Structural synthesis and spatial distribution of a 335 Ma igneous suite from the Eastern Blue Ridge, Alabama Appalachians

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by

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Abstract

The Appalachian range was formed by three orogenies, the most recent being the Alleghanian beginning at ~330 Ma. A small pluton outcropping along Highway 280 near Alexander City, AL, called the 280 granodiorite, has been dated at ~335 Ma and intrudes the Devonian Elkahatchee Quartz Diorite (EQD). While little work has been done on the intrusion, it is significant because of its age: all deformation of the intrusion should be related to the Alleghanian orogeny, while most other bodies in the region exhibit significant overprinting due to previous successive orogenies. The pluton was mapped constraining the geographic extent, which is relatively small with an exposure of ~0.20 km². Fractures, faults, and foliations were measured, with normal faults striking NW - SE and dipping NE; fractures with a W - NW strike and steep SW and NW dips; and foliations with a N - NE strike and moderate SE dip. Oriented samples were taken at several locations for petrographic and microstructural analysis. Petrographic assessment suggests the pluton is a muscovite granodiorite with a metamorphic overprint. Microstructural analysis reveals quartz deformed by grain boundary migration recrystallization, indicating amphibolite grade deformation. Shear sense indicators suggest predominantly dextral, reverse shear, with a few normal sense of shear fabrics. Field observations of brittle deformation indicate dextral, south-directed extension. In comparison, the nearby Wedowee Group has amphibolite grade dextral and extensional features. The 280 granodiorite has both reverse and normal amphibolite grade kinematic indicators, suggesting a record of high temperature contraction during the Alleghanian orogeny and below greenschist grade (faults) extension during orogenic collapse and formation of the Mid-Atlantic Ridge.

Keywords: Alleghanian, Eastern Blue Ridge, Elkahatchee Quartz Diorite, structural geology, microstructures, granodiorite, Alabama Appalachians, Alexander City
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List of Abbreviations

bt       Biotite
EBR      Eastern Blue Ridge
EQD      Elkahatchee Quartz Diorite
GPS      Global Positioning System
ksp      Alkali feldspar
mu       Muscovite
NAD      North Amerian Datum
pl       Plagioclase
QAP      Quartz-Alkali Feldspar-Plagioclase Feldspar (diagram)
qt       Quartz
UTM      Universal Transverse Mercator
WBR      Western Blue Ridge
Chapter I: Introduction

The Appalachian mountains formed from a series of three Paleozoic orogenies, due to the repeated collision of the paleocontinents Laurentia and Gondwana. The orogenies include the Taconic, which occurred at ~450 Ma; the Acadian, at ~380 Ma, and the Alleghanian, at ~330 Ma (Hatcher and Merschat, 2006; Maguire et al., 1999). The mountain range stretches from western Texas and follows the North American eastern seaboard northward, resuming along the western coast of Europe, making it one of the longest mountain belts in the world. The Appalachian mountains are divided into a series of regions based on lithology, structure, age, and tectonic history. Along the central portion of the range are the Blue Ridge Province, the Piedmont Province, and the Valley and Ridge Province (Rast, 1989). The Piedmont and Blue Ridge Provinces extend from eastern Alabama northward to Virginia, while the Valley and Ridge Province extends to Pennsylvania. The Blue Ridge Province is split into East and West regions. The Eastern Blue Ridge (EBR) is part of a series of allochthonous terranes that accreted by continental collision, and is primarily composed of igneous and metasedimentary rocks (Miller et al., 2006; Sherwood et al., 2010). All three of the orogenies have produced plutonism within the EBR region; however, few formed during the Alleghanian orogeny in this region (Drummond et al., 1997). As such, most plutons are heavily overprinted from repeated tectonic events, and this geologic complexity, coupled with limited exposures, has led to restricted mapping and interpretations of lower portions of the EBR.

The focus of this mapping project was in the EBR near Auburn and Alexander City, Alabama. The study focused on mapping a previously unidentified intrusion (Figure 1), dated at 335 Ma (Schwartz, personal communication 2017), just before the Alleghanian orogeny. Because of such timing, the pluton provides a record of an important pulse of magmatism and
deformation related to mountain building during the Alleghanian orogeny, one of the few intrusions to do so. Referred to as the 280 granodiorite, its extent is not well constrained and is not recognized on the Alabama state geologic map. This project set out to use traditional mapping methods of deformational features and sample collection to produce the first map of the 335 Ma intrusion, and produce measurements and descriptions of the intrusion’s structural features, with analysis of the samples and data resulting in the determination of the brittle and ductile deformation history and textural/petrographic analysis of the intrusion.

This study verified that the 280 granodiorite is a body distinct from other suites in the area. In this study, the lithology of the 280 granodiorite body was compared to accepted descriptions of nearby recognized formations, such as the Elkahatchee Quartz Diorite, Zana Granite, Hissop Granite, Emuckfaw Group members, and Wedowee Group members.

Figure 1: Image of 280 granodiorite outcropping along the intersection of US Highway 280 and AL-63 in Alexander City, AL.
Chapter II: Literature Review

Laurentia, the ancestral North American continent, and Gondwana, the ancestral South American and African continents, collided throughout the Paleozoic Era before the most recent collision created Pangaea during the Mississippian through Permian Periods (Dalziel et al., 1994). The first orogeny, the Taconic, occurred at ~450 Ma (Corrie and Kohn, 2007). It began with island arc accretion onto Laurentia as a result of subduction, leading to continent-continent collision, and is characterized by large-scale plutonism (Dalziel et al., 1994). Subsequent rifting formed separate continents again, which eventually led to subduction reinitiating for the second orogenic event, the Acadian, which began at ~380 Ma (Corrie and Kohn, 2007). Segments of Avalonia and terranes accreted onto Laurasia, with remnants preserved in modern day northeastern North America (Dalziel et al., 1994). The Alleghanian orogeny was the most recent event at ~330 Ma, and was the orogeny that resulted in the formation of Pangaea by the collision of Gondwana and Laurentia (Dalziel et al., 1994).

The Alleghanian orogeny formed the modern Appalachian mountains, and has been determined to have been an oblique dextral collision (Figure 2), with subduction initiating along the northern margin and progressing south (Simancas et al., 2005; Chestnut, 1991). The suture zone between the colliding continents dipped south/southeast (Hopper et al., 2017). Resulting from the orogeny were localized regions of amphibolite-grade metamorphism—which peaked at ~320-292 Ma—with crustal thickening, and typically exhibit dextral normal faults overprinted by mylonites, which is indicated by grain boundary recrystallization (Steltenpohl et al., 1995). Further extensional deformation continued into the Permian and Early Mesozoic from gravitational collapse and rifting (Steltenpohl et al., 1995).
Pangaea rifted apart starting in the Jurassic Period, leaving a series of accreted terranes on the North American continent that form various provinces within the Appalachian mountains as evidence of the collision. One such province is the Blue Ridge Province, extending southwest from Virginia into Alabama. The Blue Ridge Province is split into two regions: the Western Blue Ridge Province (WBR), a thrust sheet of gneissess, metavolcanic, and metasedimentary sequences; and the Eastern Blue Ridge Province (EBR) (Figure 3), a predominantly metavolcanic and metasedimentary Ordovician terrane potentially having formed in the Laurentian back-arc basin (Corrie and Kohn, 2007; Miller et al., 2006; Barineau et al., 2015).

In Alabama, the EBR is predominantly comprised of the Ashland-Wedowee-Emuckfaw belt, which exhibit amphibolite grade rocks with several bounding faults exhibiting dextral normal shear associated with the Alleghanian orogeny (Barineau et al., 2015). Also prominent within the Alabama EBR is the Elkahatchee Quartz Diorite (EQD), a batholith characterized by
its high biotite content, well-developed crystal-plastic foliation, and melanocratic composition (Drummond et al., 1997). Other local bodies include the Zana Granite, Hisopp Granite, and members of the Emuckfaw and Wedowee Groups, as well as the Kowaliga Gneiss and the Pinchoulee Gneiss (Szabo et al., 1988). Wedowee members are metasedimentary, notably graphitic schists to phyllites with local biotite gneiss, while Emuckfaw members are metagraywackes interbedding garnet-biotite schists and infrequent amphibolite (Neathery, 1975). Pinchoulee Gneiss, a member of the Hatchet Creek Group, is a migmatitic biotite-feldspar gneiss (Neathery, 1975), and the Kowaliga Gneiss is a coarse-grained quartz monzonite to granodiorite body containing plagioclase augen (Drummond et al., 1994). The Zana Granite also ranges from granite to quartz monzonite composition, though cross-cut with pegmatite dikes and has a gneissic texture; the Hisopp Granite is meso- to leucocratic, with variation from granite to granodiorite and exhibiting strong lineation (Deininger, 1975; Szabo et al., 1988).
Once igneous bodies are emplaced, they are weaker than the surrounding country rock while they cool, making them susceptible to developing ductile shear zones, and, once cooled, often exhibit steep strike-slip faults (Pennacchioni and Zucchi, 2013). Small plutons typically record noticeably different structures than that of batholiths; they are nearly entirely influenced by the regional strain field at the time of their emplacement, rather than by internal forces (Pinotti et al., 2016).
Chapter III: Methods

The primary instruments used in the field were field books for note taking and sketches, topographic maps to plot structural measurements and track and label rock types based on their geographic location, rock hammers and chisels to break off samples after orientation, Brunton compasses to measure the orientation of structural features, and hand lenses for rock identification. At the outcrop, each observed section was mapped by marking on a topographic map of the area and by taking GPS coordinates using Universal Transverse Mercator (UTM) based on North American Datum (NAD) 83. Once the location of a sample stop was established, the stop was noted in a field notebook, which serves as a transcript of observations and measurements. Each stop involved recording what stop it is (cross-referenced with the topographic map), a brief description of important details in how to reach that location from the previous stop, and any important information such as hazards or inaccessibility. Observation of a rock, including any visible structures (e.g., folds, fractures, alignments) or contacts between rock units were made and recorded. Specific information regarding the rock, including color, texture, mineralogy, rock name, and deformation structures was also recorded. Structures were measured using Brunton compasses, which enable strike and dip to be measured for planar features and trend and plunge to be measured for linear features. Structural measurements were recorded, as well as postulations, before ending the entry in the field books. This sequence took place at each location the pluton was observed, until the geographic extent of the pluton had been constrained.

Outcrops exhibiting deformational features were sampled after being oriented in space and marked to preserve their orientation. Samples were taken that appeared to be representative of the pluton or outcrop, and at any time there seemed to be textural or mineralogical variation. Samples were taken from all parts of the pluton to ensure the full variability of the pluton’s
structures, textures, and compositions was able to be assessed. To orient a sample, an in situ segment of the outcrop—uncompromised by fractures or weathering and with a relatively flat face—was oriented by measuring the strike and dip of the sample face. This orientation was marked on the sample. The sample GPS coordinates at that location were recorded. Oriented samples were then taken to the lab and set up in a sand box, and using the notations marked on the sample, reoriented in space as they had been in the outcrop. By doing so, all observations from outcrop to microstructure scale were able to be placed in the regional context.

Data analysis and lab work began once the field work was complete. A map was created using the marked GPS coordinates logged in the field books and the stops marked on the topographic maps, and compared to results from petrographic analysis. If a rock sample was notably different in mineral assemblage and/or texture, it was not considered part of the same igneous suite.

Samples taken in the field were cut down to oriented billets in the University of Southern Mississippi geology lab using a tile saw and a lapidary saw. Hand samples were cut parallel to lineation and perpendicular to foliation to capture the XZ—or kinematic—plane. Once thin slices (~3-5 mm) of the hand samples were cut with the tile saw, they were marked to billet size and oriented to the orientation of the hand sample. When cutting the billet, one notch was cut in the side oriented in the up direction, and two notches in the side to which the sample had been striking. These oriented cuts were then sent to Spectrum Petrographics, Inc., where thin sections were created from the billets. The thin sections are the standard thickness of 30 µm, with no cover slips so as to enable further analysis, such as using micro-beam techniques. A petrographic microscope was used to analyze the thin sections, reaffirming and refining mineralogical assessments from hand samples. Thin sections also reveal details on deformation mechanisms,
kinematics, and alignment structures. Microstructure analysis, when paired with oriented samples, can help to determine the shear sense of the deformation, assisting in determining the regional shortening direction.

From the orientation measurements collected in the field, stereonets, a method of plotting three-dimensional structures on a two-dimensional graph, were generated using the program Stereonet (Allmendinger et al., 2012; Cardozo and Allmendinger, 2013). Stereonets enable structure orientation to be plotted and the spatial relationship between outcrop structures and regional structures to be assessed. Analysis can indicate structures at a scale difficult to see in the field, or diagnose multiple deformation events.
Chapter IV: Results

Data was collected from 18 locations, spread across two main areas, and is tabulated in Appendix A. Stops 1.1 through 1.14 are located within the first area, with 1.1-1.13 at one main outcrop at the intersection of U.S. Highway 280 and Alabama Highway 63, while 2.1 through 2.4 are located along Elkahatchee Creek by Highway 63 (Figure 4).

Figure 4: Series of maps regarding the setting of the 280 granodiorite. 1a. Locations of samples collected for this project, with reference to Alexander City, Highway 63 and Interstate 280. The black box is highlighted in 1b, while the white box is highlighted in 1c. 1b. Sample locations along main outcrop of the 280 Granite. 1c. Sample locations taken along Elkahatchee Creek. From left to right, purple tint indicates EQD, while tan represents the Wedowee Group, gray the Emuckfaw Group, and red Zana Granite.
Lithology

The main outcrop along highways 280 and 63 is composed of varying amounts of plagioclase feldspar, quartz, alkali feldspar, and muscovite, with occasional biotite and few trace minerals. The outcrop is fine-grained, with a light orange weathering. Plagioclase feldspar crystals are generally the largest crystals visible within the samples. Many samples contain plagioclase crystals that exhibit optical zoning (Figure 5). Progressing from the southeast corner of the outcrop along the exposure towards the northwest corner, plagioclase generally become larger and slightly more angular. Alkali feldspar is usually anhedral, while quartz and muscovite is small and predominantly defines the foliation.

![Figure 5: Plagioclase feldspar crystal exhibiting optical zoning in EBR-AC-03 (left) and EBR-AC-10 (right). Red arrows point to more apparent zone boundaries.](image)

Approximate mineral proportions for all samples taken are summarized in Table 1. Sample EBR-AC-01, taken at Location 1.1 from the southeastern margin of the outcrop, contains the least concentration of quartz but the most alkali feldspar, and has a higher muscovite content. Progressing northwest from 1.1 along the outcrop, quartz content gradually increases while alkali feldspar decreases; plagioclase concentration remains roughly constant. The relative
Table 1: Approximate percentages of mineral composition from each sample.

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Figure 6: A. Overview of EBR-AC-06, representative of the 280 granodiorite composition. B. Overview of sample EBR-AC-11, taken from the Elkahatchee Quartz Diorite. C. Overview of sample EBR-AC-15, from the Emuckfaw Group. Abbreviations: pl = plagioclase, ksp = alkali feldspar, qt = quartz, mu = muscovite, bt = biotite
mineral proportions adhere to this trend until sample EBR-AC-11, which in the field was posited to be the Elkahatchee Quartz Diorite. The high concentration of plagioclase feldspar, absence of alkali feldspar, and a large proportion of biotite make it distinct from the rest of the outcrop. Samples EBR-AC-13, EBR-AC-14, and EBR-AC-15 are thought not to be a part of the 280 granodiorite. EBR-AC-14 and 15 were sampled from an area known to be in the Wedowee Group, exhibiting a much finer grain, stronger demonstration of foliation, and a composition with less plagioclase and more muscovite (Figure 6). EBR-AC-13 will be discussed

Figure 7: QAP diagram with the compositions at each stop, excluding EBR-AC-11, sampled from the EQD, and EBR-AC-14 and EBR-AC-15, sampled from the Wedowee Group. The compositions plotted in a pattern increasing in plagioclase and quartz contents while decreasing the potassium feldspar content. This generated a plot predominantly within the granodiorite classification. From the outer edge of the pluton (1.1 in Figure 2) moving inwards towards the EQD (1.12 in Figure 2) would be classified from a plagioclase-rich granite grading towards a quartz-rich tonalite, respectively.
in greater detail later on, but compositionally has less quartz and more muscovite than seen in the samples from the main outcrop.

Plotting the mineral proportions of samples EBR-AC-01 through EBR-AC-10 and EBR-AC-12 on a QAP diagram, the outer southeast edge of the outcrop classified as a plagioclase feldspar-rich granite grading towards the EQD to a quartz-rich tonalite, with a predominant classification of granodiorite (Figure 7).

Structural Measurements

Foliations were observed within all phases present, though as mentioned previously, quartz and muscovite are the predominant indicators. The average foliation strike is 024°, with an eastward dip of 34° from horizontal (Figure 8). All foliations exhibit an eastward dip, with the exception of two outliers. One outlier, 203/65 NW, was taken at location 1.14. It is noted that the measurement was taken at a point where the integrity of the measurement could be

Figure 8: Two equal-area stereonets of foliation measurements taken from the 280 Granodiorite. A includes the outliers discussed in the text, with B only included all points aside from the two anomalous measurements. Plotted using Stereonet program (Allmendinger et al, 2012; Cardozo and Allmendinger, 2013).
compromised, as there was a fracture behind the point at which the measurement was taken. The second outlier, 119/76 SE, taken at location 2.4, did not appear to be taken from a part of the outcrop with questionable integrity; however, a secondary measurement at the same location conforms with the other data.

Metamorphic lineations were measured in a few samples by cutting them in the lab and re-orienting them based on their field orientation. The lineation, defined by elongate quartz and muscovite crystals, is shallow, plunging less than 20° (Figure 9). This indicates a significant amount of strike-slip motion.

![Figure 9: Stereonet with the lineation measurements plotted. EBR-AC-05 has a lineation of 20→024, while EBR-AC-06 has a lineation of 06→196 (Allmendinger et al, 2012; Cardozo and Allmendinger, 2013). Red = reverse; blue = normal; black = strike slip.](image)

All fractures are steeply dipping at angles 75° or greater, with one exception at 68°. This exception, 259/68 NW, was taken at 1.7 amongst three other fracture measurements of 298/86 SW, 295/88 NE, and 294/75 NE. Both strike and dip noticeably vary from all others measured at that location and at the other locations, and the NW dip direction is also incongruous with the NE/SW directions seen in all other measurements. Aside from the outlying measurement, the
fractures group into two close groups depending on dip direction, represented by the two large petals in the rose diagram (Figure 10). Between the two groups, the mean vector is 109.7° ± 06.2°, which is fairly consistent and is parallel to the NW-SE shortening direction.

Figure 10: Stereonet of the fractures measured, with a rose diagram overlay to better show the two groupings of fractures and the anomalous nature of the NW dipping fracture. The general trend shows two groups of fractures dipping to the NE and SW, with an angle between the two clusters of approximately 24.6° (Allmendinger et al, 2012; Cardozo and Allmendinger, 2013).

Figure 11: Stereonets plotting fault measurements. A. All faults included. B. Faults with observed slickenlines. Stereonet constructed with Stereonet program (Allmendinger et al, 2012; Cardozo and Allmendinger, 2013).
Seven faults were measured, and while all dipped either NE or SE, the strikes and dips vary wildly: strike ranges from 027 to 172, while dip is as shallow as 5° and as steep as 90°. Figure 11 summarises the spread in a stereonet. Few faults have observable slickenlines. The fault at location 1.1 does, however, and was determined to be a right lateral normal fault, with an orientation of 20 → 201. A fold hinge with a trend and plunge of 05 → 221 was observed at location 1.11, at which there is a pod of the pluton body within the EQD.

**Microstructures**

Shear sense indicators, such as sigma and delta clasts, are predominantly plagioclase crystals, with pressure shadows filled by quartz, alkali feldspar, and muscovite. Most samples exhibit right lateral shear, and upon comparison to their oriented samples were determined to indicate dextral, reverse shear. Results are not clear-cut, however, and some shear sense indicators exhibit normal sense of shear. Subsequent assessment of mineral lineation (briefly touched on previously) demonstrates a strike-slip component. Figure 12 shows sigma and delta clasts as shear indicators.

![Figure 12: Examples of plagioclase crystals indicating right-lateral shear: A. Right lateral sigma clast of plagioclase. B. Left lateral delta clast of plagioclase. Abbreviations for mineral identification are as follows: qt = quartz, ksp = alkali feldspar, pl = plagioclase feldspar, mu = muscovite, and bt = biotite.](image)
Boundaries between quartz crystals are irregular and lobate, with intrusions of one quartz crystal into another (Figure 13). This type of texture is indicative of grain boundary migration recrystallization, regime 3 of quartz boundary recrystallization as defined by Hirth and Tullis (1992). The quartz behavior and regime indicate amphibolite grade deformation, supporting a middle range pressure and temperature scheme.

Figure 13: A. Quartz cluster indicative of amphibolite grade deformation. B. Quartz grain boundary migration, noted by the red arrow, indicates regime 3 quartz boundary recrystallization (Hirth and Tullis, 1992). Abbreviations for mineral identification are as follows: qt = quartz, ksp = alkali feldspar, pl = plagioclase feldspar, mu = muscovite, and bt = biotite.
Chapter V: Discussion

The geographic extent of the 280 muscovite granodiorite is undetermined. The 280 muscovite granodiorite appears to outcrop only at the exposure sampled. Sample EBR-AC-13, approximately 0.33 km to the south, does not seem to be a part of the body. The outcrop from which the sample was taken is split with a contact, with the northern third (the part closest to the main outcrop) appearing to be the EQD (as it is white and black) and the southern two-thirds felsic, where EBR-AC-13 was sampled. The only outcrop of the 280 muscovite granodiorite appears to be at the sampled exposure (Figure 1), some of which contacts the EQD. Therefore, the 280 body has a surface exposure of ~0.20 km², centered around the outcrop and the northern edge along the contact with the EQD.

From the southeast corner of the outcrop towards the northeast where the 280 muscovite granodiorite contacts the EQD, the granodiorite has modal variation. Near the EQD, the composition is a tonalite. With a higher proportion of plagioclase, it is likely that the 280 muscovite granodiorite cooled earlier nearer to the EQD since plagioclase would be one of the first minerals on the solidus. The further from the EQD, there were higher proportions of alkali feldspar, which may indicate a small differentiation, being more differentiated away from the EQD, as it cooled at different rates. This apparent outer edge also appears to record ductile deformation to a greater extent than near the EQD, which supports a slower cooling rate, meaning this part of the pluton was hotter longer and therefore more susceptible to ductile deformation. The EQD could have influenced this by more rapidly cooling the adjacent part of the 280 granodiorite, making it stronger and less susceptible to ductile deformation.

The ductile deformation defined by microstructures predominantly indicates a reverse shear with a dextral strike-slip component. Crystallized quartz grain boundaries indicate
amphibolite grade metamorphism. With the Alleghanian initiating at ~330 Ma, and the 280 muscovite granodiorite dated to 335 Ma, the body was emplaced in the mid-lower crust shortly prior the initiation of the Alleghanian orogeny. The 280 muscovite granodiorite would still be ductilely deformable throughout the orogeny. As the main tectonic event for the region at the time, the dominantly strike-slip sense of shear in the ductile deformation recorded should be characteristic of the tectonic strain from the Alleghanian orogeny. This data conforms to the collision of Laurentia and Gondwana, indicating an indirect collision, with the continents first colliding along the northern margin before zippering down further south, creating the dextral shear indicated by Central Appalachian foreland basin analysis (Chestnut, 1991) and transcurrent faults in the American northeast (Simancas et al., 2005).

Brittle deformation overprints the ductile deformation, with faults and fractures present across the outcrop. Faults able to be assessed were determined to be normal, indicating an extensional environment followed the orogenic event. The region has a variety of potential causes for brittle overprinting indicative of an extensional environment on the 280 muscovite granodiorite. Regional extension has been speculated to be a result of post-Alleghanian orogenic collapse (Barineau et al., 2015; Steltenpohl et al., 1995), though Mesozoic rifting, both related to collapse and distinct, has also been considered a cause (Steltenpohl et al., 2013). The 280 muscovite granodiorite is likely to have recorded such events through the brittle deformation overprint. This record potentially then shows the progression of the full orogenic cycle, with the initial shortening, followed by ceasing subduction with a subsequent orogenic collapse and extension.
Chapter VI: Conclusions

The 280 pluton is a small muscovite granodiorite body with a metamorphic overprint exposed over approximately 0.20 km². The 280 muscovite granodiorite is distinct from the surrounding rocks and nearby formations, and should be considered a separate body. With all phases present defining the foliation and shear sense indicators, the pluton was still ductile during the collision of Laurentia and Gondwana during the formation of Pangaea, and recorded the north-south, oblique progression of collision. At the time subduction ceased and subsequent orogenic collapse, the pluton was no longer ductile, leaving the extensional strain to overprint brittle deformation in the form of fractures and normal faults.

With a very simplistic overview of the 280 muscovite granodiorite, there is still a great deal that can be done. A more precise assessment of the compositions could more accurately describe the variation within the body, and could better affirm the exclusion of EBR-AC-13 from the body. Additionally, working with the outcrop at 1.14, if the outcrop is indeed a separate entity, could provide support or further information for the tectonic stresses from the Alleghanian onward, if the rocks are of similar age to the 280 muscovite granodiorite. Finally, the source and cause of the intrusion is not well understood.


Appendix A

Measurements taken in the field, by Universal Transverse Mercator location using North American Datum 83 along with strike and dip or trend and plunge.

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