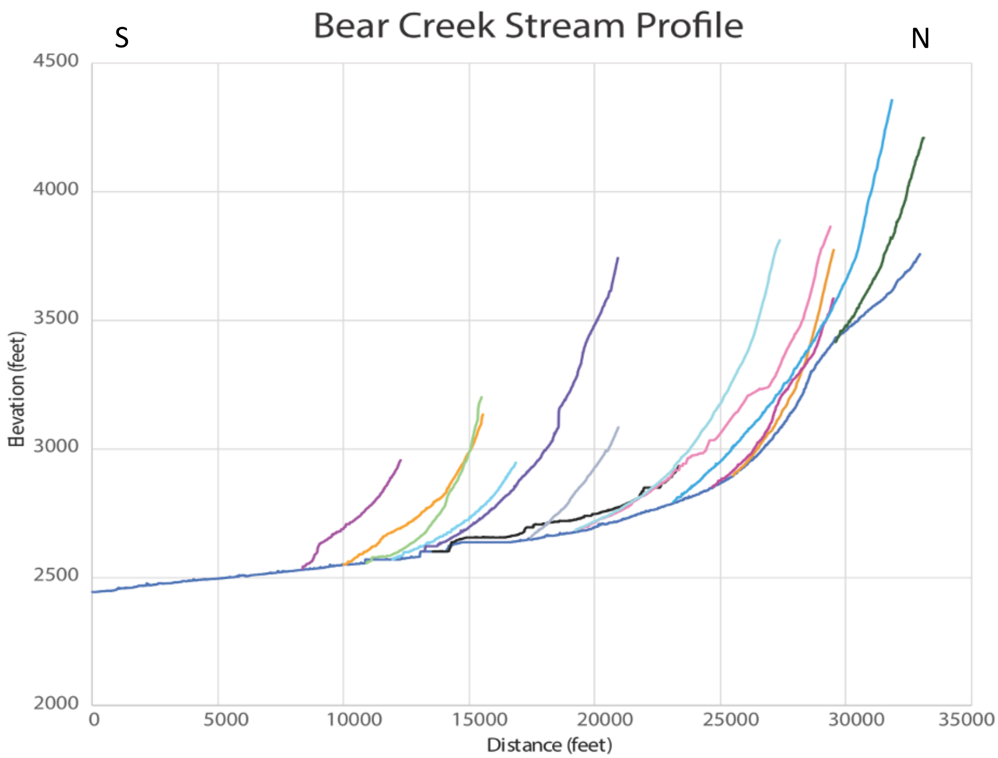


Figure 5. Bear Creek stream profile

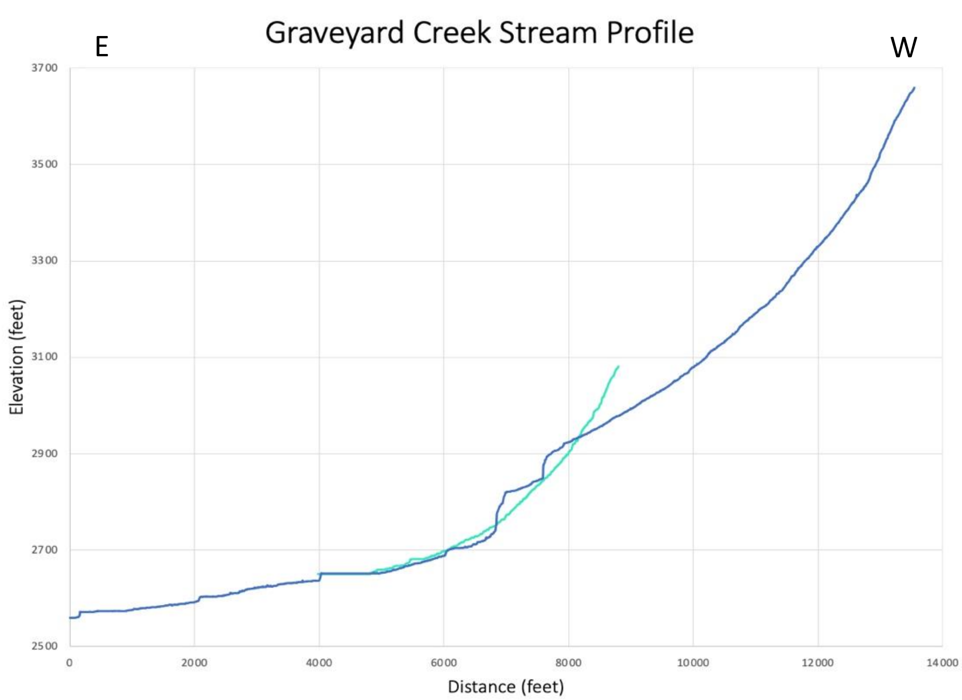


Figure 6. Graveyard Creek stream profile

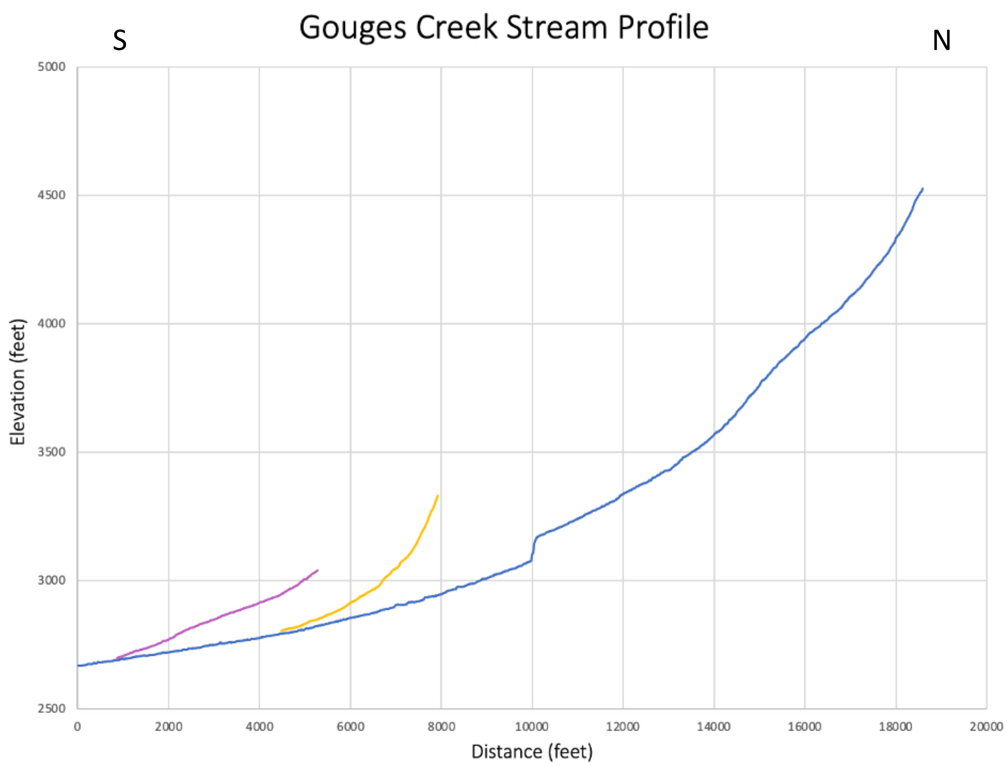


Figure 7. Gouges Creek stream profile

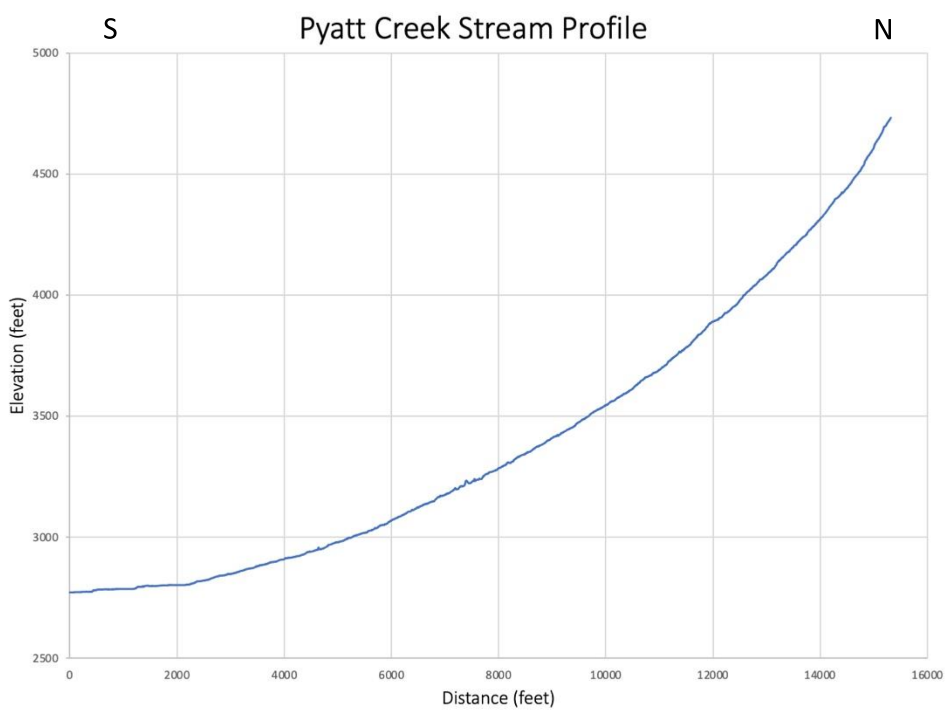


Figure 8. Pyatt Creek stream profile

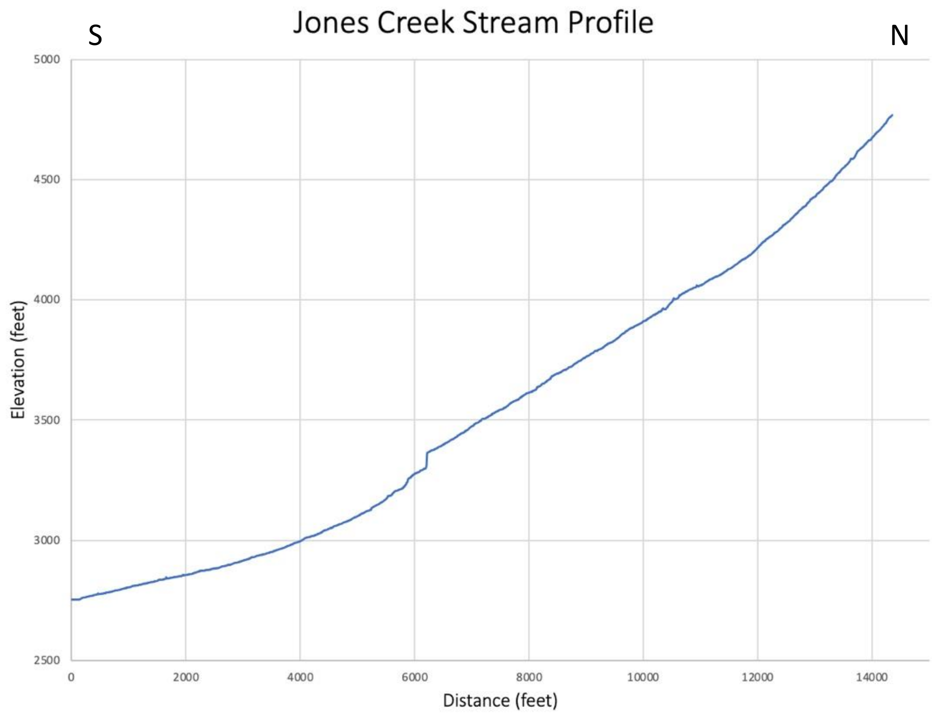


Figure 9. Jones Creek stream profile

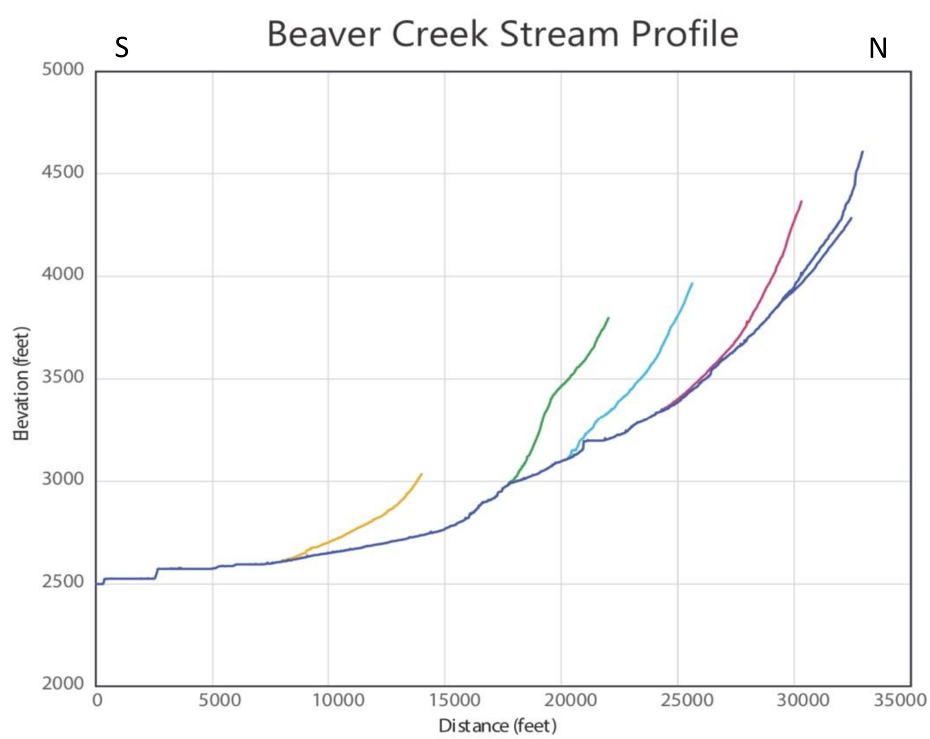


Figure 10. Beaver Creek stream profile

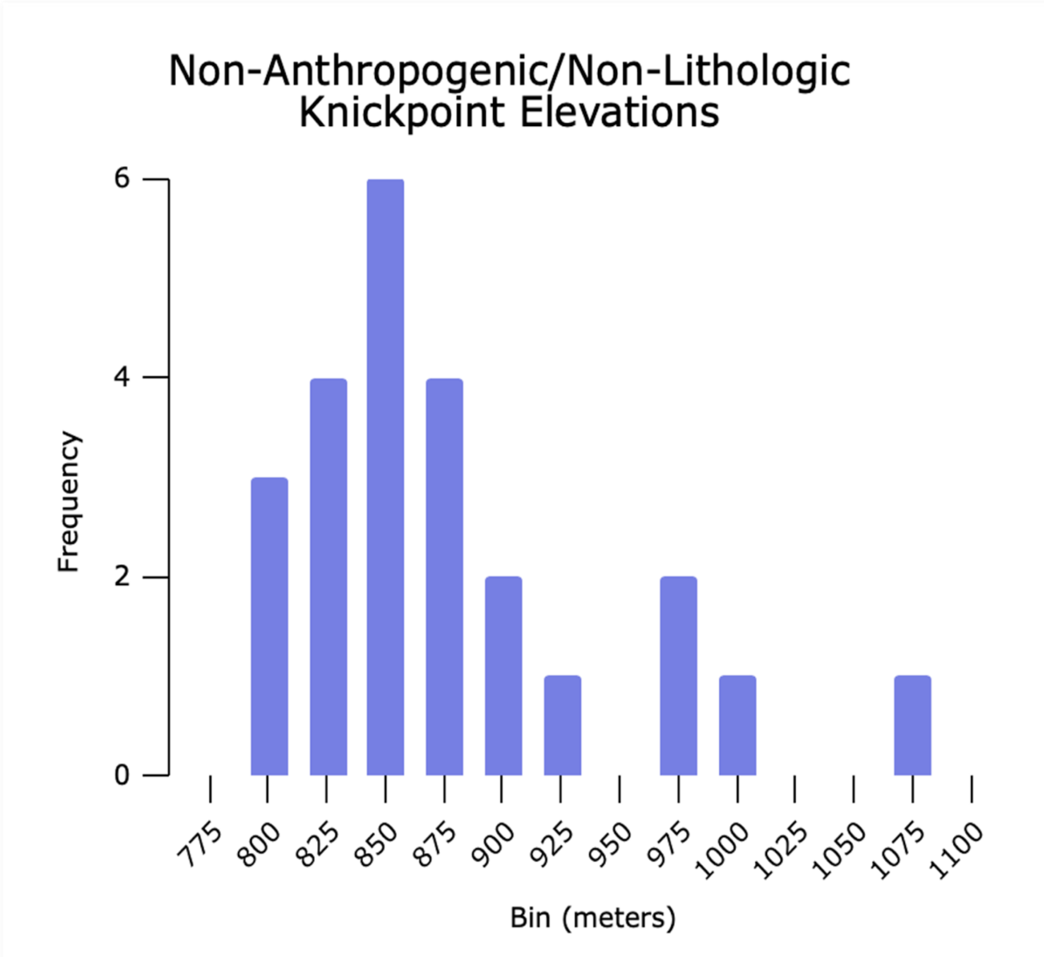


Figure 11. Histogram of 24 knickpoints discordant with lithologic contacts and anthropogenic disturbances.

## 8. Discussion

24 knickpoints discordant with lithologic contacts and anthropogenic disturbances were identified on streams flowing south into the lineament. The elevations of these knickpoints ranged from 2600 to 3510 feet, averaging 2845 feet (s.d. 230 feet). A strong cluster (60%) of these knickpoints was found between 2648 to 2867 feet. This strong cluster in knickpoint elevations from knickpoints found throughout the region suggests a wave of incision at around 2648 to 2867 feet in elevation could be actively dissecting the quadrangle. Streams that flow north into the lineament do not exhibit disequilibrium. These data are consistent with previous research that suggests the block south of the Laurel Creek Lineament records an earlier uplift history and shows that the block north of this lineament likely uplifted concurrently along with the Boone Lineament.

## 9. Conclusion

Substantial evidence of topographic aberrations, active landscape characteristics, and modern seismic activity point to active settings in the Southern Appalachians, in the absence of tectonic forcing. Recent studies correlate lineament-aligned fractures, earthquake clusters, and the rejuvenation of ancient topography, proposing they share a common derivation, delamination of the lithospheric mantle underneath the Southeastern United States. Topographic disequilibrium features, such as migrating knickpoints along river profiles, have been linked with Miocene lineaments indicative of zonal uplift in Western North Carolina. This study was successful in constraining uplift-related knickpoints on the block north of Laurel Creek lineament and determined the streams south of the lineament do not exhibit disequilibrium. This allowed the author to place the north block of Laurel Creek lineament into the chronological scheme of Miceone uplift that occurred in Western North Carolina. This research adds to a larger body of work seeking to understand the geodynamic evolution of the Southern Appalachians.

## 10. Acknowledgments

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