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Constraints on the Kinematics and Resulting Crustal Architecture within the Clyde Quadrangle, western North Carolina, USA through Geologic Mapping of the Hayesville and Burnsville faults

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Abstract

The southern Appalachians record a complex tectonic history associated with the convergence of land masses that assembled Pangea following the breakup of Rodinia that included three main mountain building events : the Ordovician Taconic, Silurian-Devonian Acadian, and the late Paleozoic Alleghanian orogenies. The NE-SW striking dextral Acadian Burnsville fault has been documented from north of Spruce Pine, NC to Asheville, NC and reactivates the contact between Grenville basement rocks that date back to the supercontinent Rodinia and the Ashe Metamorphic Suite (AMS). This contact extends southwest into the 7.5-minute Clyde quadrangle near Waynesville, NC and transitions into what has been mapped as a part of the older NE-SW striking Taconic Hayesville thrust fault. The southward extension of shearing on the Burnsville fault has remained unclear. The Clyde quadrangle encompasses the intersection of this contact with what has been mapped as the Alleghanian Fries and Chattahoochee thrust faults, and the Taconic Hayesville fault. N-S striking, west directed thrusting associated with the Fries and Chattahoochee faults has been proposed north and south of what has been mapped as the Hayesville fault in this quadrangle, respectively. This study used detailed field mapping of the rocks and structures along with documentation of the kinematics and shear sense indicators along the faults in this quadrangle to answer the following questions: (1)What is the nature of the AMS and basement rock contact in this quadrangle, and (2) How are the Taconic Hayesville and Alleghanian Chattahoochee and Fries faults related in time to deformation Acadian deformation? Vertical NE-SW striking mylonite, shallow NE-SW trending stretching lineations, and dextral shear sense indicators suggests that dextral shearing associated with the Burnsville fault continues into this quadrangle and locally overprints a portion of the Hayesville fault. Acadian dextral shearing is not offset by the Alleghanian Fries and Chattahoochee thrusts in this quadrangle, indicating that these thrusts predate shearing on the Burnsville fault and are not Alleghanian structures.

1. Introduction

The assembly of the southern Appalachians are predominantly associated with the convergence of land masses that resulted in three mountain building events: Ordovician Taconic, Silurian-Devonian Acadian, and the late Paleozoic Alleghanian orogenies. The tectonic history of this area is associated with the assembly of Pangea following the ~1 Ga Grenville aged assembly and subsequent rifting of Rodinia[1-5]. The Taconic (~450 mya) and Acadian (~360 mya) orogenies resulted in metamorphism, thrusting, folding, and intrusions of igneous rock[6,7]. These earlier orogenic events are overprinted by thrusting associated with the Alleghanian orogeny (~330 mya) when Pangea was finally assembled. The lack of information about the Acadian orogeny can be attributed to similar metamorphic conditions of the Taconic and Acadian orogenies and Alleghanian overprinting. These orogenies all resulted in deformation that make it difficult to decipher between geologic events in the southern Appalachians today[8-9].

Despite an absence of Acadian structures in the Southern Appalachians, a handful of pioneering efforts have greatly expanded our understanding of the Acadian event through kinematic and geologic mapping, geochronology, and petrologic analyses. Studies suggest that evidence of the Burnsville fault being a dextral transform margin, amphibolite grade metamorphism at ~352 Ma, SW directed sheath folds in the inner Piedmont, and plutonism are associated with the Acadian orogeny[8,11-14]. The Acadian event is distinguished in the northern Appalachians, so these studies provide useful information into how this event affected this mountain range as a whole.

The only structure that has recorded Acadian deformation in the Blue Ridge is the Burnsville fault located in western North Carolina. The Burnsville fault is a dextral strike slip fault that has a documented ~3 km wide vertical shear zone north of Asheville, NC composed of mylonitic gneiss, schist, and amphibolite deformed under amphibolite conditions[14] (Figure 1). Petrologic analysis reveals that the last movement along the Burnsville fault occurred between 360-377 mya[10]. Constraining the kinematic evolution of this fault system provides a unique opportunity to crustal processes that occurred during the Acadian orogeny in the southeast Appalachians.

This fault also serves as the contact zone between the Eastern Blue Ridge (EBR) and the Western Blue Ridge (WBR) lithotectonic terranes north of the Clyde quadrangle[5]. The EBR is present east of the Burnsville fault and includes the Ashe Metamorphic Suite (AMS) encompassing amphibolite and biotite gneiss (Zamb), schist (Zas), and mylonite (Ymy) (Figure 2). The WBR includes Laurentian basement that is intruded by rifting related mafic dikes, granitic rocks and gabbros, and overlain locally by sedimentary rock. This boundary was created by thrusting collisions of island arcs upon Laurentian Grenville age basement rock[10].

The Burnsville fault is constrained between Asheville and Bakersville, but the southward and northward extensions are unclear. This study focused on the southward extension which has been subject to multiple hypotheses. Previous studies have questioned if this fault continues along the Taconic Hayesville thrust fault or the Alleghanian Chattahoochee thrust fault[5,10]. The Chattahoochee fault could also be connected to the Fries fault and truncate the Burnsville fault. The Chattahoochee fault is an Alleghanian structure due to observed truncation of ~335 Rabun granodiorite in northeast Georgia[15]. The Fries fault is also documented as an Alleghanian structure ranging from western NC to near Roanoke, Virginia.

The Hayesville and Burnsville faults are often correlated because they both serve as the WBR and EBR boundary[10]. The Hayesville fault has been documented as a pre metamorphic suture of an island arc thrust upon WBR basement rock was was active during the Taconic orogeny[1,5]. Figure 1 shows this boundary of the Hayesville thrust sheet thrust on top of Paleozoic Cartoogechaye terrane. Previous studies have brought into question the nature of the Hayesville fault and hypothesized possible reactivation of the Burnsville fault as the Hayesville fault during the Acadian orogeny[16]. Dextral motion was not observed further southwest of the field area, creating a level of uncertainty about the continuation of the Hayesville fault[5].

The objective of this study was to determine the spatial and temporal relationship of the structures included in the Clyde 7.5 min quadrangle. Geologic mapping and kinematic studies will build off of previous mapping efforts of the Clyde quadrangle near Waynesville, NC to determine the nature of the faults in this field area. This data will test multiple hypotheses for the southward continuation of the Burnsville fault: 1) it continues along the Chattahoochee fault; 2) it continues along the Hayesville fault; 3) the Alleghanian Chattahoochee and Fries faults are correlated and truncate the Burnsville fault; or 4) the contact between the AMS and basement rocks here is not the Burnsville fault.

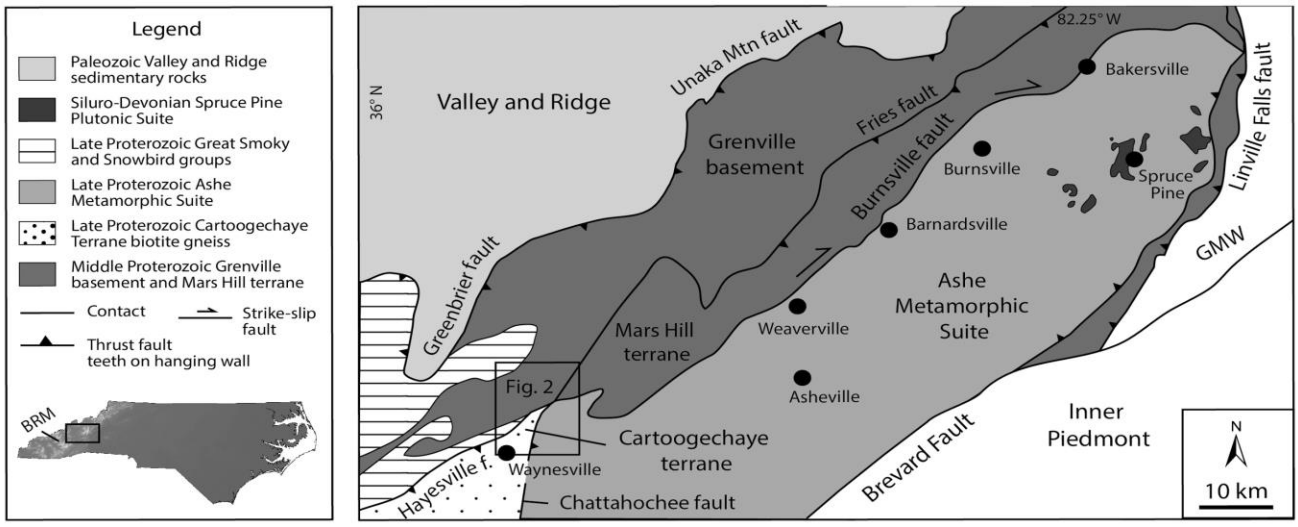


Figure 1. Simplified geologic map of the Blue Ridge Mountains (BRM) in western North Carolina, south of the Grandfather Mountain Window (GMW). Inset shows the location on a digital elevation map where light colors show higher elevation. Map from Stewart et al., modified to include the Asheville and Waynesville[17-21].

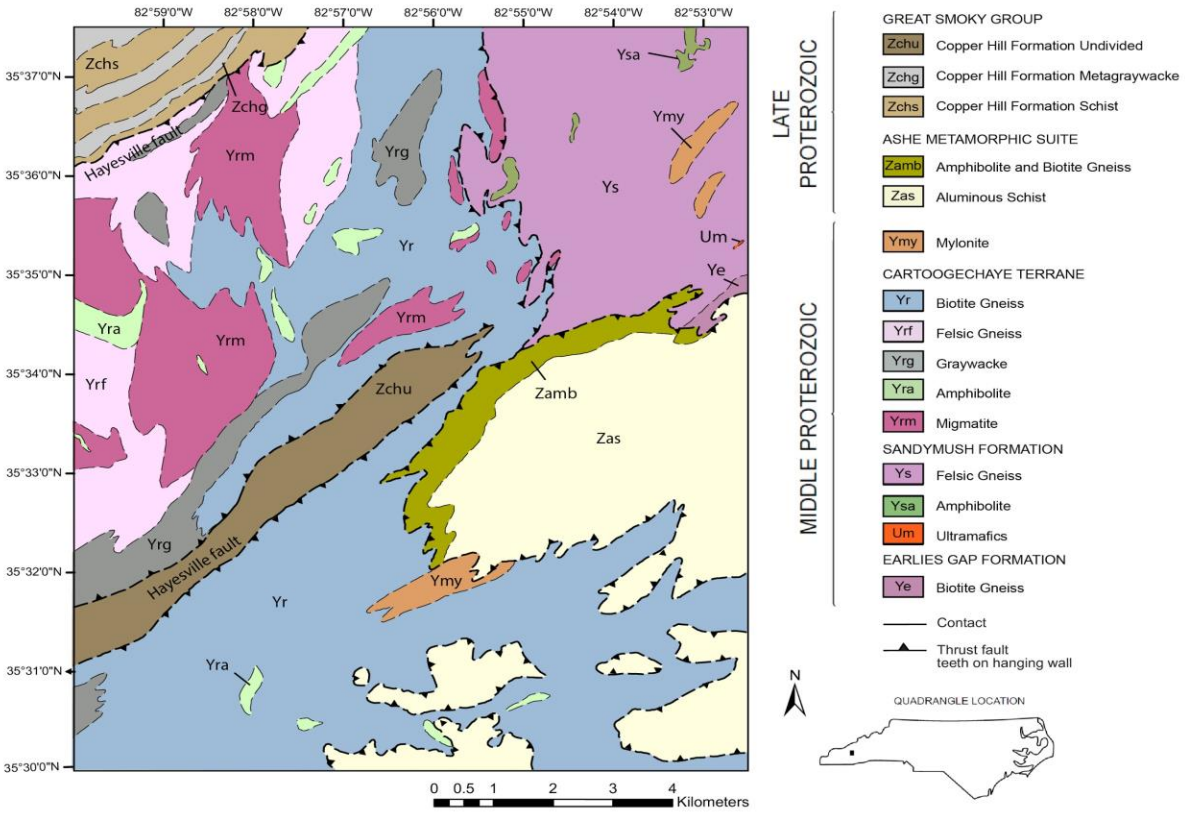


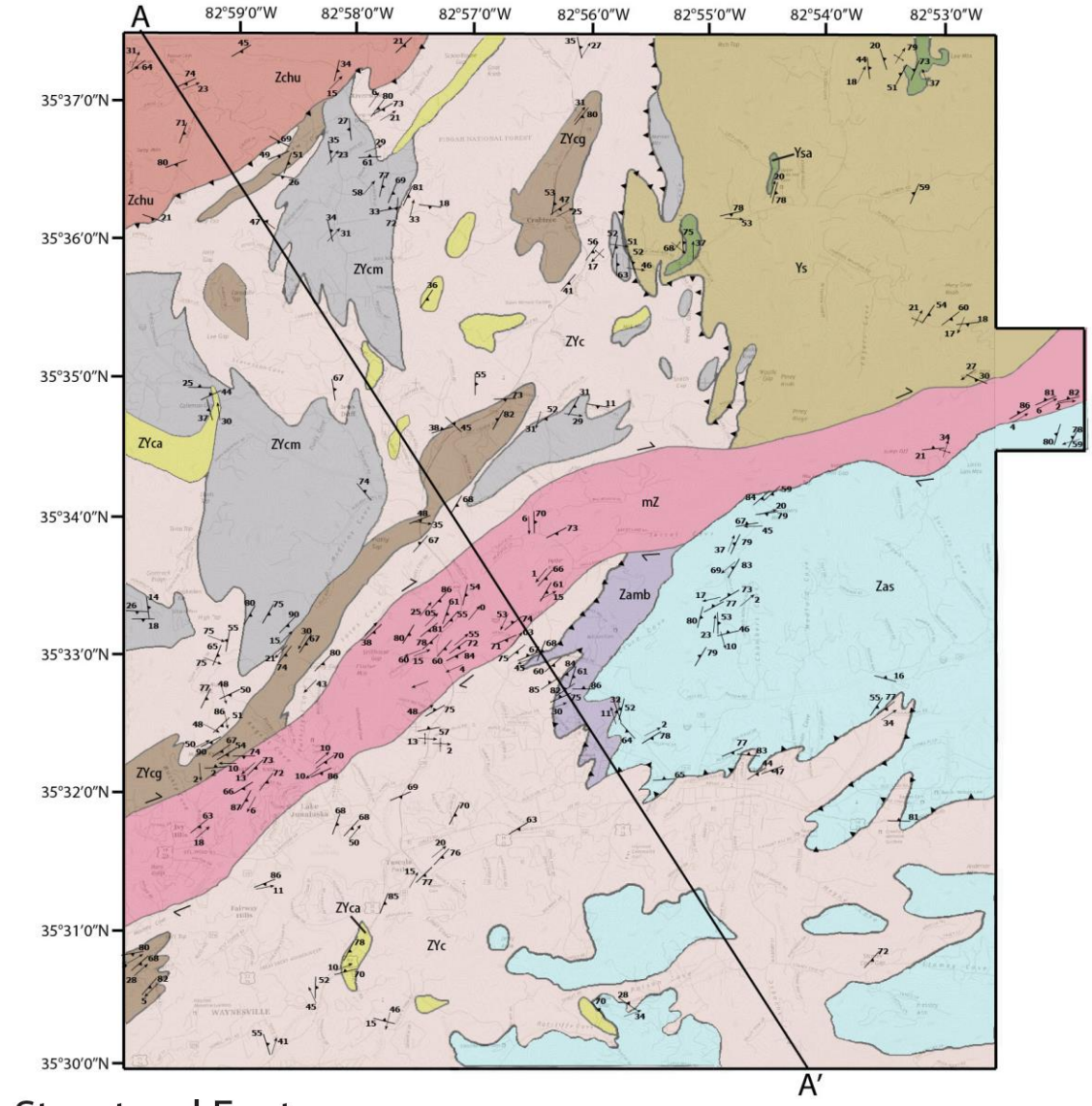
Figure 2. Previously published geologic map of the Clyde 7.5-minute quadrangle, North Carolina from Merschat and Wiener[21,22]. The Sandymush and Earlies Gap Formations correlate to the Mars Hill terrane shown in Figure 1.

2. Methods

Detailed geologic mapping of the Clyde 7.5 minute quadrangle was conducted on a 1:24,000 scale. Lithology, orientation, and kinematic data was collected from exposures along public and private roads, where access was granted. Field methods includes measurement and documentation of foliation, lineation, kinematics, and fold orientations. An iPad equipped with FieldMove software was utilized for data collection in the field.

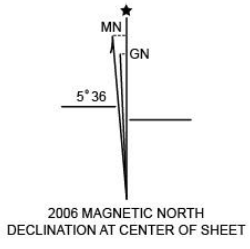
Special attention was paid to macroscopic kinematic indicators such as boudins, tails of rotated porphyroclasts, and S-C fabrics to determine shear sense along the shear zones within the study area. The published geologic map of this quadrangle by Merschat and Wiener provided a base understanding of the rock units in the field area[22]. The mineralogy, color, texture, and other distinguishing features of each lithologic unit was assigned according to their observations.

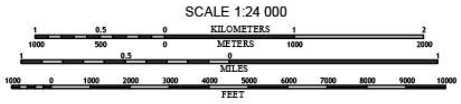
3. Results



Structural Features

- Mineral Foliation
- Mineral Lineation
- Anticline
- Syncline
- Contact
- Thrust fault, teeth on hanging wall
- Strike-slip fault





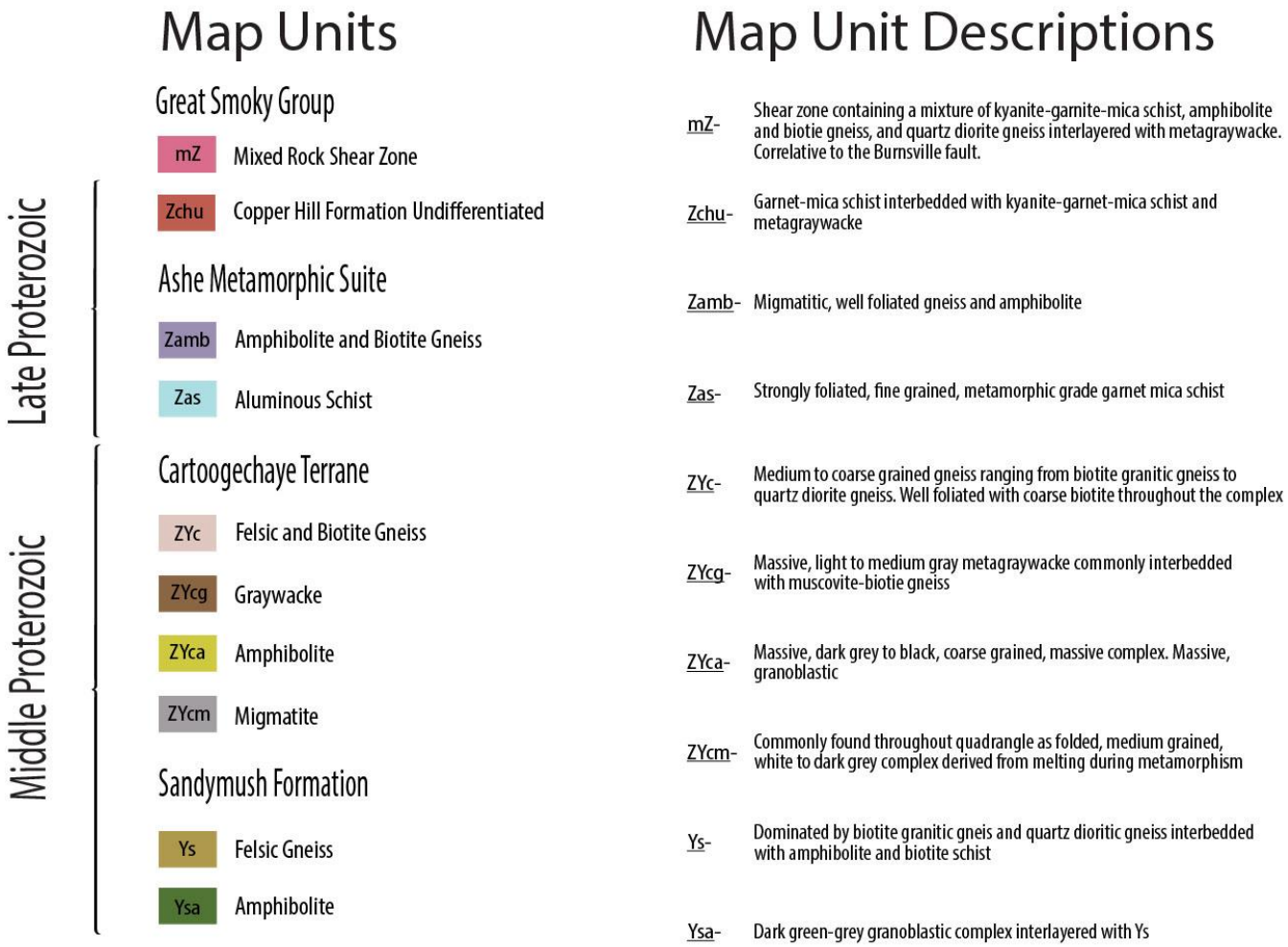


Figure 3. Geologic map of the Clyde 7.5 minute quadrangle from this study and Merschat and Weiner[21,22].

3.1 Rock types

A majority of the rock types, orientations, and contacts mapped by Merschat and Weiner were observed and supported in this study[21,22]. The Sandymush formation is composed of felsic gneiss (Ys) and amphibolite (Ysa) that are the oldest rocks in this quadrangle. The main units included in the Cartoogechaye terrane are felsic and biotite gneiss (ZYr), graywacke (ZYrg), and migmatite (ZYrm) with amphibolite pockets (ZYra) throughout the complex. Amphibolite and biotite gneiss (Zamb) and aluminous schist (Zas) are included in the Ashe Metamorphic Suite The Great Smoky group is composed of garnet-mica schist, kyanite-garnet-mica schist, and metagraywacke that make up the Copper Hill formation undifferentiated (Zchu). The mixed rock shear zone (mZ) is a mixture of kyanite-garnet-mica schist, amphibolite and biotite gneiss, and Cartoogechaye teranne interlayered with metagraywacke.

Some areas of Cartoogechaye amphibolite exposures were observed as felsic and biotite gneiss, but where there were no exposures to verify amphibolite facies, the interpretations from Figure 2 remain (Figure 3). The Copper Hill formation was grouped into an undifferentiated unit in the NW section of the quadrangle. Garnet-mica schist, kyanite-garnet-mica schist, and metagraywacke were seen throughout Zchu, but distinct contacts between the rocks were not observed.

ZYr was grouped into the same unit since the gneiss was consistently interbedded between biotite granitic gneiss and quartz diorite gneiss. The metagraywacke was characterized by a massive, light to medium gray complex

commonly interbedded with ZYr. Migmatite was seen throughout the terrane as highly deformed mappable bodies that were derived from high grade metamorphism.

The Grenville basement included in this quadrangle were consistent with Merschat and Weiner's map excluding the ultramafic body and biotite gneiss[21,22]. The mylonite within the Sandymush formation and the Ashe Metamorphic Suite were not observed. Zamb and Zas of the EBR were present throughout the southeastern part of the quadrangle.

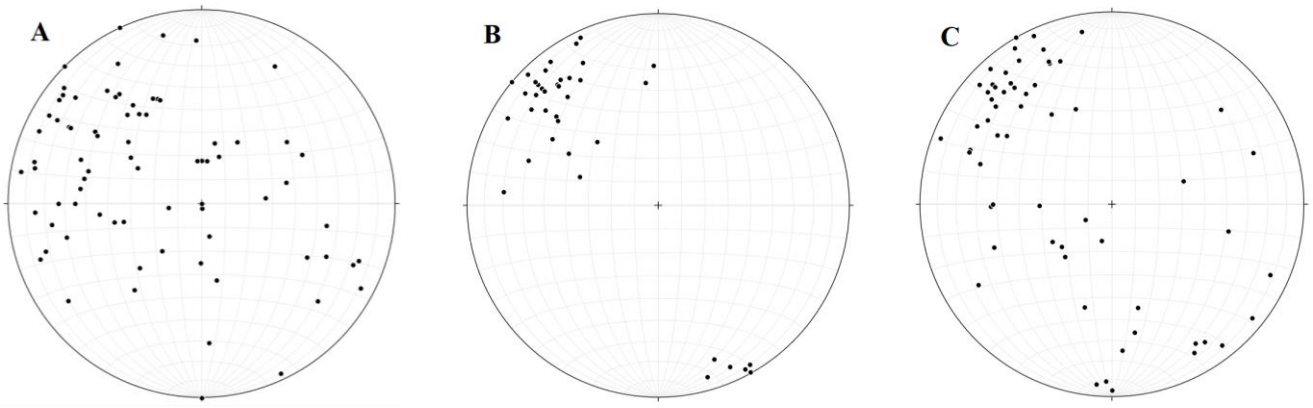
The Mz unit that extended from the southwestern part of the quadrangle to the northeast included rocks from three different formations within the quadrangle. The northeast part of the shear zone included basement rock and AMS while the southwest section included Cartoogechaye terrane and Copper Hill formation. There was a lack of rock outcrops within the NE section of the shear zone, so the quadrangle was extended to include observed mylonite just outside of the field area.

3.2 Structural observations

Rock formations included in mZ were characterized by near vertical dipping and northeast to southwest foliations that averaged around ~N45°E (Figure 4B). Strong lineations within the shear zone were also trending northeast to southwest running parallel to the foliations with shallow to horizontal plunges (Figure 4E). Rock outcrops with these finding were plenty within the Copper Hill formation.

The foliations and lineations outside of the shear zone did not show any consistency or correlation to the data within the shear zone (Figure 4A, 4C, 4D, and 4F). The foliation strikes varied widely throughout the Cartoogechaye terrain and basement rock. There was no clear average of the foliation strike south and north of the shear zone. Lineations also varied outside of the shear zone and were not as strong as those within the Copper Hill formation.

Thrust motion was found along the Fries fault with foliations running NE and down dip lineations with plunges of 51° (Figure 6A). No thrusting evidence was observed along the Chattahoochee fault. Similar rock types throughout the SW section of the shear zone and the Copper Hill formation were found, but the orientations of the rocks were not consistent.



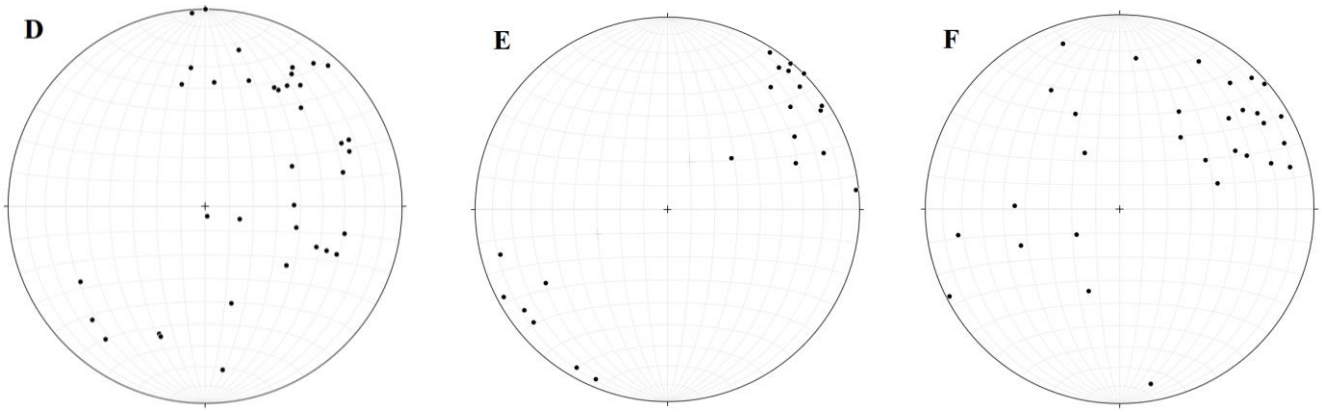


Figure 4. (A) Poles to foliation north of the shear zone (mZ) (Fig. 3). (B) Poles to foliation within the shear zone. (C) Poles to foliation south of the shear zone. (D) Mineral lineations north of the shear zone. (E) Mineral lineations within the shear zone. (F) Mineral lineations south of the shear zone.

3.3 Kinematic observations

Steeply dipping, northeast to southwest trending mylonite was seen throughout the shear zone indicating dextral shearing. Shear sense indicators were commonly observed within the kyanite-garnet-mica schist which extends ~4 km from the west of the quadrangle (Figure 5A and 5B). There were limited exposures in the mixed shear zone beyond ~4 km until mylonite was found slightly outside of the quadrangle in the most eastern part of the shear zone (Figure 5C).

Macro shear sense indicators were observed within the quadrangle as boudins and stretched porphyroclasts (Figure 5A and 5B). Some shear indicators were seen within Zyrg and Zyr, so the shear zone was extended outside of the kyanite-garnet-mica-schist. These indicators were all indicating dextral shearing motion. In the northeastern most section of the shear zone, NE trending, shallow stretching lineations were observed. Folds present in this outcrop indicated transpression through strike slip motion.

Throughout the Cartoogechaye terrane, NW directed thrusting was seen through sheath folds and NW directed lineations (Figure 6C). Shear sense indicators and lineations were observed throughout the basement complex, but did not reveal information about past orogenic events. The shear sense indicators throughout mZ were the most reliable and revealed information about the relationship of structures included in the quadrangle.

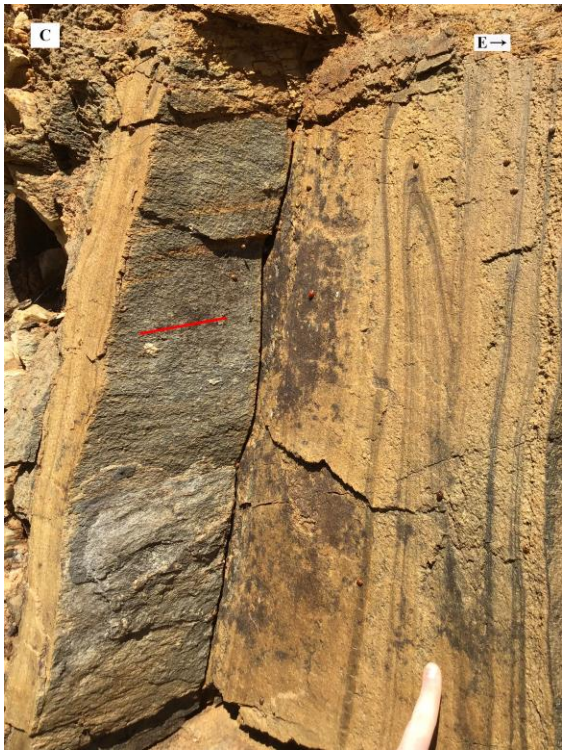


Figure 5: (A) (B) Dextral shearing along the Burnsville fault. Viewed looking down. (C) Shallow stretching lineations indicated in red and folds indicating transpression within the northeastern most part of the shear zone (mZ).

Figure 6: (A) Down-dip stretching lineation indicating thrust motion along the Fries fault. (B) Fault slicks not associated with the Burnsville fault found in Yrg unit above mZ. (C) Sheath fold showing NW directed Taconic thrusting within the NW migmatite unit.

4. Discussion

The Clyde quadrangle encompasses a complex area of land that has been deformed throughout the assembly of the southern Appalachians during three orogenies making it hard to discriminate between deformation. During the Taconic orogeny, the AMS was thrust over the Grenville basement rock. This complex was then thrust on top of the Cartoogechaye terrane followed by this entire complex being thrust on top of the Great Smoky Group north of the Clyde quadrangle (Figure 7). Thrusting deformation occurred during the Taconic orogeny followed by Acadian shearing along the Burnsville fault. Alleghanian thrusting is thought to overprint earlier deformation, but inquiries about the Alleghanian structures locally arose from results of this study.

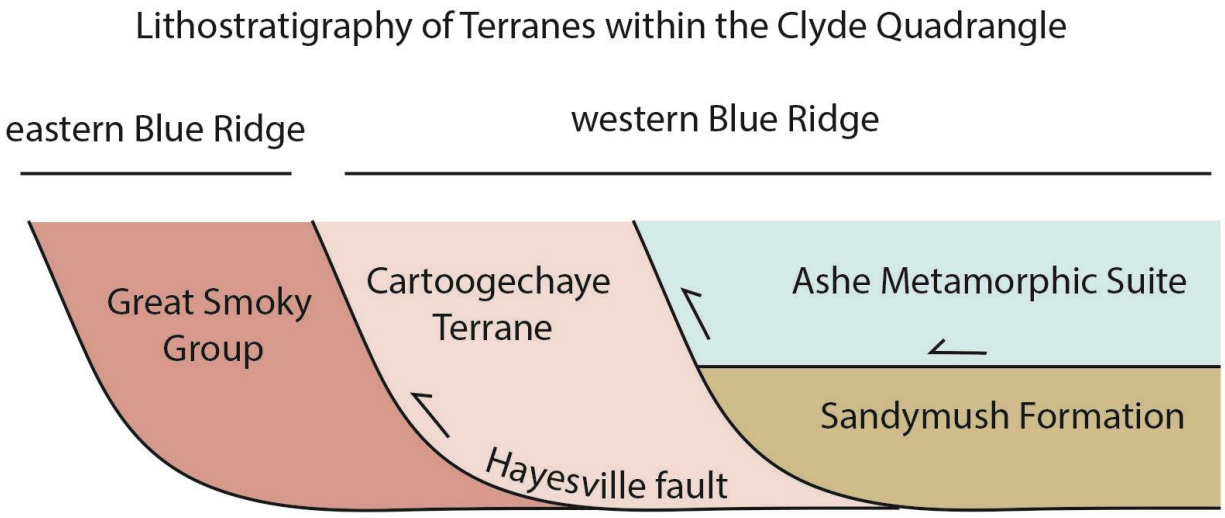


Figure 7. A representation of thrust faults and rock units within the Clyde quadrangle and their relationship to each other. The colors and rock names correlate to those in Figure 3.

Field observations along the structures in the quadrangle revealed that the Burnsville fault overprinted what has been mapped as the Hayesville fault and proved that deformation along the Fries and Chattahoochee faults are not attributed to the Alleghanian orogeny locally. The Burnsville fault reactivates the contact between AMS and basement rock northeast of this quadrangle and it is believed that the Hayesville fault is reactivated as the Burnsville fault during the Acadian orogeny. This leads to the conclusion that the thrusting observed along the Fries and Chattahoochee fault predates the Acadian orogeny.

Dextral shearing and steeply dipping foliations along the Hayesville fault correlate to the Burnsville fault[23]. The kinematic indicators and rock orientations along the portion of the Hayesville fault included in this quadrangle resemble those along the Burnsville fault mapped in previous studies. The lack of exposures within the shear zone from ~4 km east of the westernmost part of the quadrangle may have created uncertainty about the northeastern extension into the Burnsville fault. The correlation between the two structures was solidified by mylonite present slightly outside of the quadrangle. This exposure showed extremely close similarities to those along the Hayesville fault with near vertical dipping foliations and close to horizontal stretching lineations.

The reactivation of the Hayesville fault as the Burnsville fault creates implications about the other structures included in this quadrangle. It was previously hypothesized that the Fries and Chattahoochee thrust faults offset the Hayesville and Burnsville faults during the Alleghanian orogeny. Since no offset was observed in this quadrangle the thrusting observed along the Fries fault most likely correlates to thrusting events during Taconic orogeny.

If this thrusting is attributed to the earlier Taconic orogeny, the Fries and Chattahoochee faults may not be included in this quadrangle. There is still uncertainty as to the faults continuations from the north and the south, but it is unlikely that these Alleghanian structures were active within the field area. This hypothesis supports the Burnsville continuing along the Hayesville fault rather than the Chattahoochee as previously suggested. Further studies on the continuation of these faults would provide a better understanding of Alleghanian deformation within the southern Appalachians.

Further studies on the southwestern extension of the Hayesville fault would be helpful to better understand the Acadian reactivation as the Burnsville fault. Dextral shearing was not observed along the Hayesville southwest of the Clyde quadrangle which presents a counter argument of results from this study. A detailed mapping project of the southwest continuation of the Hayesville fault would provide useful insight that will either support or challenge this studies findings. Since deformation in this field area is difficult to differentiate, Argon-argon dating within this quadrangle would also be useful for solidifying the ages of deformation.

5. Conclusion

This study determined the structural and temporal relationship of the structures included in the Clyde 7.5 minute quadrangle by completing detailed geologic mapping and documenting shear sense along the faults in this field area. Dextral shearing evidence was found throughout the southwestern portion of the quadrangle and extended northeast towards the Burnsville fault. This suggests that the Taconic Hayesville fault was reactivated during the Acadian orogeny as the Burnsville dextral strike slip fault. NE-SW trending mylonite with steeply dipping foliations, shallow NE-SW trending stretching lineations, and shear sense indicators within the shear zone in this field area correlate to findings along the Burnsville fault. The thrusting observed along the Alleghanian Fries and Chattahoochee faults predates the Acadian orogeny and does not offset the Burnsville fault in this quadrangle. Further studies are needed to determine where exactly the Fries and Chattahoochee faults continue from the north and the south and if they are included in the Clyde quadrangle.

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