University of North Carolina Asheville
Journal of Undergraduate Research
Asheville, North Carolina
May 2020

Constraining The Timing Of Acadian Dextral Transpression Along The Burnsville Shear Zone Within The Clyde 7.5-Minute Quadrangle, Western North Carolina

Caylynn Westberg
Environmental Studies Department
The University of North Carolina Asheville
One University Heights
Asheville, North Carolina 28804 USA

Faculty Advisor: Dr. Jackie Langille

Abstract

Following the Grenville orogeny, rocks across the Appalachians record deformation from the Ordovician Taconic, Silurian-Devonian Acadian, and the late Paleozoic Alleghanian orogenies. While there is an abundant record of Taconic and Alleghanian deformation in the Blue Ridge of the southern Appalachians, a record of the Acadian event is limited with the Burnsville shear zone representing the only record of deformation from this event. This shear zone was previously mapped south of the Grandfather Mountain Window from Burnsville, NC southwest towards Clyde, NC and records dextral transpression. This shear zone has been correlated to the Gossan Lead fault north of the Grandfather Mountain Window. While previous studies have constrained the timing of this shear zone near Burnsville, NC, the age of deformation toward its southernmost mapped extent near Clyde, NC has not been constrained. Dynamic recrystallization textures of quartz along with electron backscattered diffraction (EBSD) patterns from quartz [c] axes from samples collected within the shear zone in the Clyde quadrangle place constraints on the deformation temperatures. These constraints were combined with $^{40}Ar/^{39}Ar$ cooling ages from muscovite to bracket the timing of deformation. Quartz exhibits subgrain rotation recrystallization (SGR) with many portions of the shear zone overprinted by bulging recrystallization (BLG). Combined with opening angles of quartz [c] axis cross girdles, deformation occurred from temperatures of ~400-500° C and was overprinted at temperatures of ~390° C. These data combined with new ages and a muscovite closing temperature of ~400° C suggest that dextral transpression was ongoing in the Clyde quadrangle at ~350 Ma. This is markedly younger than previous constraints north near Burnsville where deformation occurred at >500° C between ~377 and 360 Ma.

1. Introduction and Background

The tectonic history of the Appalachian Mountains includes three major mountain building events including the Ordovician Taconic, Silurian-Devonian Acadian, and late Paleozoic Alleghenian orogenies[1]. The Ashe Metamorphic Suite (AMS) was thrust onto the Grenville basement rocks during the Taconic Orogeny (Figure.1). During the Acadian, this contact was overprinted by dextral strike-slip shearing. The Alleghanian thrust these structures over the Valley and Ridges rocks (Figure. 1). The Clyde 7.5-minute quadrangle contains the southernmost contact between the AMS and the Grenville basement rocks (Figure. 1). This contact has been mapped as a Taconic thrust fault that was overprinted by dextral strike-slip shearing, termed the Burnsville shear zone, during the Acadian[2,3,4]. This fault was originally mapped near Burnsville, NC[3]. The southern extent has been documented south toward Asheville into the Clyde quadrangle near Waynesville, NC[5,6]. This southern portion of the Burnsville fault locally overprints the older Taconic Hayesville faulting in the Clyde Quadrangle[6]. This study presents new deformation temperature and cooling ages to bracket the timing of deformation in the Clyde quadrangle (Figure. 1).

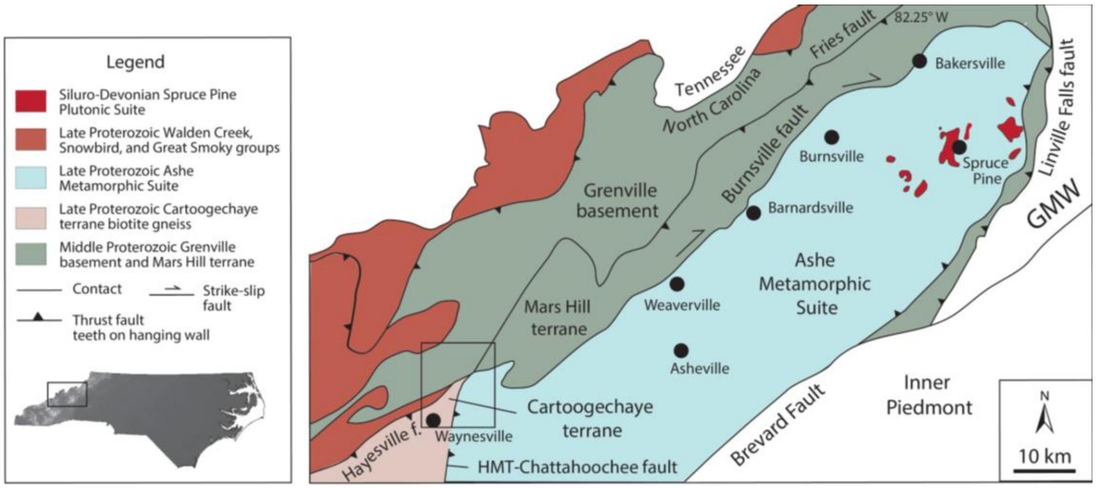


Figure 1. Simplified geologic map of a portion of the Blue Ridge Mountains (BRM) in western North Carolina, south of the Grandfather Mountain Window (GMW). The box is the Clyde 7.5-minute quadrangle. HMT, Holland Mountain thrust fault. From Langille et al. (2020). Structures within the basement rocks have been simplified but include the Unaka-Linville Falls, Fork Ridge, Sams Gap-Pigeonroost, and Fries thrust sheets. Inset shows the geographic position of the geologic map on a digital elevation model of North Carolina where light colors represent higher elevations.

This portion of the Burnsville shear zone contains four main rock types: the Copper Hill Formation, Ashe Metamorphic Suite, Cartoogechaye Terrane, and Sandymush Formation. The Copper Hill Formation, located within the Great Smoky Group, is composed of garnet-mica schist, kyanite-garnet-mica schist, and metagraywacke[6]. This unit is dominated by muscovite and is strongly foliated, coarse-grained, and porphyritic[6]. The Ashe Metamorphic suite includes biotite gneiss with metagraywacke and aluminous schist[6]. The Cartoogechaye Terrane contains biotite gneiss, metagraywacke, and quartz diorite gneiss with lenses of amphibolite[6]. In the northeastern portion of the quadrangle the fault overprints the contact between the Ashe Metamorphic Suite and Sandymush formation[6]. Going southwest the shear zone overprints portions of the Cartoogechaye Terrane and was previously mapped as the Copper Hill Formation[6]. The Burnsville Fault is characterized by ultramylonite to mylonite that has well defined lineations that trend northeast or southwest with a shallow plunge, parallel to the strike[6].

Ages of deformed leucogranite rocks from the shear zone near Burnsville combined with hornblende $^{40}Ar/^{39}Ar$ cooling ages suggest the shear zone was active between ~362-377 Ma toward the end of the Acadian orogeny (Figure. 2)[3]. $^{40}Ar/^{39}Ar$ ages can be obtained from muscovite. This study presents new muscovite ages from samples from this portion of the shear zone. An $^{40}Ar/^{39}Ar$ age from muscovite records the last time that the rock was at a temperature of ~400° C. Deformation temperatures were combined with the age to bracket the timing of deformation.

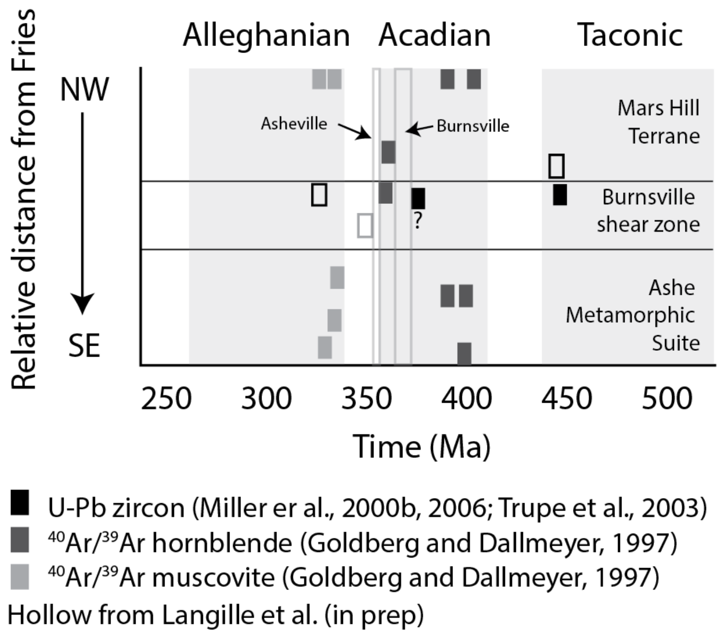


Figure 2. New and existing U-Pb zircon and $^{40}Ar/^{39}Ar$ age constraints across the Fries thrust sheet (green in Figure. 1), through the Burnsville shear zone. Grey represents ages for the Taconic, Acadian, and Alleghanian orogenies. The question mark near the 377 Ma U-Pb age from Trupe et al. (2003) indicates that the relative location within the Burnsville shear zone for this sample is unknown. The area labeled as Burnsville indicates the approximate time of deformation constrained by Trupe et al. (2003) near Burnsville, NC and that labeled Asheville is from Langille et al. 2020.

2. Methodology

$^{40}Ar/^{39}Ar$ dating methods were used to obtain the age of muscovite from within the Burnsville shear zone to bracket the timing of deformation. The isotopic age method of dating measures the amount of the isotope ^{40}Ca and/or ^{40}Ar present in a rock. The radioactive parent of these elements is ^{40}K. The age obtained is the time that it took for ^{40}K to decay to ^{40}Ca and/or ^{40}Ar. The decay begins once a rock cools to a certain temperature (the closure temperature), which varies for different types of minerals. The original amount of ^{40}K can be determined assuming: 1) a constant decay rate of ^{40}K that is not dependent upon pressure or temperature, 2) the ^{40}K/total K isotopes are constant, 3) the radiogenic ^{40}Ar was produced after the mineral crystallized, 4) the amount of non-radiogenic ^{40}Ar is in a ratio to ^{36}Ar, 5) the sample was and still is in a closed system[7]. Three samples were collected along the Burnsville shear zone, they all contained muscovite and were analyzed for their cooling age by the New Mexico Tech Geochronology Research Lab. The closure temperature for muscovite is ~400° C.

Recent work by Stith (2018) showed that deformation on the Burnsville shear zone in this study area occurred at temperatures between 280° and 500° C[8]. Combining these ages with deformation temperature brackets the time of deformation. To further evaluate the deformation temperature, Electron Backscatter Diffraction (EBSD) and quartz deformation indicators were used to constrain the deformation age for the Burnsville fault. EBSD data was collected by Gareth Seward at the University of California Santa Barbara and using the EBSD equipped SEM at Appalachian State University under the guidance of Dr. Jamie Levine. Deformation temperatures were determined by plotting [c] axes of quartz orientations on a lattice preferred orientation (LPO) plot (Figure 3), this yields patterns indicative of the temperature that the rock was deforming under ductile conditions. If quartz in the thin section expresses dominantly basal <a> slip, deformation temperatures are <400° C. If prism <a> is dominant, its deformation temperature is ~400-500° C. If there was a weak pattern no deformation temperature could be determined.

If the EBSD pattern has an opening angle (Figure 3), deformation temperature can be calculated using equation 1[9].

$$T\ (°C) = 6.9\ OA\ (degrees) + 48\ (250°\ C \leq T \leq 650°\ C\ and\ OA \leq 87°) \quad (1)$$

Quartz textures in thin sections were also analyzed to determine deformation temperatures during deformation. If a thin section had bulging recrystallization, it formed at a low temperature around 280-400° C. Subgrain rotation recrystallization forms around 400-500° C. Quartz grains that deformed over 500° C exhibits grain boundary migration.

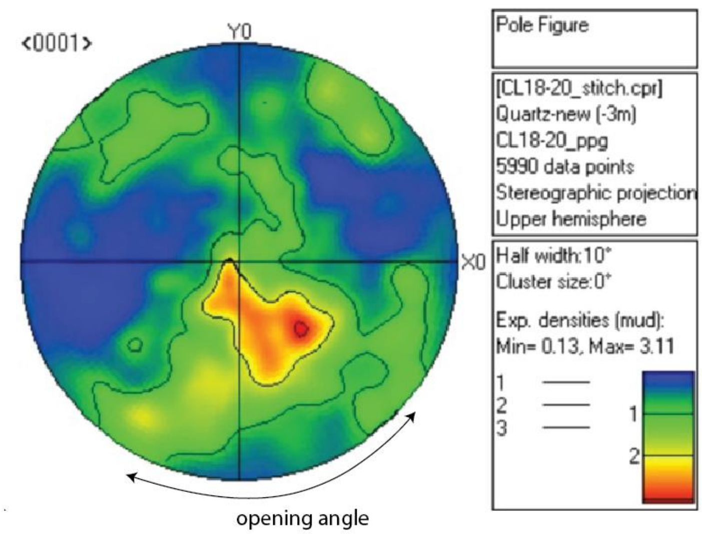


Figure 3. EBSD data of sample CL18-20 showing dominant prism <a> (red at center of LPO) slip and opening angles in the [c] axis pattern.

3. Results

3.1 Quartz Indicators

Quartz thin sections acquired from within the shear zone show micro-tectonic deformations that occured within the formation of the quartz. In thin section CL18-01, bulging recrystallization that overprints subgrain rotation suggest that this portion of the fault was deforming at 400-500° C and later overprinted at temperatures of 280-400° C (Figure 4A). Sample D7S2, D8S2, SH17-01 exhibit subgrain rotation with minor bulging recrystallization, this suggests that it was also deformed at these temperatures (Figure 4B, C, D).

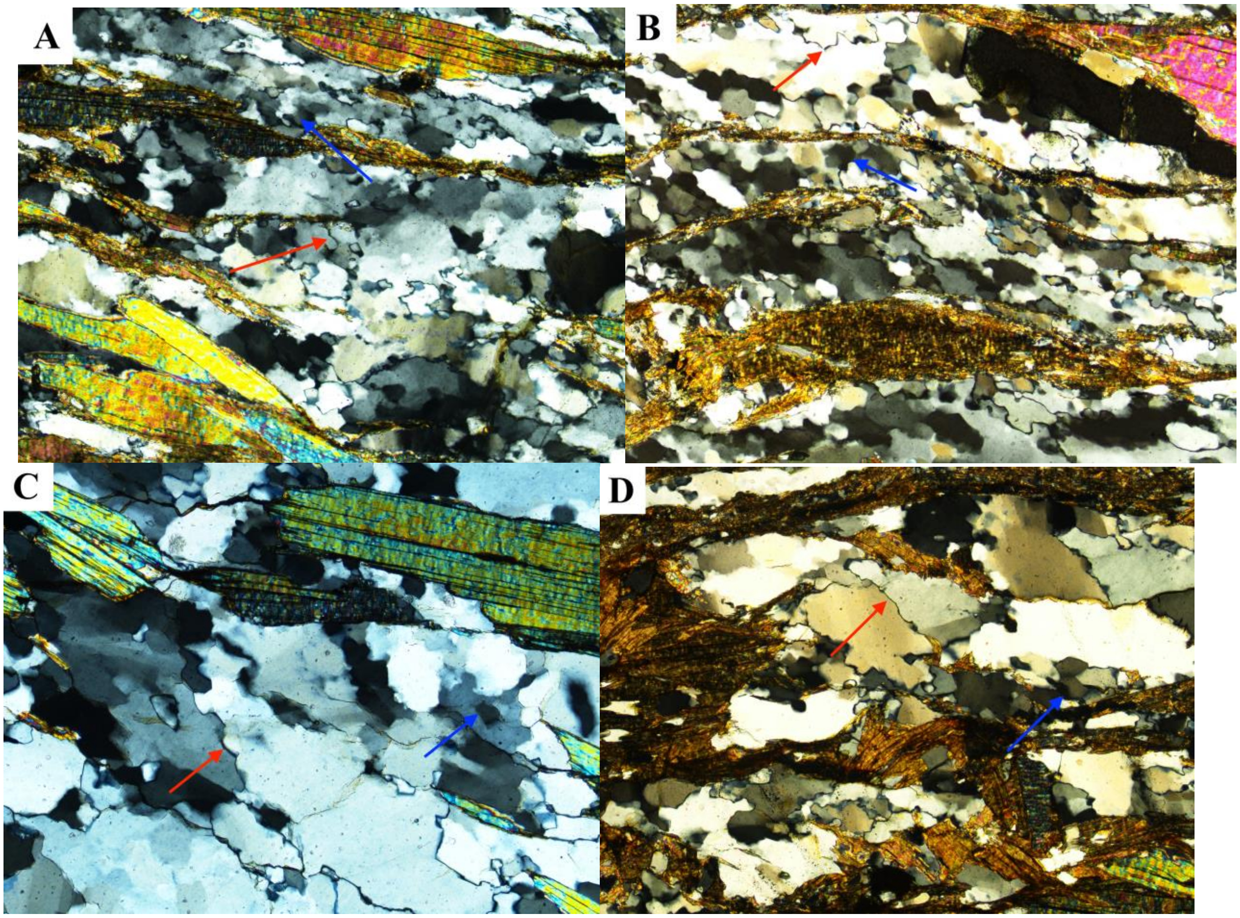
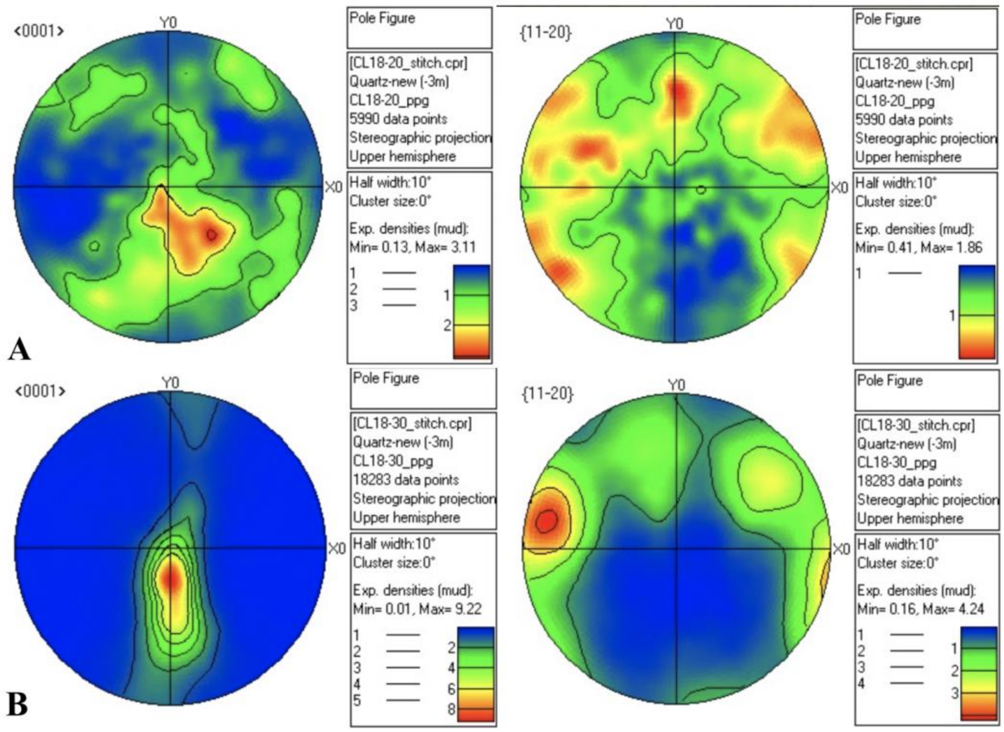


Figure 4. Quartz deformation in samples. A) Sample CL18-01exhibits BLG overprinting SGR. B) Sample D7S2, SGR with minor BLG overprinting. C) Sample D8S2, BLG with SGR overprinting. D) Sample SH17-01 exhibits BLG with SGR overprinting. Red arrows show BLG and blue show SGR.

3.2 EBSD Data

Plotting [c] <0001> and <a> axes {11-20} orientation from quartz in samples deformed under ductile conditions provides patterns that constrain deformation temperature. CL18-20 and D7S2 have opening angles. Sample CL18-20 has an opening angle of approximately 50° which means it formed at a temperature around 393° C (Table 1). Sample D7S2 has an opening angle of approximately 55°, meaning it formed at approximately 427° C (Table 1). CL18-30 has prism <a> slip which corresponds to a temperature of ~400-500° C. D8D2 shows basal <a> slip which corresponds to a temperature of <400° C. SH17-01 has a poor fabric.



<0001>
Y0
X0
Pole Figure
[CL18-20_stitch.cpr]
Quartz-new (-3m)
CL18-20_ppg
5990 data points
Stereographic projection
Upper hemisphere
Half width:10°
Cluster size:0°
Exp. densities (mud):
Min= 0.13, Max= 3.11
{11-20}
Min= 0.41, Max= 1.86
A
<0001>
[CL18-30_stitch.cpr]
CL18-30_ppg
18283 data points
Min= 0.01, Max= 9.22
{11-20}
Min= 0.16, Max= 4.24
B

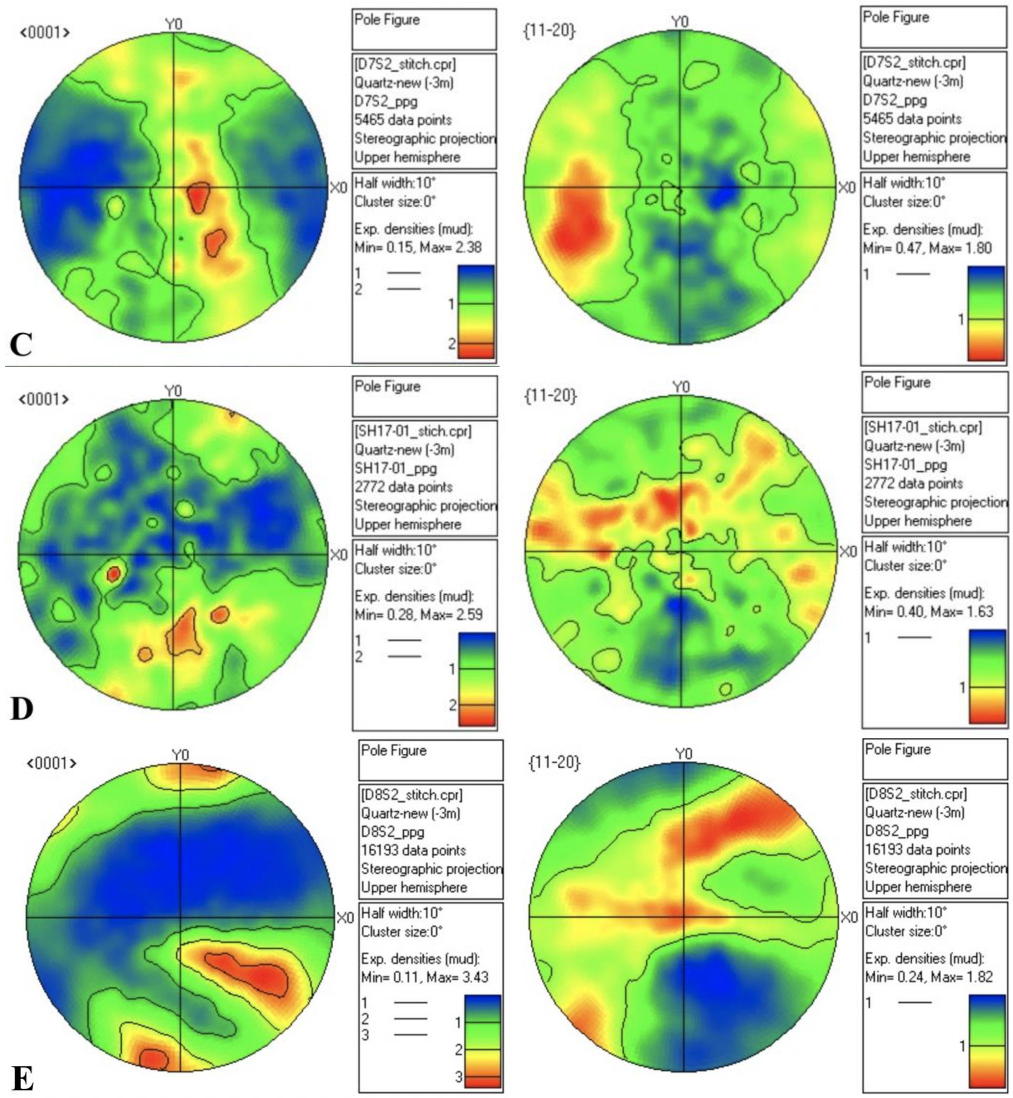


Figure 5. EBSD data A) CL18-20 B) CL18-30 C) D7S2 D) SH-1701 E) D8S2

Table 1. Sample and EBSD temperature based on EBSD indicators.

Sample	EBSD Temperature	EBSD Indicator
CL18-20	~393	OA ~50, faleiros 2016 eq 1, basal, rhomb, prism
CL18-30	400-500	no OA, prism <a> dominant
D7S2	~427	OA ~55, faleiros 2016 eq 1, basalt, rhomb, and prism
D8S2	<400	no OA, aleiros 2016 eq 1, basalt <a> only
SH17-01	na	Weak Pattern

3.3 Muscovite Ages

Muscovite samples collected in the field were analyzed for their ages last present at ~400° C. These ages allowed a bracket to be placed on deformation. Based on these ages it was determined when the fault was active. Sample CL19-33 records a muscovite age of 368.45±0.16 Ma, sample CL19-32 was 354.09±0.17 Ma, and CL19-31 circa 352.07±0.13 Ma (Figure 6).

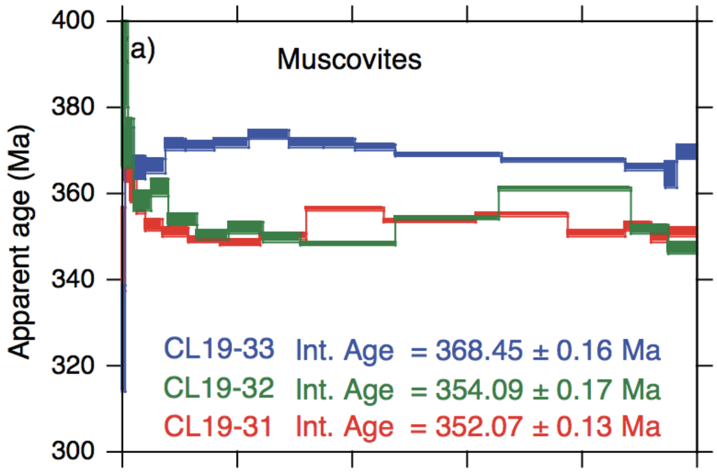


Figure 6. Muscovite closure temperature ages from samples within the Burnsville Faulting System.

4. Discussion

Past research, involving $^{40}Ar/^{39}Ar$ ages from hornblende, deformed leucogranite, and deformation temperatures from quartz, shows that the northern portion of the fault, close to Burnsville, was active 377-360 Ma (Figure 1)[3]. Muscovite $^{40}Ar/^{39}Ar$ cooling ages from the shear zone near Asheville suggest that deformation within the shear zone in that locality was active between ~350-362 Ma (Figure 2). EBSD and quartz deformation textures from this study suggest that the shear zone was active at temperatures of ~400° C, combined with a cooling age for muscovite of ~400° C, this suggests that deformation in this study area was ongoing at 350 Ma. These data suggest a younging of ages when the shear zone was at ~400° C toward the south, potentially reflecting a southward propagation of deformation.

5. Conclusion

The Burnsville Shear Zone is a dextral-strike slip fault that exhibits a younging of muscovite $^{40}Ar/^{39}Ar$ ages towards the south from Burnsville, NC toward Clyde. Previous studies suggest that the Burnsville fault was active circa ≥368 Ma north near Burnsville, NC while the toward the south near Clyde has an age circa <352 Ma. These ages are determined through the combination of muscovite ages and deformation temperatures suggesting this younging and deformation temperatures showing a correlation in cooler temperatures as you move south. This suggests that during the Acadian orogeny the contact between the Ashe Metamorphic Suite and Grenville basement rocks was overprinted in the north first and sheared down to the south, where it continued along the Hayesville fault.

6. Acknowledgments

Supported by the U.S. Geological Survey, EDMAP Program, under assistance Award No. G18AC00099 and from the University of North Carolina at Asheville. 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. Dr. Jamie Levine at Appalachian State Geology and Gareth Seward at UC Santa Barbara for help with acquisition of EBSD data.

7. References Cited

1. Adams, M., & Su, Q. ,1996, The Nature and Timing of Deformation in the Beech Mountain Thrust Sheet between the Grandfather Mountain and Mountain City Windows in the Blue Ridge of Northwestern North Carolina. The Journal of Geology, v.104 no.2, p. 197-213.
2. Stewart, K., Adams, M., and Trupe, C., 1997, Paleozoic structural evolution of the Blue Ridge thrust complex, western North Carolina, in, Stewart, K., Adams, M., and Trupe, C., eds., Paleozoic structure, metamorphism, and tectonics of the Blue Ridge of western North Carolina: Carolina Geological Society Fieldtrip Guidebook, p. 21-31.
3. Trupe, C., Stewart, K., Adams, M., Waters, C., Miller, B., and Hewitt, L., 2003, The Burnsville fault: Evidence for the timing and kinematics of southern Appalachian Acadian dextral transform tectonics: Geological Society of America Bulletin, v. 11, p. 1365-1376.
4. Waters-Tormey, C., and Stewart, K., 2010, Heterogeneous wrench-dominated transpression in the deep crust recorded by the Burnsville fault and related structures, Blue Ridge, North Carolina: Implications for the Acadian Orogeny in the Southern Appalachians: The Geological Society of America Memoirs, v. 206, p. 917-934.
5. Langille, J., Corradino, J., Cottle, J., Seward, G., in prep, Strain partitioning constraints of Acadian transpression across the Burnsville shear zone near Asheville, North Carolina, USA: Geological Society of America Bulletin.
6. Langille, J., Stachowicz, L., and Sith, J., 2020, Southwest extension of dextral transpression along the Burnsville fault into the Clyde 7.5-minute quadrangle, western North Carolina: Journal of Maps, DOI: 10.1080/17445647.2020.1737255
7. Ar-Ar methods, n.d., http://www.geo.uu.nl/~kikeb/thesis/database/ar/methods.html (accessed April 2019).
8. Stith, F., 2018, The Burnsville fault: Determining the southwest extension and relation to the Hayesville fault. UNCA Journal of Undergraduate Research.
9. Falerios, F.M., Moraes, R., Pavan, M., Campanha, G.A.C., 2016, A new empirical calibration of the quartz c-axis fabric opening-angle deformation thermometer. Tectonophysics, v.671, p. 173-182