GEOLOGY OF THE CALHOUN CRITICAL ZONE OBSERVATORY

by

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(Under the Direction of Paul Schroeder)

ABSTRACT

The Calhoun Critical Zone Observatory (CCZO) is an interdisciplinary field site, located in Union, South Carolina that examines Critical Zone response to human interaction and the role the underlying bedrock has on Critical Zone structure. Currently, no detailed work has been done to map the bedrock or structural geology in the area. In order to advance this understanding, the present study used geologic mapping, petrography, X-ray Diffraction, and geochemical analysis to characterize the lithologies present at the CCZO. The field site was interpreted to contain a portion of the Central Piedmont Suture which bounds the Cat Square and Charlotte terranes present at the field site. The new interpretation of the Central Piedmont Suture lies farther west than previously described and provides new territory to investigate the history of the Appalachian orogeny.

INDEX WORDS: Calhoun Critical Zone Observatory, Geology, Mapping, Geochemistry, Central Piedmont Suture, Southern Piedmont, Cat Square terrane, Charlotte terrane, Appalachian orogeny, Union County, South Carolina

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Calhoun Critical Zone Observatory

The Calhoun Critical Zone Observatory, located in Union, SC, is one of nine in a national network of interdisciplinary field sites organized under the direction of the U.S. National Science Foundation since 2013 (Fig. 1). These Critical Zone Observatories examine the structure, fluxes, and responses of components in the terrestrial sphere that reaches from the upper portion of the crust to the treetops, all of which are influenced by meteoric water (Banwart, 2012). Since the inception of this concept, it has been noted the coevolution of the Critical Zone occurs with humans with Banwart (2012) stating that "growth in human population and demand for wealth creates ever-increasing pressure on global soils, leading to soil losses and degradation worldwide. Critical Zone science studies the impact linkages between these pressures, the resulting environmental state of soils, and potential interventions to protect soil and reverse degradation."

To further examine Critical Zone response to human activity, the CCZO was selected as a field site due to its unique land use history. The CCZO experienced heavy anthropogenic landscape change during the 20th century that led to massive erosion due to poor farming practices and subsequent recolonization of forest communities (Coughlan et al., 2017). This recent perturbation allowed for an ideal outdoor experimental area to tease apart factors of land use, geomorphology, climate, and underlying geologic variability into Critical Zone studies.

Many published studies out of the CCZO have sought to examine the changes in Critical

Zone processes in these highly weathered soils by comparing sites that have different land use

histories, hillslope positions, and watershed scales (e.g., Billings et al., 2018; Hodges et al.,

2019; Wade et al., 2020). These studies were unable to consider the effects differing bedrock

lithologies might have had on their results because the CCZO has not had a detailed geologic

map prepared (Fig.1).

In addition to examining the relationship between humans and the Critical Zone, the

CCZO was also directed to look at how changes in bedrock lithology affect Critical Zone

development (Dietrich and Lohse, 2014). Despite this directive, no detailed work had been done

to map the bedrock lithologies in the area, which was the motivation for the present study. The

production of a geologic map would provide greater control on experimentation and more

importantly, provide key insight to potential relationships between the Critical Zone structure

and the surrounding bedrock lithologies.

1.2 Mapping in South Carolina

Lack of a detailed geologic map was not only a concern at the CCZO, but also a concern

for many quadrangles in South Carolina. At the present time, a significant part of South Carolina

remained unmapped at the quadrangle scale (Fig. 1). To the west of the CCZO, one map named

the Philson Crossroads quadrangle was produced by Horkowitz (1984). This map showed two

distinct geologic terranes, or structurally bound allochthonous groups of rocks that share a

distinct history from surrounding rocks (Howell, 1995). These two groups are the Cat Square

terrane and the Charlotte terrane (Fig. 2).

Charlotte terrane lithologies mapped in Philson Crossroads had been used by multiple

studies to examine the nature of volcanism in the peri-Gondwanan island Carolinia which will be

detailed more in later sections (e.g. Dennis and Wright, 1997; Dennis and Shervais, 1991; West, 1998). The production of more detailed geologic maps in the surrounding area would not only aid in providing new areas to research the geologic history of the region, but it would also benefit the CCZO's goal to further understand interactions between the bedrock and the Critical Zone.

1.3 Geography

The CCZO lies in the western portion of Sumter National Forest in Union, South Carolina (Fig. 3). This portion of South Carolina is a part of the Piedmont physiographic province defined by gently rolling hills on highly weathered saprolitic Ultisols that reached depths up to 100 ft (Fig. 4; Thornbury, 1965). At the field site, fluvial systems showed dendritic patterns often originating from highly developed gullies and interfluves (Richter et al., 2014). Floodplains in the area were well developed occurring adjacent to higher order streams. Interfluves displayed the highest degree of weathering and saprolitization while fluvial channels frequently revealed bedrock mirroring their transport-limited and weathering-limited local environments respectively (St. Clair et al., 2015).

1.4 Geologic History of the CCZO

The geologic history of the CCZO spans across a billion years of Earth history and involved the formation and break up of two separate super-continents, Rodinia and Pangea (Hatcher et al., 2010). During the formation of Rodinia, the Grenvillian orogeny occurred from 1.3–1.0 Ga along proto-Laurentia's margin. This mountain belt (although at much different paleolatitudes) followed a similar strike to the present-day Appalachians (Thomas, 2006). Subsequent rifting of Rodinia in the Neoproterozoic developed the Iapetus Ocean basin in between Laurentia and Gondwana around 565 Ma (Merschat, 2009). This ocean basin accumulated mixed sediments from both Laurentia and Gondwana (as evidenced through zircon

geochronology) and would serve as the protolith for the Cat Square terrane (Huebner et al., 2018).

Along the Gondwanan margin, the newly formed oceanic crust was subducted under the continent forming a volcanic island arc around the Neoproterozoic–Paleozoic boundary. Here, the island Carolinia developed with major eruptive events at 633 Ma and 528 Ma (Fig. 5; Wortman et al., 2000). The middle Paleozoic marked the closure of the Iapetus Ocean leading to the collision between Carolinia and Laurentia in the late Ordovician (Pollock et al., 2011). Gondwana thrusted over Laurentia zippering from north to south with some dextral strike slip component through the late Paleozoic forming the Appalachian Mountains (Secor et al., 1986; Hatcher, 2010). The extensive thrusting formed nappes along the Laurentian border emplacing several exotic terranes sutured onto Laurentia (Fig. 5; Griffin, 1972; Williams and Hatcher, 1983).

By the end of the Mesozoic, the collisional tectonics ended and extension would cause Pangea to rift apart to the Tethys Ocean around 200–183 Ma which would later develop to the Atlantic Ocean (Frizon de Lamotte, 2015; Hibbard, 2002). This extension left behind several joint sets, still observable in the field today (Merschat, 2005). In recent history, intensive weathering exposed the high pressure and high temperature metamorphic rocks from the interior of the Appalachian Mountains.

1.5 Cat Square Terrane

The Cat Square Terrane was formed from the accretion of the Iapetus Ocean basin during the late Silurian and Devonian (Hatcher and Mershcat, 2006). Sediments collected in the ocean basin share a complex history with the surrounding environments. The oldest detrital zircons in the Cat Square were dated using U/Pb to the Grenvillian orogeny sharing both Laurentian and

4

Gondwanan affinity (Huebner et al., 2018). A younger pulse of zircons was observed from the Ordovician-Silurian which serves as the maximum age of the Cat Square terrane (Huebner et al., 2018). If the rocks were older than the Ordovician-Silurian, they would not have been able to incorporate these detrital zircons.

These volcanogenic and weathered sediments were thrusted and buried onto the Laurentian margin undergoing high grade metamorphism during the orogeny. This resulted in the formation of a sequence of metasedimentary rocks including paragneiss, amphibolites, pelitic schists, calc-silicates, and orthogneisses intruded by anatectic peraluminous granitoids during the Silurian-Devonian (Merschat and Hatcher, 2007). Gneisses were described as the most abundant unit appearing as a metagraywacke with a "K-feldspar plagioclase-biotite-quartz" composition having "abundant quartzofeldspathic leucosome(s)" (Huebner, 2018). Granites in the Cat Square terrane have been described as medium-grey slightly foliated rocks with K-feldspar, quartz, biotite and minor muscovite mineral assemblages (Griffitts and Overstreet, 1952).

These rocks generally form lenticular structures that follow the strike of the Appalachian (and Grenvillian) Mountains which is perpendicular to the vergence of Gondwana (Fig. 2; Griffits and Overstreet, 1952; Secor et al., 1986a). The overall structural fabric of the Cat Square terrane is NE trending with gently dipping sillimanite-grade migmatic rocks that were deformed into recumbent nappes (Hatcher, 2006). Two major fault systems bound the Cat Square terrane (Fig. 2). To the north, the Cat Square meets the Tugaloo terrane at the Brindle Creek Fault, and to the south, the Cat Square meets the Charlotte Terrane at the Central Piedmont Suture (Merschat et al., 2005). Rocks of the Cat Square terrane were crosscut by NE trending silicified breccias related to faulting during the Mesozoic opening of the Atlantic Ocean (Secor et al., 1986).

1.6 Charlotte Terrane

The Charlotte terrane was formed from the accretion of Carolinia onto the Laurentian margin. Initially, the mafic volcanic protolith that would become the Charlotte terrane was erupted off the coast of Gondwana in an island arc setting where oceanic crust from the Iapetus Ocean was subducted under Gondwanan crust (Pollock et al., 2011). The subduction zone led to the formation of two major arc systems, the Hyco magmatic arc, ~633–612 Ma, and the Albemare arc, 555–528 Ma which are separated by the volcaniclastic Virgilina sequence (Hibbard et al., 2007). Rifting separated Carolinia from Gondwana around ~545 Ma to form the Rheic ocean and began the convergence of Carolinia and Laurentia (Hibbard et al., 2013). Although not precisely dated, Carolinia is thought to have converged with Laurentia in the Devonian producing several plutons in the process (Pollock et al., 2011). In the southern portion of Laurentia, Gondwana would converge during the Alleghanian orogeny between ~315–268 Ma exposing Carolinia to high pressures and temperatures (Dallmeyer et al., 1986).

These metamorphic conditions altered the mafic volcanic rocks of Carolinia into those seen in the Charlotte terrane today. Locally, this terrane was described to contain rocks including meta-diorite, meta-gabbro, hornblene-gabbros, and meta-clinopyroxenites that typically formed zoned complexes ~10 km in diameter. The weakly foliated meta-diorites make up the majority of the rocks in the terrane while the meta-gabbros and meta-clinopyroxenites are subordinate (Dennis and Shervais, 1996). These meta-plutonic rocks are a slight departure from other rocks in the Carolina superterrane, of which the Charlotte terrane is a part. Other parts of the Carolina superterrane were described as containing more metamorphosed volcanic ash which produced expansive slate belts in the Carolinas (Griffin, 1974).

The structural fabric is slightly different between the Cat Square terrane and Charlotte terrane. The Charlotte terrane trends slightly more north and has a steeper dip than the Cat Square terrane (West, 1998). However, the Charlotte terrane rocks still reside in a nappe tectonic regime and display recumbent folds with some reclined folding (Griffin, 1972). Rocks of the Charlotte terrane were also crosscut by NE trending silicified breccias related to faulting during the Mesozoic opening of the Atlantic Ocean (Secor et al., 1986).

1.7 The Central Piedmont Suture

The Central Piedmont Suture lies along the interface between the Cat Square and Charlotte terranes extending from Georgia through the Carolinas (Fig. 2; Huebner, 2017). Historically, the suture had been interpreted as both a low angle normal fault and a thrust fault but has been more commonly referred to as a thrust fault system (Dennis, 1991; West, 1998). The Central Piedmont Suture has a dextral component as well (Merschat, 2009). In South Carolina, the fault has been readily identified through a sharp lithologic contact between the mafics of the Carolina superterrane abutted next to the felsic gneisses of the Cat Square terrane (Horkowitz, 1984).

1.8 Hypothesis

From background research on the Appalachian orogeny, the present study sought to confirm that the CCZO would display both the Cat Square terrane as well as the Charlotte terrane joined by the Central Piedmont Suture. Additionally, it hoped to find evidence of thrust tectonics with the Charlotte terrane overriding the Cat Square terrane.
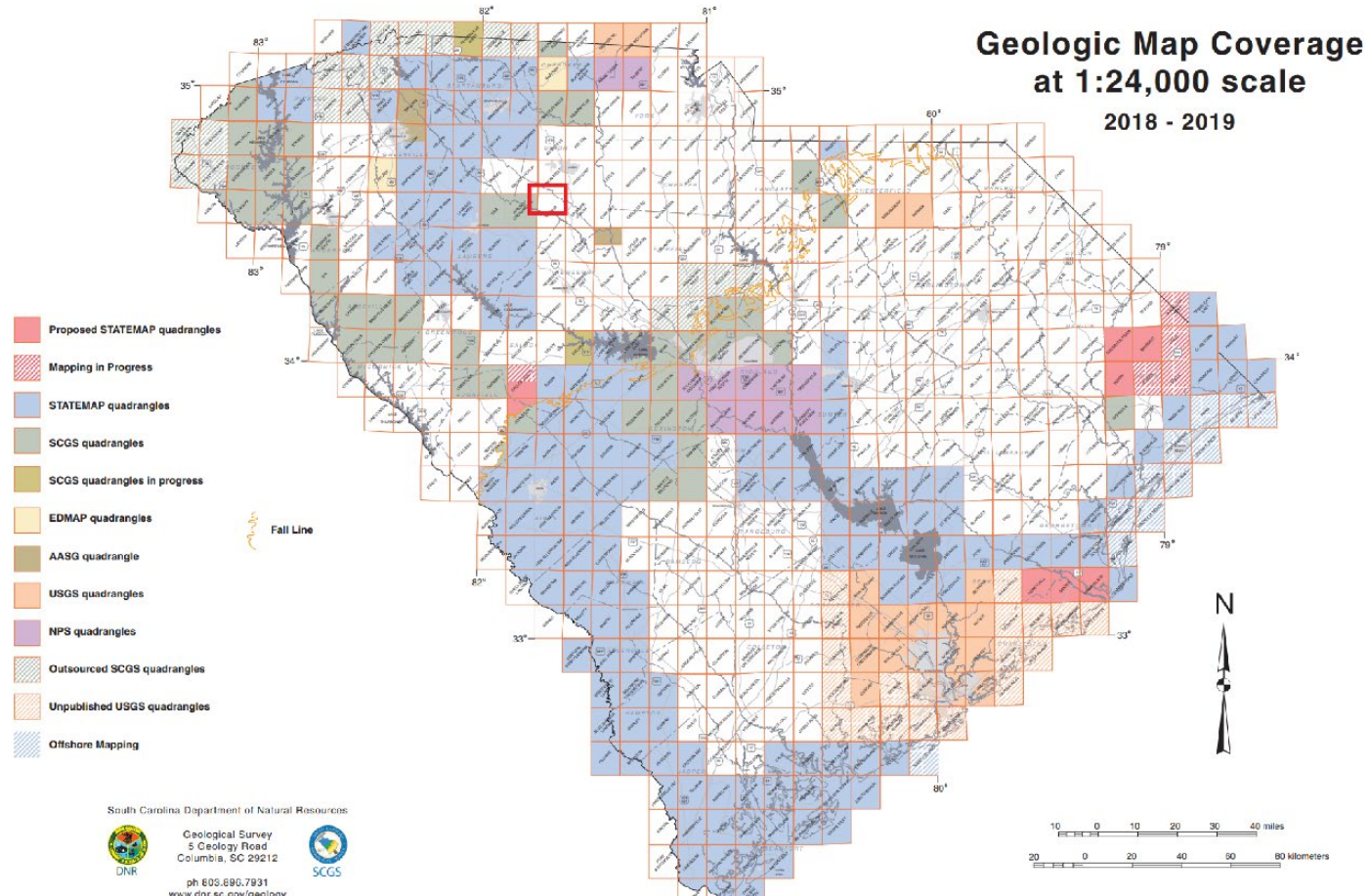
Figure 1: In South Carolina, areas in white do not have a quadrangle scale map produced. The CCZO and the mapped region are located in the red rectangle overlapping with the Sedalia, Union West, and Cross Anchor quadrangles (modified from SCDNR, 2018).
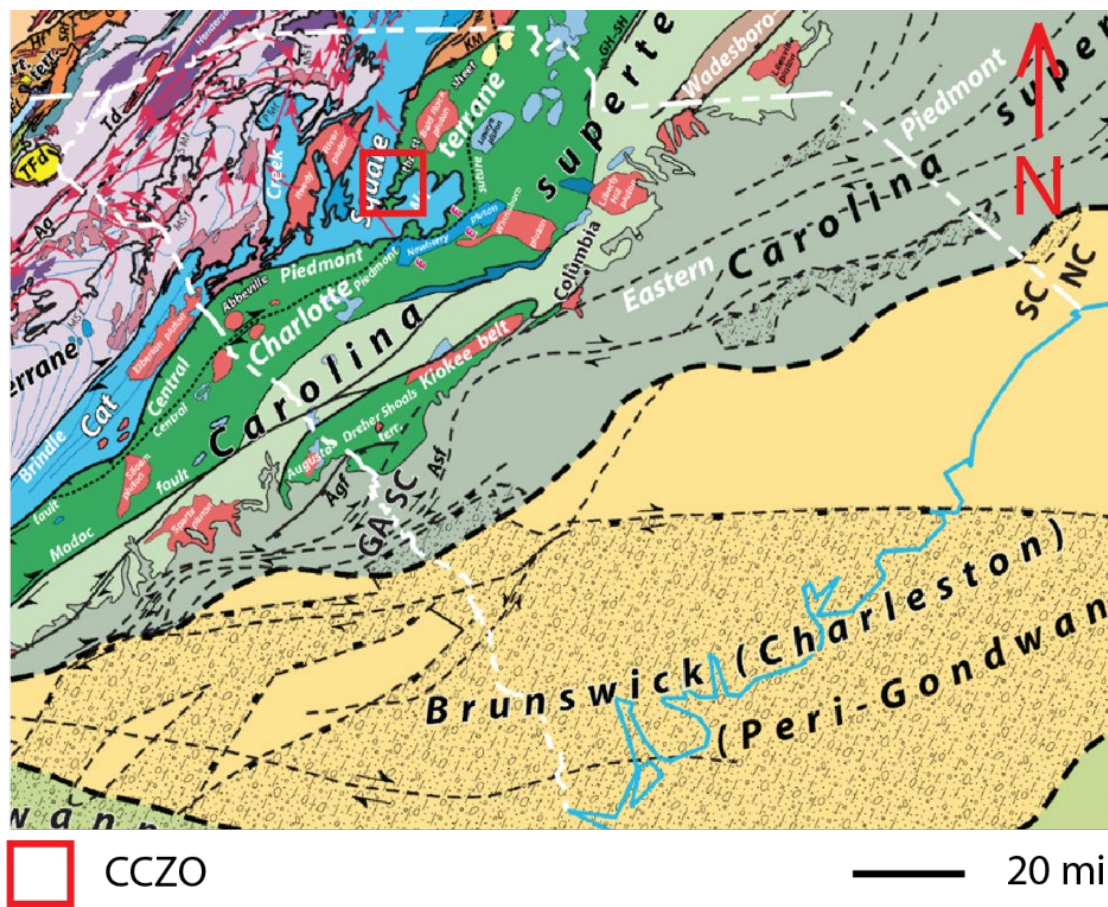
Figure 2: Regional geology of South Carolina with field area highlighted in red. The boundary between the light blue Cat Square and green Charlotte terrane represents the Central Piedmont Suture (adapted from Hatcher et al. 2007).
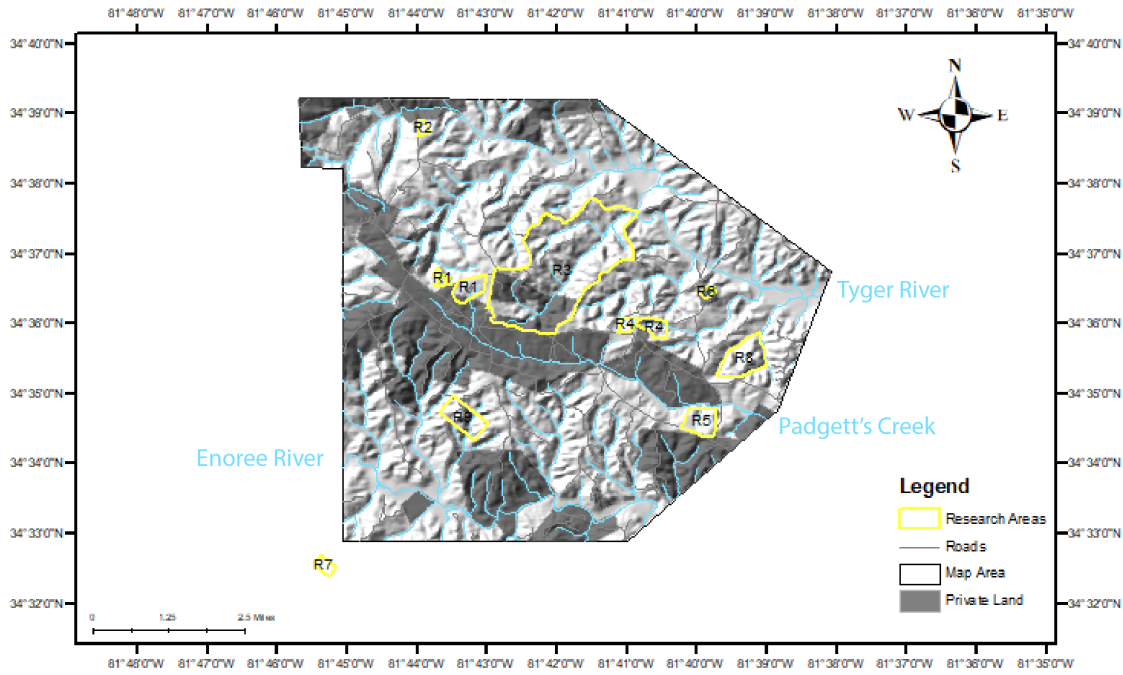
Figure 3: The field area is bound to the north by the Tyger River and to the south by the Enoree River. Within this, several research areas of the CCZO are located except for R7 that was previously mapped by Horkowitz (1984). The field site was mostly contained in the Sumter National Forest apart from private land.
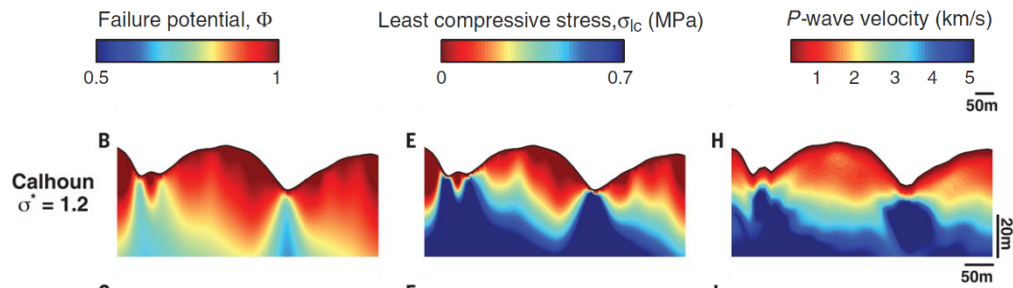
Figure 4: A typical cross section of the landscape within the CCZO. Cold areas of the figure show more competent rock. Outcrop preferentially occurred in low lying areas where water accumulates to remove overlying sediments (reprinted from St. Clair et al., 2015).
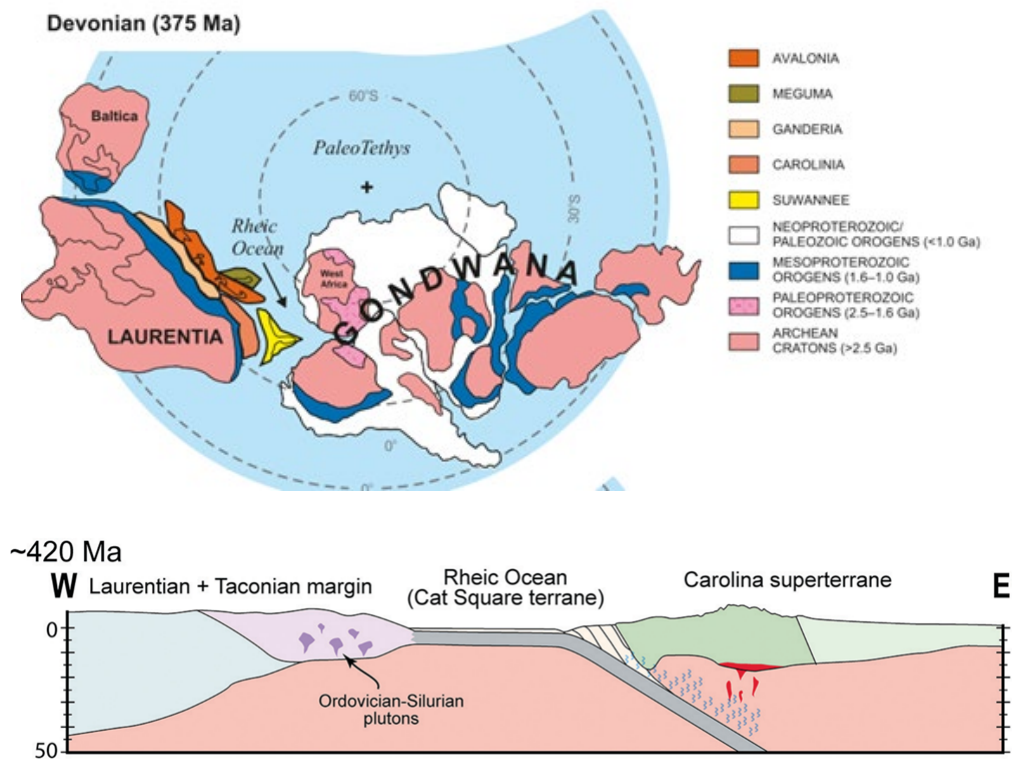
Figure 5: During the Paleozoic, ocean basins between Carolinia and Laurentia began to close as exotic terranes, shown above in between Laurentia and Gondwana, began to accrete onto the Laurentian margin. Part of Carolinia depicted above in dark pink would develop into the Charlotte terrane (adapted from Pollock et al., 2011).

CHAPTER 2

METHODS

2.1 Geologic Mapping

Reconnaissance mapping of the greater area was performed during the winter 2019 by observing the road cut geology along major and forest service roads in order to build a basic understanding of the field site. Although the CCZO mainly resides within the Sedalia quadrangle, the adjacent Philson Crossroads quadrangle was visited to verify previously described lithologies and verify existing map boundaries. Representative hand samples were taken from the field to build a rock library and descriptions were made for all present lithologies.

The following summer, detailed geologic mapping was performed beginning by extending the contacts of the Philson Crossroads quadrangle into the CCZO field site. Field data was collected at a watershed scale by walking along streambeds and gullies where there was the highest likelihood of exposure. Interfluves were then walked to search for float especially in complex areas or watersheds with low exposure within the stream beds.

At each rock sighting, the lithology and structure were characterized. First, the general texture of the rock was examined before fresh unweathered surfaces were exposed when available. After exposure, bulk mineral assemblages were recorded, and least altered samples were labeled for later thin section production. Labels were applied with a system based off their watershed identifier and then assigned a number (e.g. the first rock found in Holcombe's Branch was assigned the label HB01) and recorded in a sample index. On outcrops with preserved structures, visual assessment was used to determine the degree weathering to gauge the

likelihood that the surface rock was bedrock and not a detached block. Only locations interpreted with a high degree of confidence were sampled using a Brunton compass to record structural features like foliation, brittle fracture planes, and fold axes/limbs.

Throughout the majority of the field site, fresh outcrop was not available for analysis and saprolitic textures were relied upon for lithologic identification and structural analysis. The overall color, physical texture, presence of quartz and micas, as well as the presence of gneissic banding preserved in the saprolite were used as important indicators of potential lithologies. Low confidence was placed on lithologic identification from saprolite but was critical to use in conjunction with float to identify approximate lithologic contacts in interfluvial areas.

While the effects of saprolitization obfuscate mineralogical determinations, they also provided a higher confidence in structural measurements. The saprolite was generally assumed to be weathered in place and resistant minerals provided clear visual evidence of original shape preferred mineral orientations and foliation in the parent rock. Evidence of mass wasting was searched for before recording structural measurements in saprolite to reduce the possibility of making measurements in a slump or landslide.

These data were recorded in on watershed scale maps, in a field notebook, and location with a handheld GPS. Upon returning from field work, all data were copied into a master spreadsheet for later use in ArcGIS software included in the supplemental materials.

2.2 Petrology

In order to produce detailed mineralogical descriptions of each lithology, 15 of the least altered hand samples were sent to Quality Thin Sections for standard (30 μm thickness) thin section preparation. Samples were selected focusing on the western portion of the field site where more complex field relationships would benefit from petrographic determination.

Petrographic analysis was performed using a Nikon Eclipse LV100N polarized light microscope with an attached camera. For each thin section, approximate mineral abundances were produced through visual determination. When present, composition of plagioclase feldspars was estimated using the Michel-Levy method. Mineral grain boundaries were described to observe deformational history, and major fabrics and textures were recorded. Additionally, the degree of chemical weathering was noted based on the presence of sericite in the sample.

Because not every lithology was competent enough to produce a thin section, X-ray diffraction was also implemented to characterize mineral assemblages. Each sample was powdered using a mortar and pestle and ~5 g of were weighed out. The powder was then milled down to 10 μm using a McCrone Mill. Then, a 10% by weight internal standard of zincite was added before powdered mounts were pressed. Samples were externally calibrated with a corundum sample (NIST 1976b) before analysis on a Bruker D8 Advanced X-ray Diffractometer using Co-radiation. Diffraction peaks were compared against data in the International Centre for Diffraction Data (ICDD) powder diffraction file (PDF4) using the EVA software suite by Bruker.

2.3 Geochemistry

Geochemical characterization of two granitic bodies at the field site were performed. Samples were collected using a composite sampling methodology where multiple hand samples across the lithologic unit were crushed and mixed together before a 5 g portion was separated. These composite samples were then sent off to Activation Laboratories in Ontario, Canada for their 4-LITHO geochemical characterization of major oxides and trace elements. This method uses a lithium metaborate/tetraborate fusion approach analyzed by induction coupled plasma

(ICP) and ICP-mass spectroscopy (ICP-MS). Calibration is performed using USGS and

CANMET reference materials, with totals running between 98.5 and 101.0 %.

The geochemical results were compared with literature data from the Cat Square (n=24)

and Charlotte terrane (n=28) compiled from Huebner, 2017 as well as Butler and Fullagar, 1978.

These data were processed and analyzed in R using the GeoChemical Data toolkit and Tidyverse

packages (Janoušek, 2006; Wickman et al., 2019).

CHAPTER 3

RESULTS

3.1 Mapping Results

The CCZO field site revealed five different major lithologic groups. Towards the western portion of the field site, two mafic rock types were found including a meta-diorite and a meta-tonalite unit. In all portions of the field site, felsic meta-granodiorite and meta-granite units were observed. Additionally, a biotite gneiss/amphibolite unit was found throughout the field site that contained subordinate units of chlorite schist and quartzite. These units were bound to the north and south by alluvium (See Appendix A).

Structurally, few measurable structures were observed in the field site due to the high degree of weathering and poor exposure. However, foliations predominantly had NE strikes around 40° with a dip of 25° SE and did not appear to be uniform throughout the area. Folding was not observed regularly on outcrop scales only appearing in context of large portions of the mapped area. Dikes were observed, but only appeared infrequently (Fig. 6). These dikes were not continuous and were often only observable at one location. Throughout the field site, conjugate joint sets were observed with small apertures.

3.2 Unit Descriptions

Biotite-Hornblende-Quartz Meta-Diorite (bhqd)

This unit was located along the western boundary of the field site and covered an area of 0.65 mi^2 within the mapped region. Outcrops were normally found in streambeds where preservation was poor showing a high degree of saprolitization and preventing petrographic

16

analysis (Fig. 7a). Instead, this unit was identified in the context of the adjacent map (Horkowitz, 1984).

Although the biotite-hornblende-quartz meta-diorite unit never appeared as competent rock on an outcrop scale, there were larger spans of saprolite surrounded by float in the mapped region (Fig. 7b, c). The saprolite had a dark red-brown color with a slight shimmer from the biotite and a sandy texture. Float appeared as spheroidal highly altered boulders with oxidation rinds.

In hand sample the rock appeared as dark grey with a shiny luster. Minerals were medium grained and phaneritic. Cleavage was easily distinguished for both the biotite and hornblende although the dark color made the determination more difficult. Less weathered samples were competent requiring effort to split with a hammer. For weathered samples, the unit produced a distinctive black and white appearance with chemical alteration of the mafic minerals and feldspars. The feldspars specifically altered to a bright white chalky clay (Fig. 7a).

Previous descriptions of this unit note major phases of "hornblende, biotite, plagioclase, quarts, K-spar and epidote" with minor amounts of "sphene, apatite, zircon, and Fe-Ti opaques" (Horkowitz, 1984). Plagioclase was reported to have an average calcic andesine composition (An 38–46) (Horkowitz, 1984). Important mineral features include the presence of "warped pericline twins" as well as "anhedral quartz grains" that show "undulose extinction," a crystallographic response to high strain that causes misalignment of crystallographic domains throughout the mineral (Horkowitz, 1984; Passchier and Trouw, 2005).

X-ray diffraction revealed a mineralogy of albite, pyroxene, talc, and a montmorillonite-chlorite structure. Peaks were relatively sharp for albite but appeared broader for the other mineral phases (See Appendix B).

Meta-Tonalite (tn)

Located in the extreme northwest portion of the field site and covered an area of 0.19 mi^2. Exposure consisted of clusters of small boulders approximately 10–40 cm in diameter. In the small stream bed, these clusters would extend intermittently for 2–3 m stretches. Boulders showed varying degrees of weathering with most having fresh rough edges. Soils in the area were of a similar characteristic to the biotite-hornblende-quartz meta-diorite unit having a dark red-brown and sandy texture.

In hand sample, the meta-tonalite appeared as a black very fine-grained rock (Fig. 8). Occasionally, the rocks would have a bright orange oxidation rind. Individual minerals were barely distinguishable to the point of almost being aphanitic, however, individual cleavage of both hornblende and pyroxene were distinguishable as well as the characteristic conchoidal fracture in quartz (Fig. 8).

Thin sections analysis showed the tonalite unit has major phases of quartz (40%), plagioclase (35%), and hornblende (25%) with trace amounts of orthopyroxene (Figs. 9a, b). Quartz in the sample was fine to medium grained, anhedral, and exhibited undulose extinction. Frequent fractures were present within the grains and dihedral angles were present along grain boundaries (Fig. 9c). These boundaries were also subject to grain boundary migration (Fig. 9d). Plagioclase was fine to medium grained, anhedral, and showed regular albite and polysynthetic twinning. The maximum identified composition was An(55). Hornblende was dominantly fine grained with infrequent medium grains, and it was subhedral to anhedral. The tonalite displayed a seriate-interlobate texture (Fig. 9b).

Biotite Meta-Granodiorite (bgd)

This unit was located along the western and southern portion of the field site and covered an area of 5.2 mi^2 within the mapped region. Outcrops were moderately to well preserved in both streambeds and higher order gullies with some continuous sections spanning 5–10 m in the southern portion of the mapped area.

Several large microcline porphyroblasts and slight schistosity without migmatic textures distinguished the biotite meta-granodiorite from all other granitoids in the mapped area (Fig. 10a). On an outcrop scale, the biotite meta-granodiorite unit was slightly darker grey than the meta-granite outcrops and lighter grey than the biotite gneiss units (Figs. 10b). Soils appeared yellow-brown to red-brown and sandy with shiny micas and were not a distinguishing indicator.

In hand sample, the rock was medium grey with a medium grained matrix and very coarse grained porphyroblast of 3–4 cm (Fig. 10a). Early stages of both foliation and schistosity were evident in leucosome-like bands as well as minor shape preferred orientation in biotite (Figs. 10b, c). However, these features and the porphyroblasts were not always present from hand sample to hand sample.

Thin sections that did not sample the microcline phorpyroblasts had major phase abundances of feldspar (40%), quartz (30%), biotite (15%), hornblende (10%), clinopyroxene (5%), and trace amounts of zircon and epidote (Figs. 11a, b). Feldspars were predominantly fine to coarse grained anhedral An(33) plagioclase (35%) that showed albite twinning and occasional fracture. Fine to medium grained anhedral microcline (5%) was also present with characteristic microcline twinning with grains exhibiting occasional fracture as well. Myrmekite was common while sericite was a rare texture in thin section (Fig. 11c). Quartz was fine to medium grained, anhedral, showed undulose extinction, developed subgrains, and rare dihedral angles along grain

19

boundaries. Additionally, the grains were frequently fractured and contained regular biotite

inclusions. Biotite and hornblende were both fine to medium grained and anhedral while

clinopyroxene, zircon, and epidote were fine grained and euhedral.

Overall, the rock had a seriate interlobate texture and was protomylonitic (Fig. 11d).

Grains were slightly inequigranular with frequent fractures and highly deformed grain

boundaries. Slight chemical weathering was evident in the formation of sericite in the feldspars.

X-ray diffraction data was consistent with the thin section mineralogy showing mostly

quartz (38.8%), microcline (24.5%), albite (20.3%), and biotite (16.3%). Differences in modal

mineralogy may be due to the inclusion of microcline porphyroblasts in the powdered sample

(See Appendix B). All peaks in the pattern were sharp.

Biotite Gneiss/Amphibolite

This light grey lithology was located in the northeastern part of the field site and covered

an area of 16.7 mi^2 within the mapped region (Fig. 12a). Outcrops were normally found in in

streambeds and gullies with variable preservation. Expansive outcrops on the scale of 10s of

meters were observed in low-order streams while abundant boulders are found in gullies.

On an outcrop scale, the gneissic unit shows distinctive foliation with poorly formed

leucosome and melanosomes (Fig. 12a). Folds were rarely observed on mesoscopic scales, but

the rock was ptygmatic on rare occasions. Outcrops varied in color from dark grey for the biotite

gneiss portions to dark black for amphibolitic lenses (Figs. 12b, c). These amphibolite lenses

stretched for 3–5 m in length while the biotite gneiss portions were more expansive reaching

over 10 m in sections. This lithology was not always competent readily breaking apart easily

with a hammer. Soils were composed of two types. The first soil was generally yellow to red-

brown and sandy while the other appeared in small regions of dark red-brown soils lacking a quartz component.

In hand sample, leucosomes were subordinate to the melanosomes and appeared as medium to coarse grained continuous plagioclase foliations 1–2 cm in thickness. Melanosomes were medium-grey and showed well defined schistosity due to the abundance of biotite with variable thicknesses on the order of 2–10 cm (Fig. 12a). Two minor units appeared within the biotite gneiss/amphibolite unit that were not expansive enough to include on the scale of the map. These included a garnet quartzite and a chlorite schist.

In thin section, the biotite gneiss showed major phases of feldspar (40%), quartz (30%), and biotite (17.5%) and hornblende (12.5%) with trace amounts of zircon and chlorite (Fig. 13a, b). Feldspars ranged from fine to coarse grained with both An(30) plagioclase (30%) and microcline (15%) present which exhibit their respective twins. The feldspars both exhibited frequent fracture as well as alteration to sericite, and myrmekite was common in the sample. Quartz was fine to coarse grained and anhedral with frequent fracture (Fig 13c). It frequently showed well developed subgrains along grain boundaries. Gran fracture was present in the quartz as well (Fig 13d). Both biotite and hornblende were fine to medium grained and anhedral.

The rock displayed a seriate interlobate texture. Grains were slightly inequigranular with frequent fractures and highly deformed grain boundaries. Chemical weathering was evident in the formation of sericite in the feldspars (Fig. 13d).

These mineralogical observations were also observed in diffraction data in different abundances. Hornblende (51.7%), labradorite (39%), quartz (6.6%), and microcline (2.6%) were all observed in the pattern. However, no biotite was observed. Differences between the XRD and

thin section abundances may be due to the heterogeneity of the sample. For all mineral phases, the pattern showed sharp peaks (See Appendix B).

Meta-Granite

This unit was located throughout the field site and covered an area of 4.0 mi^2 within the mapped region. Outcrops were normally found in stream beds where samples showed good preservation. Spheroidally weathered boulders were also prevalent in interfluvial areas.

Outcrops of this unit were expansive ranging from 1–3 m boulder fields all the way to 5–10 m continuous units. These rocks had the brightest color of any lithology typically appearing as a white-grey with fine grained slightly aligned biotite visible (Fig. 14a). Both jointing and foliation were observed within the outcrop (Figs. 14b, c). The meta-granite was competent requiring force to break apart. The soil produced by this lithology was a light red-brown to yellow brown sandy soil.

In hand sample, the meta-granite was light grey with abundant mafic minerals showing slight shape preferred orientation. Hematite staining and weathering rinds were common leaving behind orange-brown tints along the surface of hand samples. The meta-granite was readily distinguished from other granitoid units within the field area by its lighter grey appearance and lack of microcline porphyroblasts (Fig. 14a).

Thin sections of the meta-granite revealed a composition of quartz (45%), feldspar (35%), biotite (15%), and phengite (5%) with trace amounts of zircon, tourmaline and opaques (Figs. 15a, b). Quartz was fine to medium grained, anhedral, and showed undulose extinction with the presence of subgrains. These grains were frequently fractured and contained rare inclusions of biotite and feldspar as well as pressure dissolution along grain boundaries (Fig. 15c). Feldspar was composed of both An(70) plagioclase (25%) and microcline (10%).

Plagioclase was fine to medium grained, anhedral, and showed albite twinning. Microcline was fine to medium grained, anhedral, and showed common tartan twinning. Feldspars showed minor amounts of alteration to sericite and myrmekite was common (Fig. 15d). Biotite and muscovite were both fine grained, subhedral to anhedral, and exhibited birdseye extinction. Zircons were very fine grained, subhedral and showed poor zoning.

Meta-granites at the field site exhibited an inequigranular polygonal texture that was protomylonitic. Grains were frequently fractured with common, and incipient weathering was expressed with the presence of sericite in feldspars (Fig. 15d). X-ray diffraction data was consistent showing abundant quartz, plagioclase, microcline and biotite.

Alluvium

This unit was located along the northern and southern bounds of the mapped region adjacent to the Tyger and Enoree rivers. The alluvium unit covered an area of 3.9 mi^2 and was frequently associated in the field by the presence of bamboo.

3.3 Granite Geochemistry

Cat Square Terrane

A compilation of Cat Square granites in the southern Piedmont showed that major elements are not consistent between samples (Table 1). SiO_2 and Al_2O_3 were the most abundant by weight percent (%) ($\bar{x}_{SiO2}$ = 68.30 % and $\bar{x}_{Al2O3}$ = 15.50 %). But the large standard errors mean they vary greatly within the sample set (SEM_{SiO2} = 0.88 and SEM_{Al2O3} = 0.33). This variance was clearly displayed in the large range of SiO_2 and Al_2O_3 values displayed on the Harker diagrams (Fig. 11).

Abundances of minor elements showed more consistent abundances between the sample set. Cations that substitute in feldspars decreased in abundance from K_2O to Na_2O to CaO with

standard errors half the size of the major elements ($\bar{x}_{K2O}$ = 4.48 %, $\bar{x}_{Na2O}$ = 3.06 %, $\bar{x}_{CaO}$ = 2.24 %;

SEM_{K2O} = 0.13, SEM_{Na2O} = 0.10, SEM_{CaO} = 0.20). MnO, TiO_2, and P_2O_5 were consistent across

all samples (SEM_{MnO} = 0.01, SEM_{TiO2} = 0.05, SEM_{P2O5} = 0.02). The only exception shown was

FeO which had a similar standard error as Al_2O_3 (SEM_{FeO} = 0.29; SEM_{Al2O3} = 0.33).

Geochemical relationships were evaluated using the non-parametric Spearman's Ranked

Correlation because elemental abundances were not normally distributed. A ρ of 1 indicates a

perfect positive relationship while a ρ of -1 indicates a perfect negative relationship. The oxides

Al_2O_3, MgO, CaO, TiO_2, P_2O_5 and FeO versus SiO_2 all plotted with negative trends (Fig. 11).

Al_2O_3 had the most statistically significant negative relationship to SiO_2 (ρ = -0.8210, S =

3685.60, p = 1.59e-06). Na_2O and K_2O showed no clear relationship with SiO_2 (ρ_{Na2O} = -0.3856,

S_{Na2O} = 2102.00, p_{Na2O} = 0.8613; ρ_{K2O} = 0.1676, S_{K2O} = 1684.8, p_{K2O} = 0.4447).

Rare Earth Element (REE) in the Cat Square show abundant light REEs with a negative

Eu anomaly (Fig. 17). These trends roughly follow the average composition of the upper

continental crust staying within an order of magnitude above or below (Fig. 18). Only Ta showed

a major departure in one sample with a ratio of 0.04 relative to the average continental crust. Nb,

Ta and Sr consistently plotted as depleted relative to the average while La, Ce, Nd and Sm

plotted as enriched. The heavy REEs Y, Tm, and Yb all plotted with high variance spanning

between one and two orders of magnitude.

Classification of Cat Square granites using Frost and Frost (2008) showed consistent

determinations despite large ranges of values (Fig. 19). When examining the ratio between iron

and magnesium, granites plotted as intermediate between being ferroan and magnesian (Fig.

19a). The Modified Alkali Lime Index (MALI) further define the granites as alkali-calcic to calc-

alkalic with the exception of two data points that plot as alkalic (Fig. 19b). All Cat Square

granites except one measured were peraluminous on the Aluminum Saturation Index (ASI) with values from 1 to 1.3 and silica saturated according to the Alkali Index (AI) vs Feldspathoid Silica Saturation Index (FSSI) (Figs. 19c, d).

Charlotte Terrane

Charlotte terrane granites in the southern Piedmont contained major elements abundances that were relatively consistent between samples (Table 1). The most abundant elements, SiO_2 and Al_2O_3, had smaller standard errors as all samples had similar compositions ($\bar{x}_{SiO2}$ = 75.37 % and $\bar{x}_{Al2O3}$ = 12.92 %; SEM_{SiO2} = 0.20 and SEM_{Al2O3} = 0.09). The SiO_2 values were consistently higher than the values for the Cat Square, and the Al_2O_3 values were slightly lower. These similarities appeared in the small range of SiO_2 and Al_2O_3 values displayed on the Harker diagrams (Fig. 11).

Minor elements in the Charlotte terrane showed high consistency within the sample set. Cations that substitute in feldspars decreased in abundance from K_2O to Na_2O to CaO with equally small standard errors as the major elements ($\bar{x}_{K2O}$ = 4.47 %, $\bar{x}_{Na2O}$= 4.29 %, $\bar{x}_{CaO}$ = 0.41 %; SEM_{K2O} = 0.08, SEM_{Na2O}= 0.05, SEM_{CaO} = 0.06). The Charlotte terrane did not have elemental data for MnO and P_2O_5.

No statistically significant relationships were observed between SiO_2 and other oxides within the Charlotte terrane. Instead, the oxides showed a range of distribution irrespective of SiO_2 (Fig. 11). REE and trace element data were not well described in the Charlotte terrane literature and no analysis could be made.

Granites within the Charlotte terrane plotted as highly ferroan with most values being close to one (Fig. 19a). On the MALI plot, granites dominantly plotted within the alkali-calcic field (Fig. 19b). On the ASI plot, samples plotted in both the metaluminous and peraluminous

25

fields resulting in an intermediate composition (Fig. 19c). The AI vs FSSI plot characterized the Charlotte terrane granites as silica saturated and meta/peraluminous, however, on the FSSI plot all values plotted close to the peralkaline field (Fig. 19d).

<center>*CCZO*</center>

CCZO granites showed similar oxide compositions as the Cat Square terrane. FeO, MnO, MgO, and TiO_2 were all nearly half the abundance of the Cat Square granites and had insignificantly more SiO_2 (Table 1). CCZO granites did not have a large enough sample size for any statistical analysis on among group variation (n=2).

REE and trace elements in the CCZO were relatively depleted compared to the average upper continental crust and showed a positive Eu anomaly (Figs. 17, 18). Only Rb, Ba, Th and Sr showed enriched values with all others being depleted, especially the HREEs who had concentrations nearly an order of magnitude below the average. Opposite of the Cat Square, the CCZO granites showed negative anomalies for La, Ce, Nd, and Sm, and they showed a positive anomaly for Sr (Fig. 18).

CCZO granites plotted close to the intermediate boundary between ferroan and magnesian with a slightly magnesian classification (Fig. 19a). The MALI plot showed these granites have a mixed determination between alkali-calcic and calc-alkalic (Fig. 19b). ASI plots revealed a slightly peraluminous composition (Fig. 19c). In the AI versus FSSI plot, both CCZO granites lie within the silica saturated and meta/peraluminous fields (Fig. 19d).

3.4 Tectonic Setting

Tectonic determinations were made using REEs which are enriched in specific tectonic regimes (Cabanis and Lecolle, 1989). Both Cat Square and CCZO granites plotted in the

<center>26</center>

orogenic field due to their high La abundances relative to Y and Nb. One outlier within the Cat

Square terrane plotted in the anorogenic field (Fig. 20).

Figure 6: Quartz dikes (black) were often seen in steam beds crosscutting foliation (white) at the field site ranging in thickness up to 20 cm located NE of Holcombe's Branch.
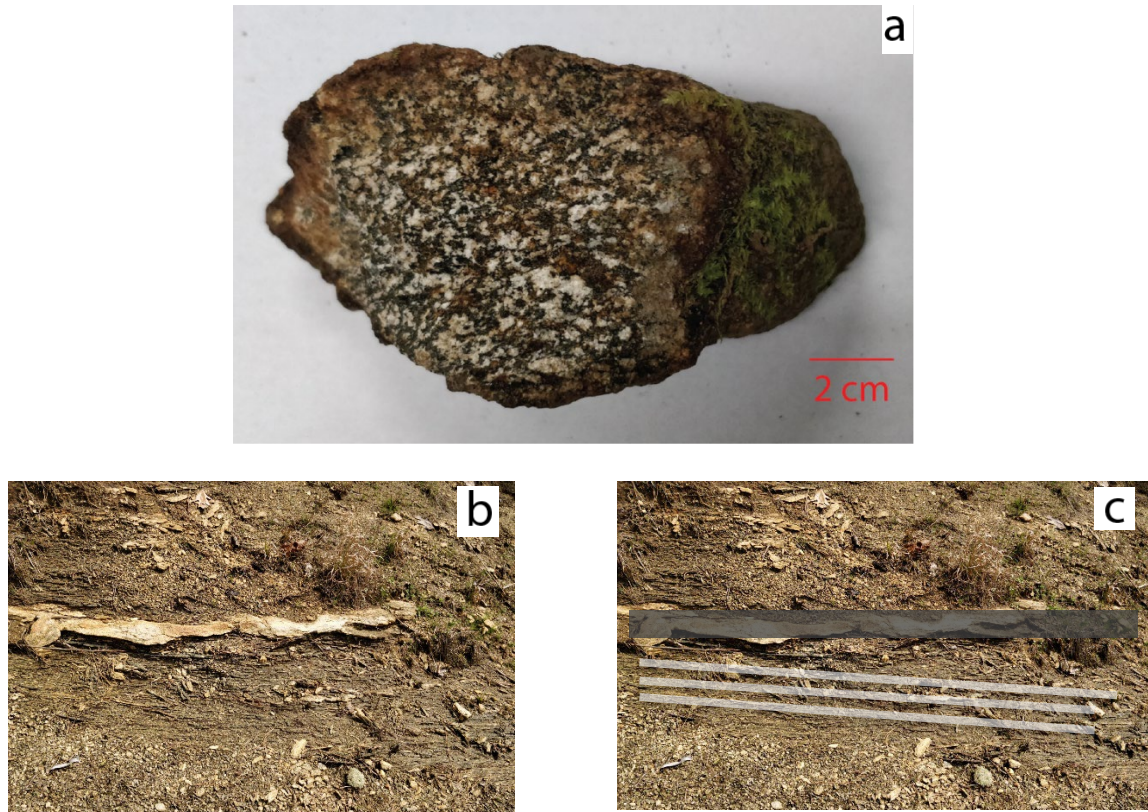
Figure 7: Biotite-hornblende-quartz meta-diorite was frequently weathered rarely preserving in hand sample. (a) The unique salt and pepper characteristic readily identified this lithology in the field. (b, c) Despite alteration, resistive unites like dikes (highlighted in black) and preferred orientations (highlighted in white) were easily identifiable.

Figure 8: Meta-tonalite (BR04) in hand sample. Oxidation rinds were typical with this lithology.

Despite a very fine grain size, cleavage plains of amphiboles and pyroxene were observable.
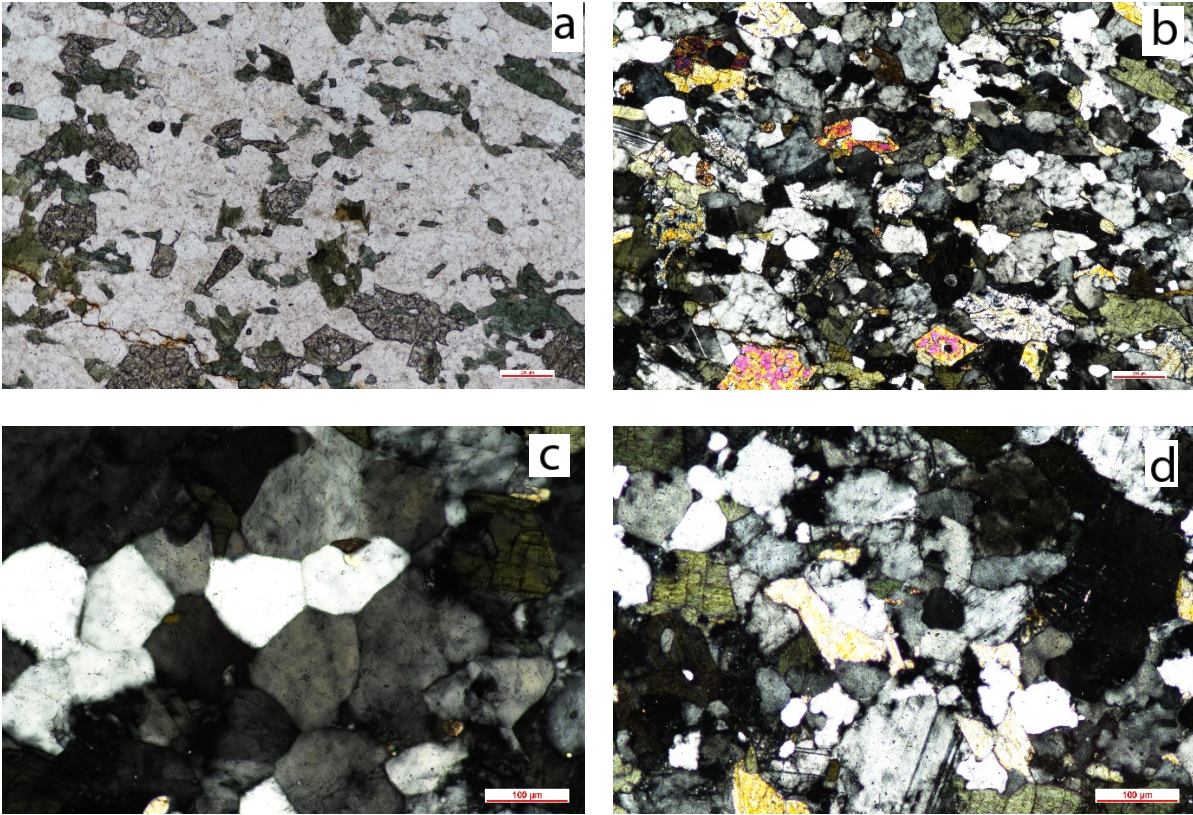
Figure 9: The meta-tonalite unit showed a primary igneous texture with subsequent alteration. (a)
The thin section in plane polarized light shows the abundance of hornblende and pyroxenes. (b)
The same region in cross polarized light. Anhedral grains compose most of the thin section. (c)
The equilibrium texture of dihedral angles in quartz grains were regularly observed. (d)
Subgrains were well developed in the meta-tonalite.
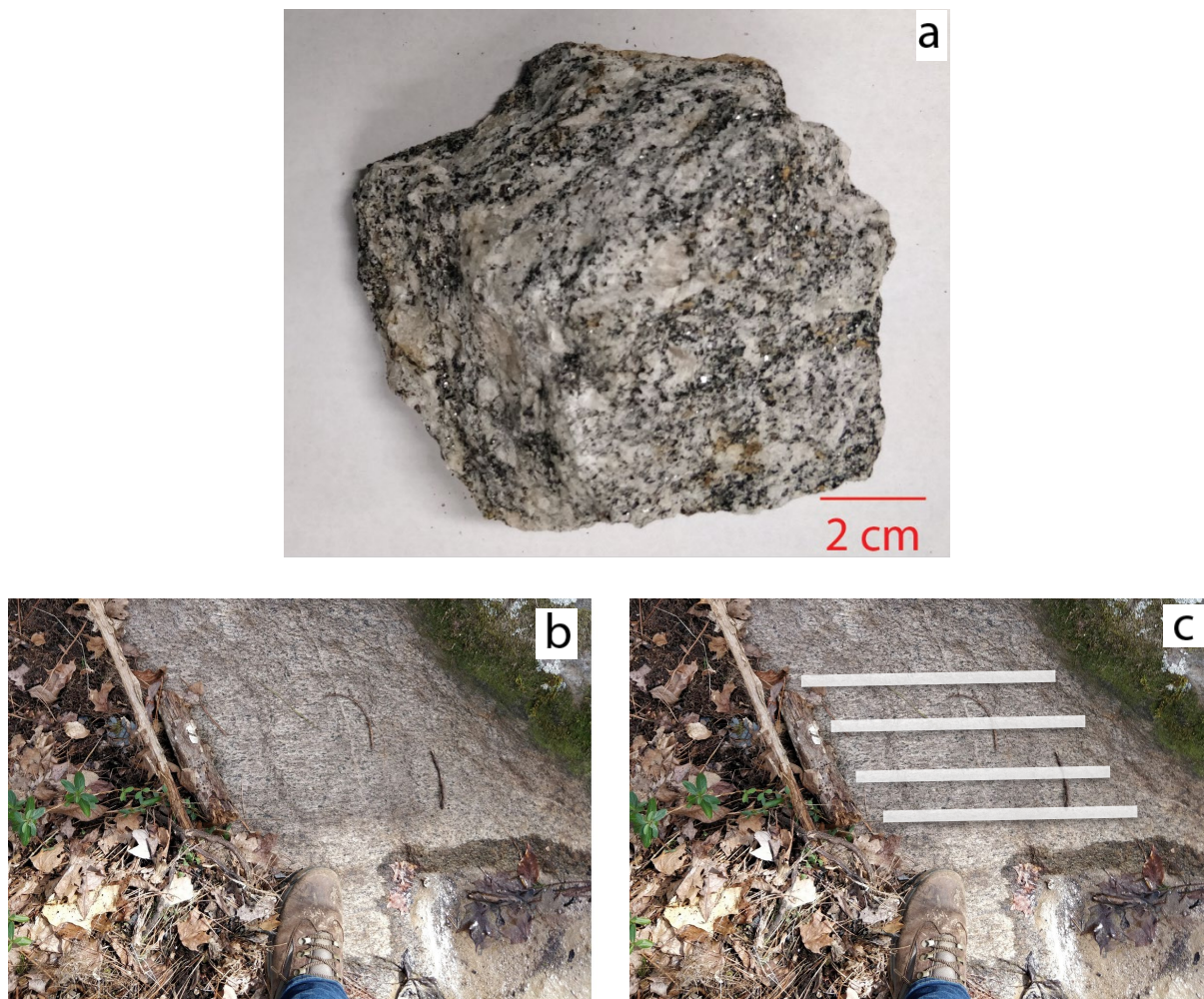
Figure 10: Biotite meta-granodiorite (SC04) was identified by its medium grey color, microcline porphyroblasts, and foliation. (a) In hand sample, well developed microcline porphyroblasts grew as large as 2 cm. (b, c) Foliation (white) was present throughout the biotite meta-granodiorite unit.
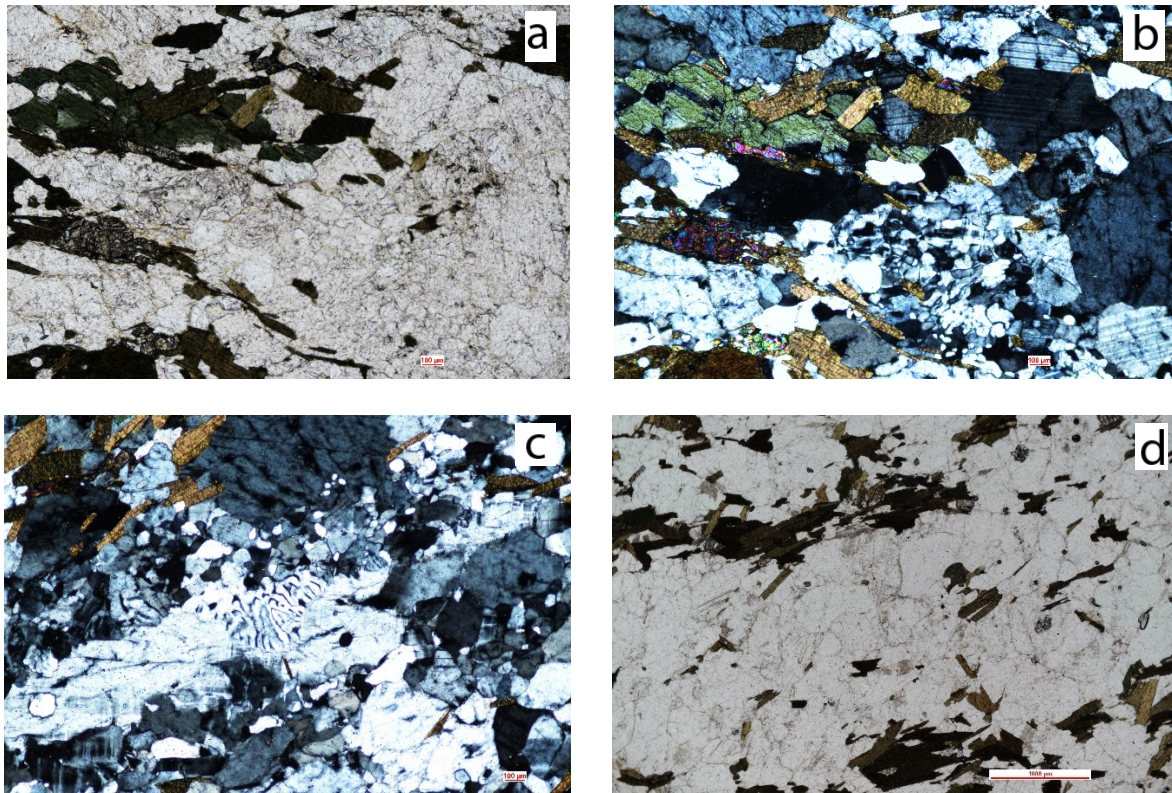
Figure 11: In thin section, incipient metamorphism was observable in this lithology. (a, b) Biotite meta-granodiorite plane polarized light, and cross polarized light. (c) The thin section frequently showed myrmekite. (d) Shape preferred mineral orientation of hornblende and biotites provide evidence of the protomylonitic texture.
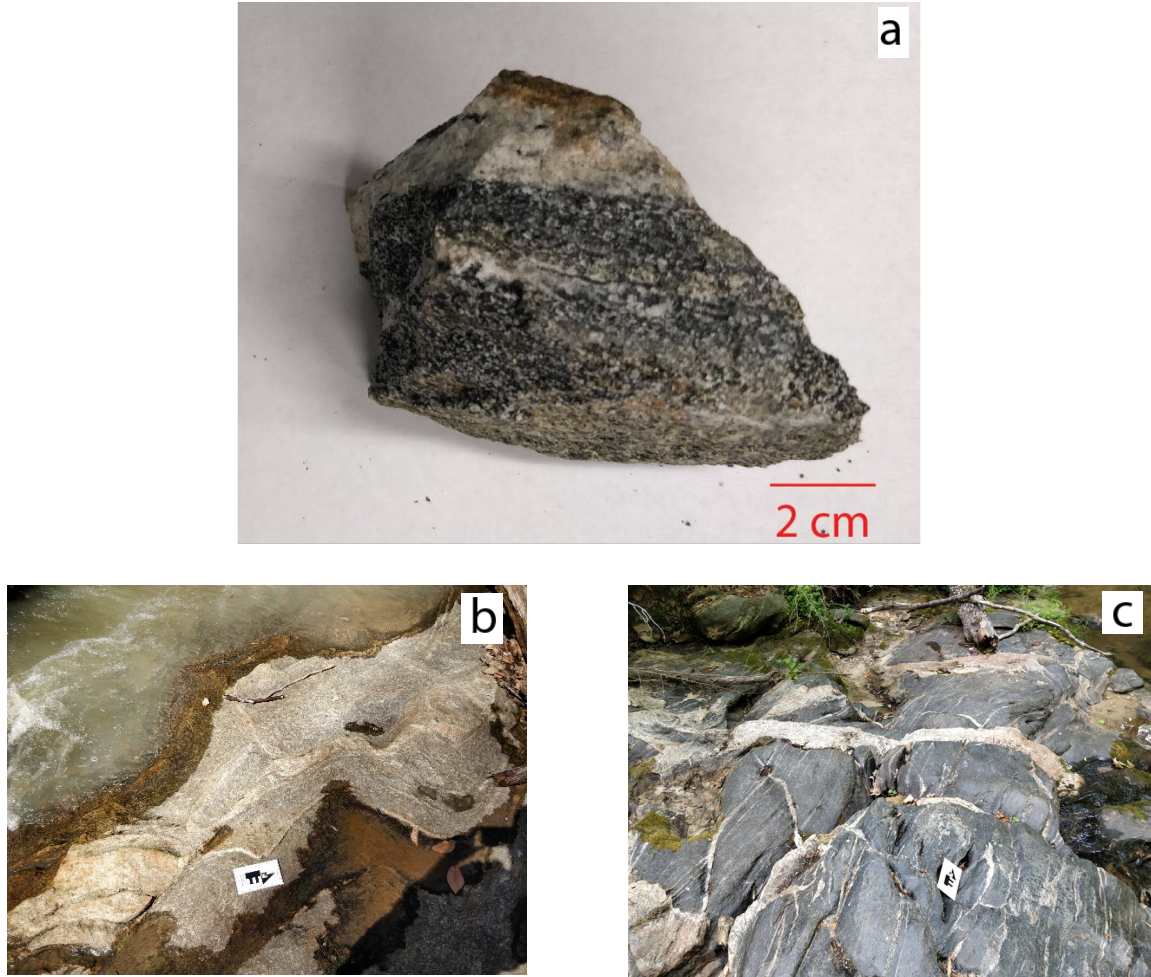
Figure 12: Biotite gneiss/amphibolite (HB21) was composed primarily of granitic gneiss with lenses of amphibolite scattered throughout the mapped area. (a) In hand sample, leucosomes and melanosomes were typically not folded or deformed. (b) Outcrops of gneiss were light to medium grey in color and rarely showed mesoscopic folding. (c) Amphibolite was typically convoluted or ptygmatic. Here prominent dikes were observed crosscutting the amphibolite.
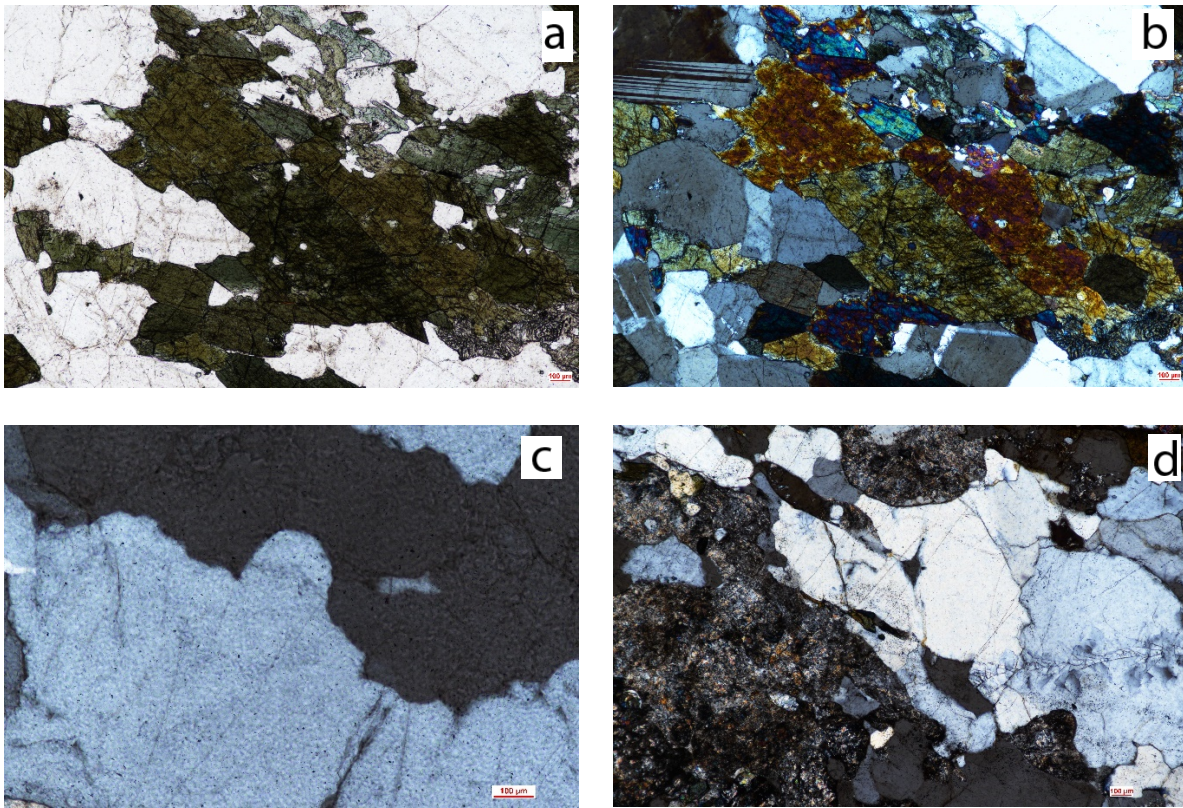
Figure 13: The gneissic portion of this unit showed highly altered grains. (a, b) Thin section in plane polarized light and cross polarized light. (c) Quartz grains displayed highly irregular grain boundaries and were typically anhedral. (d) Grain fracture was observed in several locations, and sericite was commonly observed.
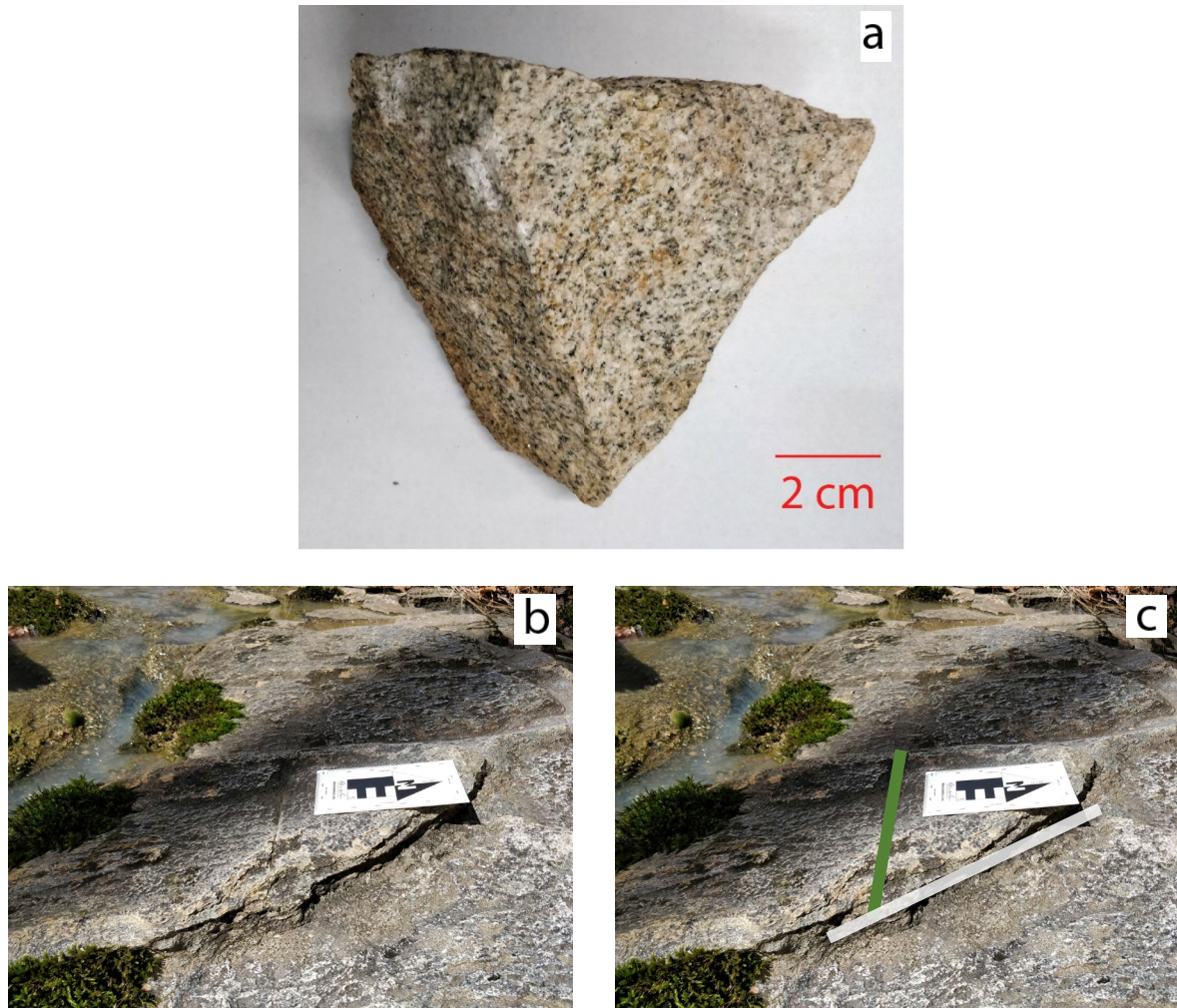
Figure 14: Meta-granite (PC04) was a highly competent unit at the field site forming expansive outcrops. (a) In hand sample, it could be distinguished from other granitoids by its bright and light grey appearance. (b) Joining (green) and foliation (white) were both observed in the meta-granite unit.
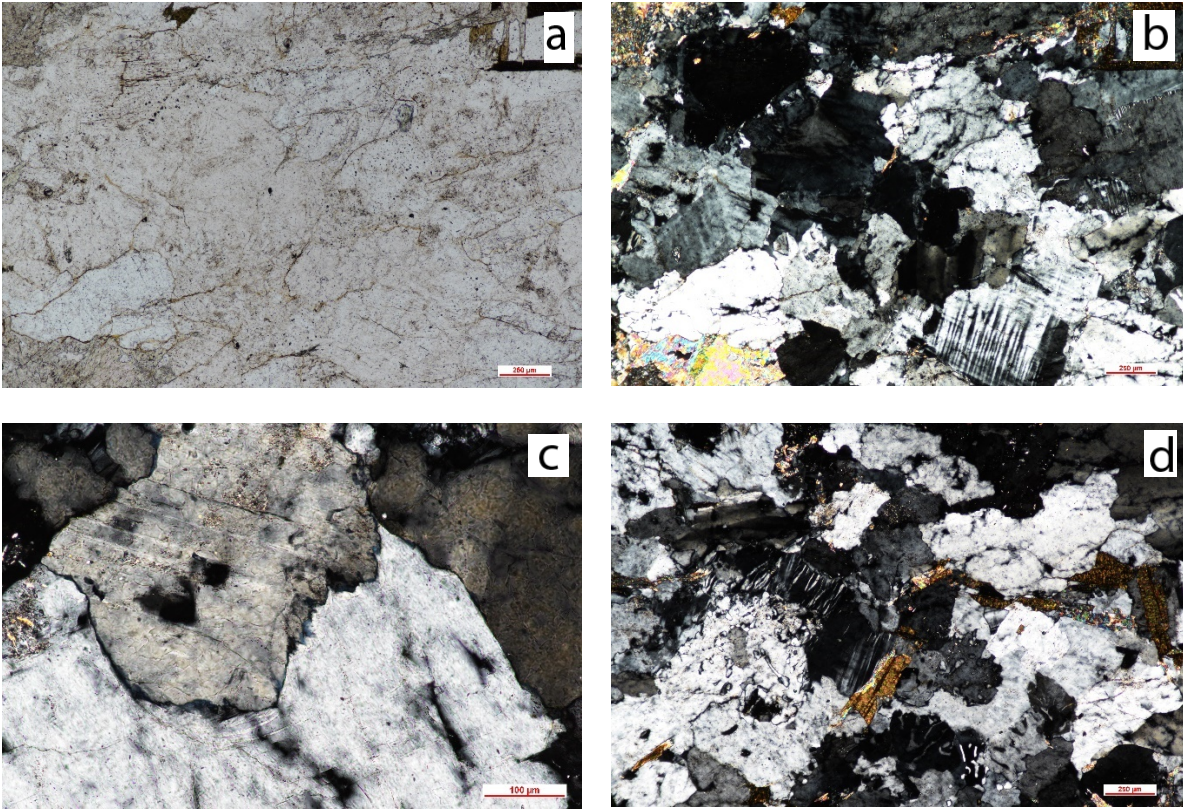
Figure 15: The CCZO meta-granite showed both biotite and muscovite unlike other granitoids in the field site. (a, b) The meta-granite in plane polarized light and in cross polarized light. (c) Pressure dissolution occurred along grain boundaries. (d) Myrmekite and grain boundary migration appeared throughout the thin sections.

Table 1: Mean weight percentages and standard error of the mean (SEM) of granites in the southern Piedmont. Charlotte terrane granites were reported to have higher SiO_2 than both Cat Square and CCZO granites. MgO and TiO_2 values are an order of magnitude different between the Charlotte terrane versus the Cat Square and CCZO granites. Data was compiled from Huebner et al., 2017 and Butler and Fullagar, 1978.

Weight %	SiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	n
Cat Square	68.30	15.50	3.21	0.07	1.02	2.24	3.06	4.48	0.51	0.19	23
CCZO	70.48	15.01	1.63	0.03	0.46	1.93	3.79	4.70	0.25	0.07	2
Charlotte	75.37	12.92	1.08	0.18	0.04	0.41	4.29	4.47	0.06	-	28

SEM	SiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	n
Cat Square	0.88	0.33	0.29	0.01	0.12	0.20	0.10	0.13	0.05	0.02	23
CCZO	-	-	-	-	-	-	-	-	-	-	2
Charlotte	0.20	0.09	0.06	-	0.01	0.06	0.05	0.08	0.01	-	28

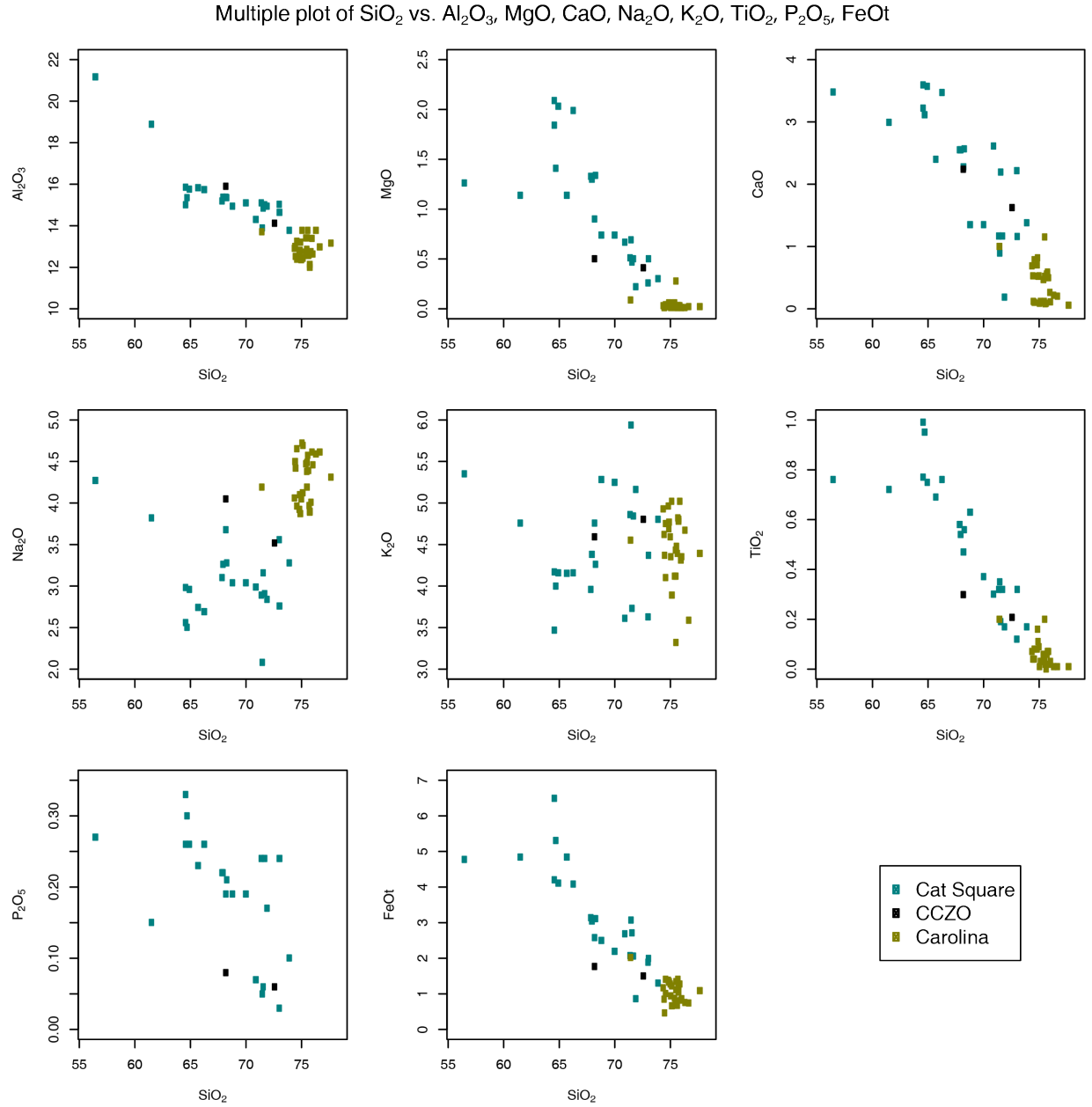Multiple plot of SiO$_2$ vs. Al$_2$O$_3$, MgO, CaO, Na$_2$O, K$_2$O, TiO$_2$, P$_2$O$_5$, FeOt

Figure 16: Elemental data plotted against SiO$_2$ weight percent displayed a closer affinity between the CCZO and Cat Square granites than the CCZO and Charlotte terrane granites. Strong trends appeared between several oxide pairs with the exception of two elements susceptible to weathering, Na$_2$O and K$_2$O. No data was available for P$_2$O$_5$ in the Charlotte terrane.

39
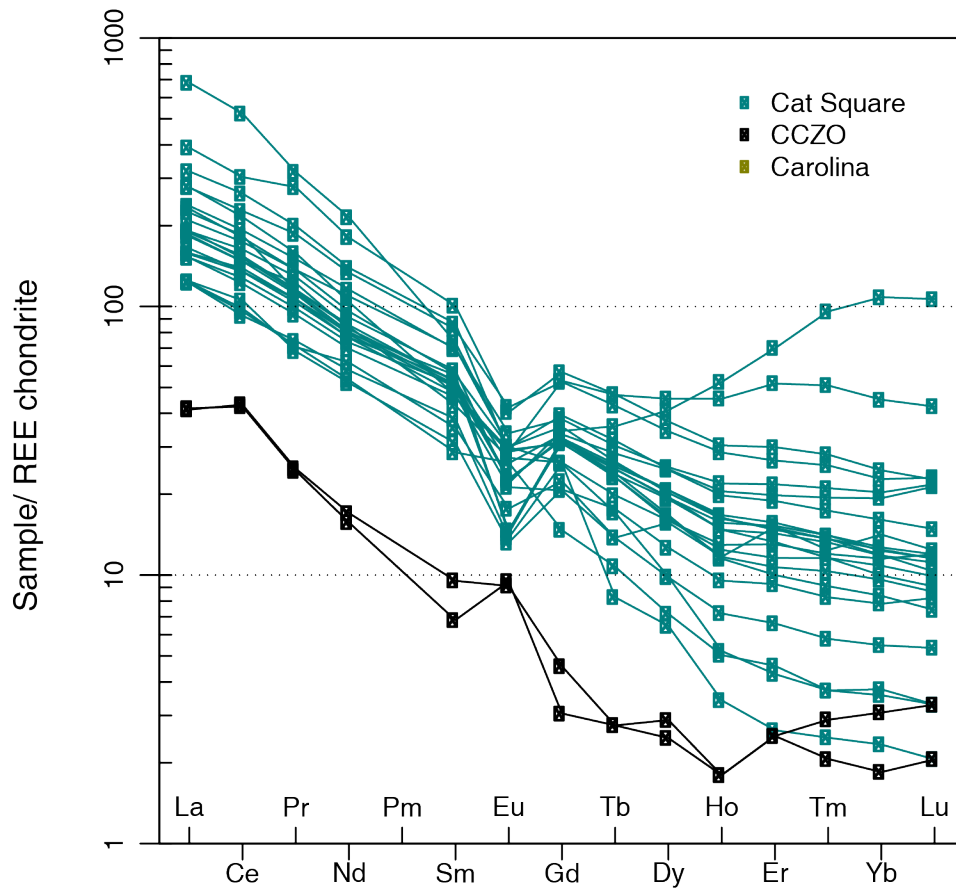
Figure 17: Chondrite normalized abundances of the Cat Square granites plotted much higher than the abundances of the CCZO granites. Additionally, Cat Square granites show a negative Eu anomaly while CCZO granites show a positive anomaly. No data was available for the Charlotte terrane granites for comparison.
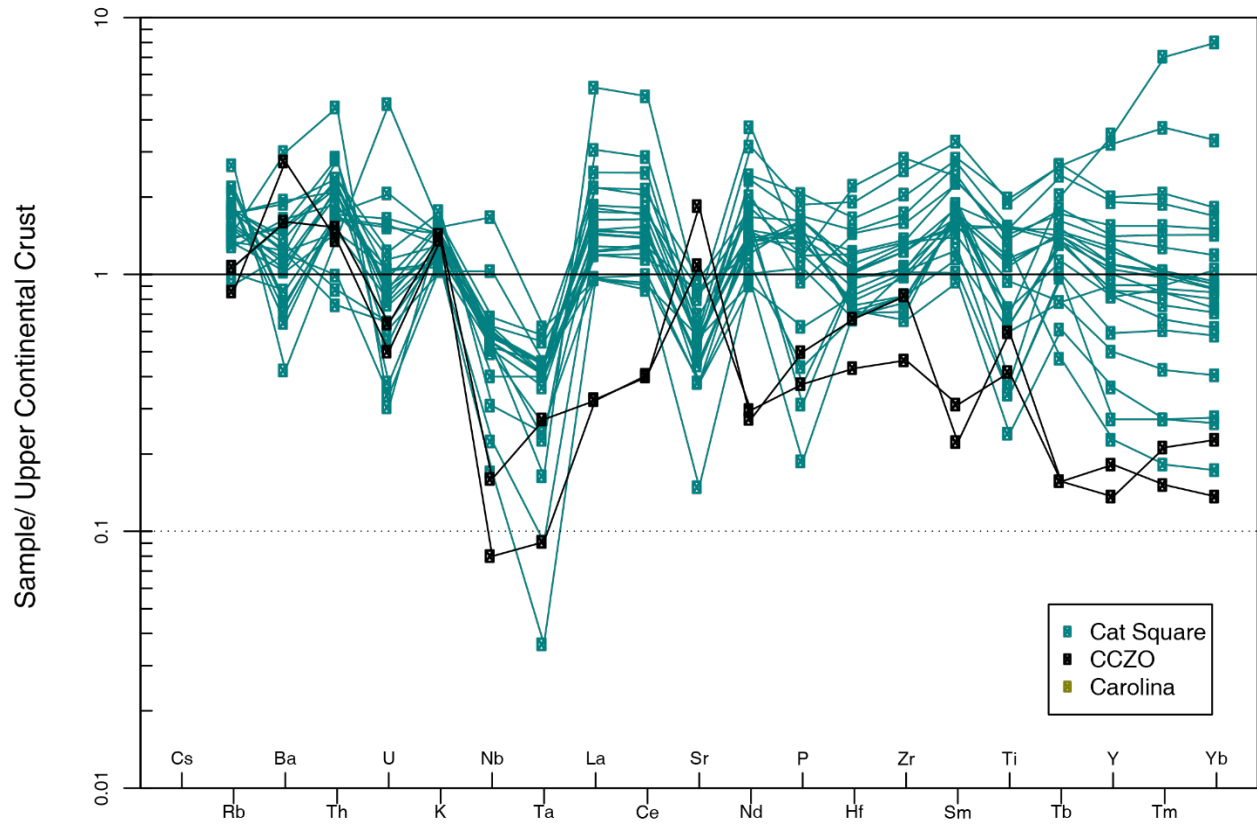
Figure 18: Abundances of Cat Square granite geochemistry closely resembles the average composition of the upper continental crust while CCZO granites show a low abundance of REEs relative to the upper continental crust.
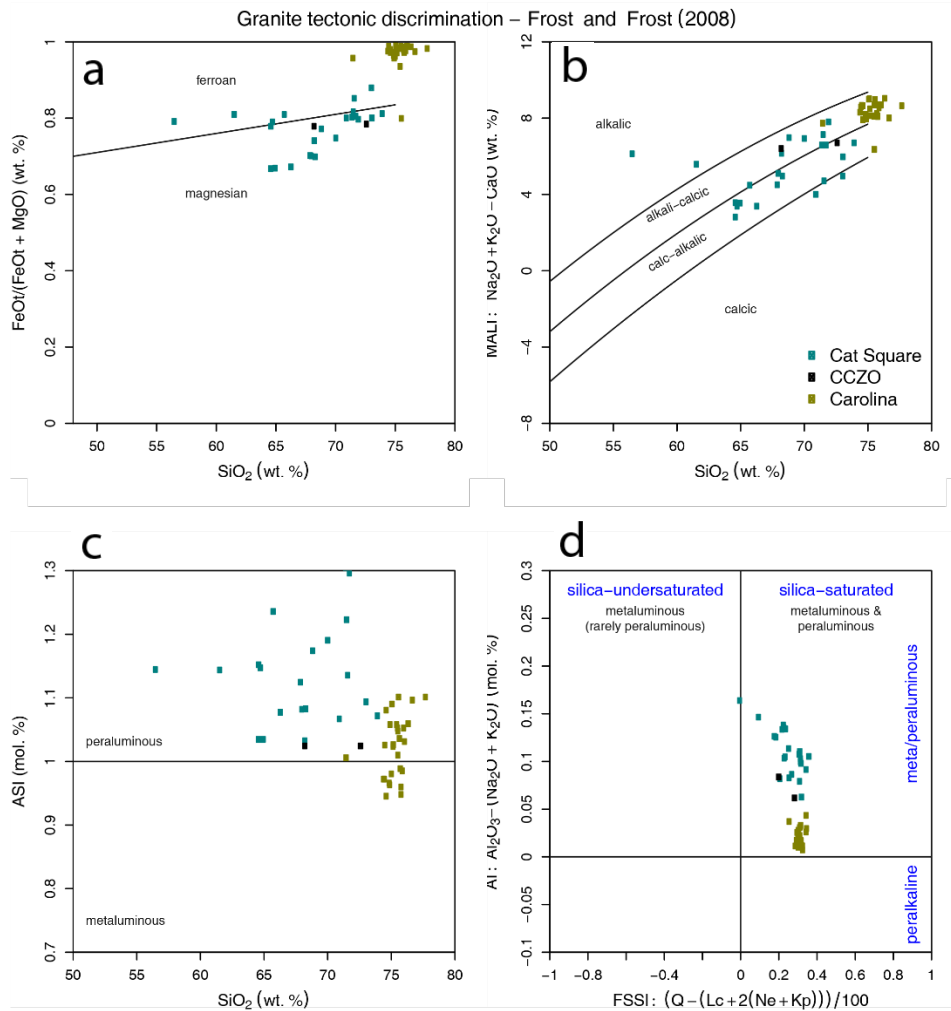
Figure 19: These plots reinforced similarities between the CCZO and Cat Square granites which were typically magnesian, peraluminous and silica saturated. (a) While most of the Cat Square granites plot as intermediate, Charlotte terrane granites plot as ferroan. (b) All three groups plot as calc-alkic to alkali-calcic. (c) Cat Square and CCZO granites are peraluminous while Charlotte terrane granites are intermediate. (d) These granites are silica-saturated and prealuminous.
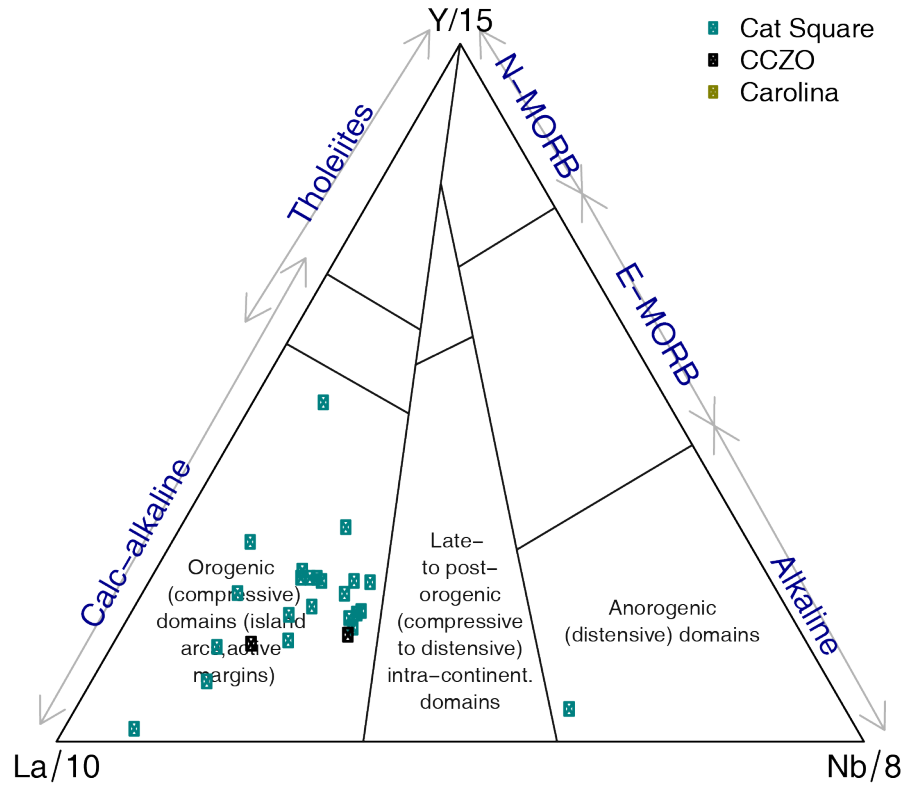
Figure 20: The plotted orogenic field that both the Cat Square and CCZO granites reside in was consistent with the regional history of the field site.

CHAPTER 4

DISCUSSION

4.1 Assignment and Interpretation of Terranes

In the mapped region, the biotite gneiss/amphibolite and the meta-granite units were attributed to the Cat Square terrane (Fig. 15). This determination was made off similarities between the structure and mineralogy of these rocks to literature descriptions found in Horkowitz (1984). Additionally, this interpretation was supported by previous regional scale mapping efforts which attributed lithologies found in the CCZO to the Cat Square terrane (Hatcher et al., 2007).

These units showed petrological and geochemical features that suggest a history of accreted ocean basin sediments which underwent high grade metamorphism. The meta-granite contained two types of micas, biotite and phengite. Clarke (1981) classified these two mica granites as S-types because they suggest a supracrustal source. One such supracrustal environment consistent with the site history would in the continent-continent collisional environment of the Appalachian orogeny. Here, accumulation of resistant minerals like quartz and feldspars could occur. This interpretation was also consistent with the geochemical data for the meta-granites at the CCZO which were peraluminous and silica saturated. These indicate a mature source from which the magma formed which leads to the possibility that the granites were crystalized from partial melting of the remnant ocean basin sediments. This scenario is further supported by the orogenic affinity displayed by the CCZO granites. Ultimately, the

observed lithologies and chemical analyses were consistent with literature descriptions of the Cat Square terrane.

The remaining biotite-hornblende-quartz meta-diorite, meta-tonalite, meta-granodiorite were all assigned to the Charlotte terrane (Fig. 21). These lithologies were parts of continuous units that crossed over from the Philson Crossroads quadrangle into the CCZO field site. Researchers from the University of South Carolina have studied these rocks which they named the Wildcat Branch Complex extensively (Horkowitz, 1984; Allen and Shervais, 1991; Allen and Shervais, 1996). This previous body of work allowed for high degree of confidence in the present studies assignment of these lithologic units into the Charlotte terrane.

4.2 Interpretation of the Central Piedmont Suture

The Central Piedmont Suture was expected to lie within the boundaries of the field site from previous mapping efforts (Hatcher et al., 2007). No physical structure was identified that could be attributed to the thrust fault within the boundary of the field area. However, there was an indisputable sharp lithologic contact between the mafic and ultramafic Charlotte terrane rocks and the felsic Cat Square terrane rocks that require a structural boundary. As such, the Central Piedmont Suture was interpreted to lie along the lithologic contact between the Charlotte and Cat Square terranes. This mode of interpretation had been applied by multiple studies in the area where the lack of a clear fault boundary was not present at the interface between the two terranes (Horkowitz, 1984; Huebner et al., 2017).

Previously, the Central Piedmont Suture had been displayed on maps farther to the east (Hatcher et al., 2007). The present study revealed that this boundary lies farther west than previously thought. Additionally, the Central Piedmont Suture delineates the Wildcat Branch Complex which will allow for further investigations into the history of volcanism in Carolinia.

45

4.3 Petrographic Interpretations

Lithologies throughout the CCZO showed evidence of their history preserved in petrographic textures that were interpreted to reflect the history of the Appalachian orogeny. The primary igneous textures present in these lithologies showed clear evidence of subsequent deformation. First, evidence of syn-orogenic deformation was interpreted to have occurred during the collisional tectonics of the Appalachian orogeny. Grain boundaries in all samples were highly irregular frequently appearing as interlobate indicating recrystallization under strain (Fig.7; Gerald et al., 1983). The effects of minor strain were also evident in the protomylonitic texture of the meta-granodiorite unit (Fig. 11d). Here, tabular minerals began to show slight alignment. Rocks within the Cat Square, like the biotite gneiss/amphibolite, also showed evidence of strain through the presence of subgrains (Fig. 13d).

Evidence of potentially post-orogenic recovery was also observed throughout the thin sections which was interpreted to have occurred during the extensional tectonic regime during the rifting of Pangea. The grain boundaries in the meta-tonalite unit, for example, provided a clear example of dynamic recrystallization with the appearance of dihedral angles (Fig. 9c). Dihedral angles form as an equilibrium texture under high pressure and low shear during which the surface free energy of the crystals is minimized (Frost and Frost, 2019). Finally, the thin sections ubiquitously displayed grain fracture interpreted to have occurred more recently due to crosscutting relationships and lack of deformation (Fig. 13d).

4.4 Structural Interpretations

While detailed structural analysis was outside of the scope of the present study, several qualitative observations assist in interpreting the field site. First, the highly irregular contact geometries between the Charlotte and Cat Square terranes are consistent with the regional nappe

tectonic regime (Fossen, 2016). Second, the isolated granitic body in the NW portion of the field site may be interpreted as a fenster with the overriding Charlotte terrane having eroded away. Additionally, the foliations observed trended NE which is consistent with regional trends and expected as it formed perpendicular to the vergence of Laurentia and Gondwana (Secor et al., 1986). In all, the limited structural data is internally consistent with the interpretation of the present study.

4.4 Rare Earth Elements in CCZO Granites

Although the CCZO granites share a closer affinity with the Cat Square granites than with the Charlotte terrane granites, the CCZO and Cat Square granites clearly separate out in their REE data. Most notably, the CCZO granites are highly depleted in total REE abundance in comparison to the Cat Square granites. Additionally, the Cat Square granites all show a negative Eu anomaly while the CCZO granites show a positive Eu anomaly. Perhaps the CCZO granites would share a closer similarity to the Charlotte terrane granites, but a more robust REE dataset from the Charlotte terrane would be needed to test this hypothesis.

4.5 Lithologic Implications on Future CCZO Studies

This study revealed new considerations which will help control lithologic influences in future studies at the CCZO. Because the CCZO hosts distinct mafic and felsic regions, lithology must be considered moving forward. Parity in lithologies should be maintained across field sites in order to remove the effects of differing parent materials, or studies should incorporate differing lithologies as a treatment to help explain variation in the landscape. This would be particularly important when attempting to characterize the effect different treatments (e.g. changing forest communities or land use history) would have on landscape evolution.

The CCZO showed two types of heterogeneity — one within lithologic units, and the other across lithologic units. Within unit heterogeneity was typified by the biotite gneiss/amphibolite unit. This unit showed distinct compositional zoning on the 3–10 m scale. Leucratic and mafic foliations were observed side by side that clearly displayed the vast mineralogical differences. These foliations should be treated as chemically and physically distinct in the context of landscape evolution especially when considering preferential weathering of mafic regions. This effect should be considered within Research Watersheds 1, 3, 4, 6, and 8 at the CCZO (Fig. 3).

Across unit heterogeneity should be an important consideration for Research Watersheds 2, 5, and 7. Here, the Charlotte terrane lithologies would detract from direct comparisons to the Cat Square lithologies in other watersheds. The impact and importance of this effect was not quantified in the present study, and the degree to which chemical heterogeneity is observed within the CCZO may be minor as the majority of lithologies observed were granitoids. Future work should seek to characterize the importance geochemistry of the different granitoids to allow for greater control on future experimentation.

Research watersheds 2, 5, and 7 as well as all meta-granitoid units may have the distinct advantage of increased chemical homogeneity throughout its spatial extent. As such, more confidence may be placed in iso-chemical and iso-mineralogical starting conditions than in the biotite gneiss/amphibolite portion of the CCZO.
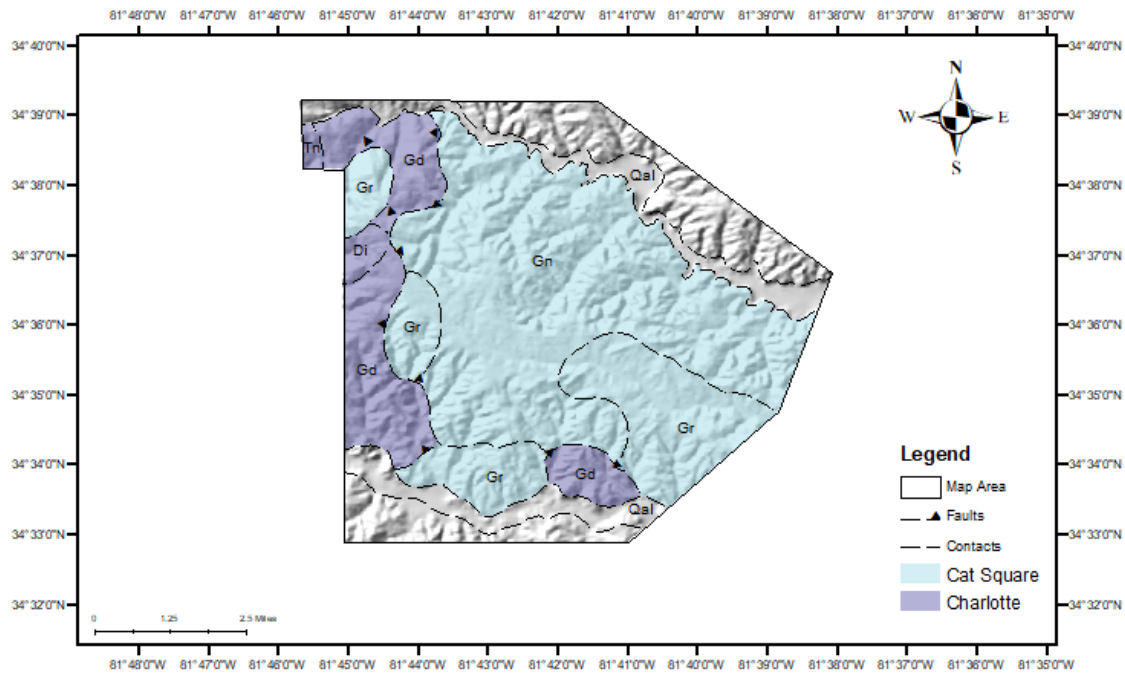
Figure 21: The Cat Square terrane composed the majority of the mapped region with smaller bodies of Charlotte terrane rocks lining the western portion of the field site. One granite body was detached from the rest of the Cat Square terrane interpreted to be a Fenster or "window" feature present in nappe tectonic regimes.

CHAPTER 5

SUMMARY

In order to provide a framework to understand the effect bedrock has on Critical Zone structure and processes, detailed geologic mapping was performed at the CCZO documenting the present lithologies and structural geology. The field site was found to host two distinct terranes, or genetically similar groups of rocks bound by faults. These were the Cat Square and the Charlotte terranes which were interpreted to mark the Central Piedmont Suture, a structural feature formed from the accretion of the peri-Gondwanan island Carolinia onto the Laurentian margin in the Paleozoic.

Using petrography, these lithologies were examined to confirm their terrane assignment and investigate the history of the region through deformational features associated with various parts of the Appalachian orogeny. Dynamic recrystallization textures were preserved in the crystallography showing distinct syn-orogenic and post-orogenic features. Geochemical analysis further classified the nature of the granites at the CCZO as intermediate, silica-saturated, and peraluminous.

As a result of this study, research at the CCZO now can incorporate lithologic variation into consideration for future experiments allowing for meaningful investigation into the relationship between the bedrock and Critical Zone architectures. Additionally, geologists investigating the development of Carolinia may now use the newly mapped areas to extend their sampling locations.

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APPENDIX A:

GEOLOGIC MAP
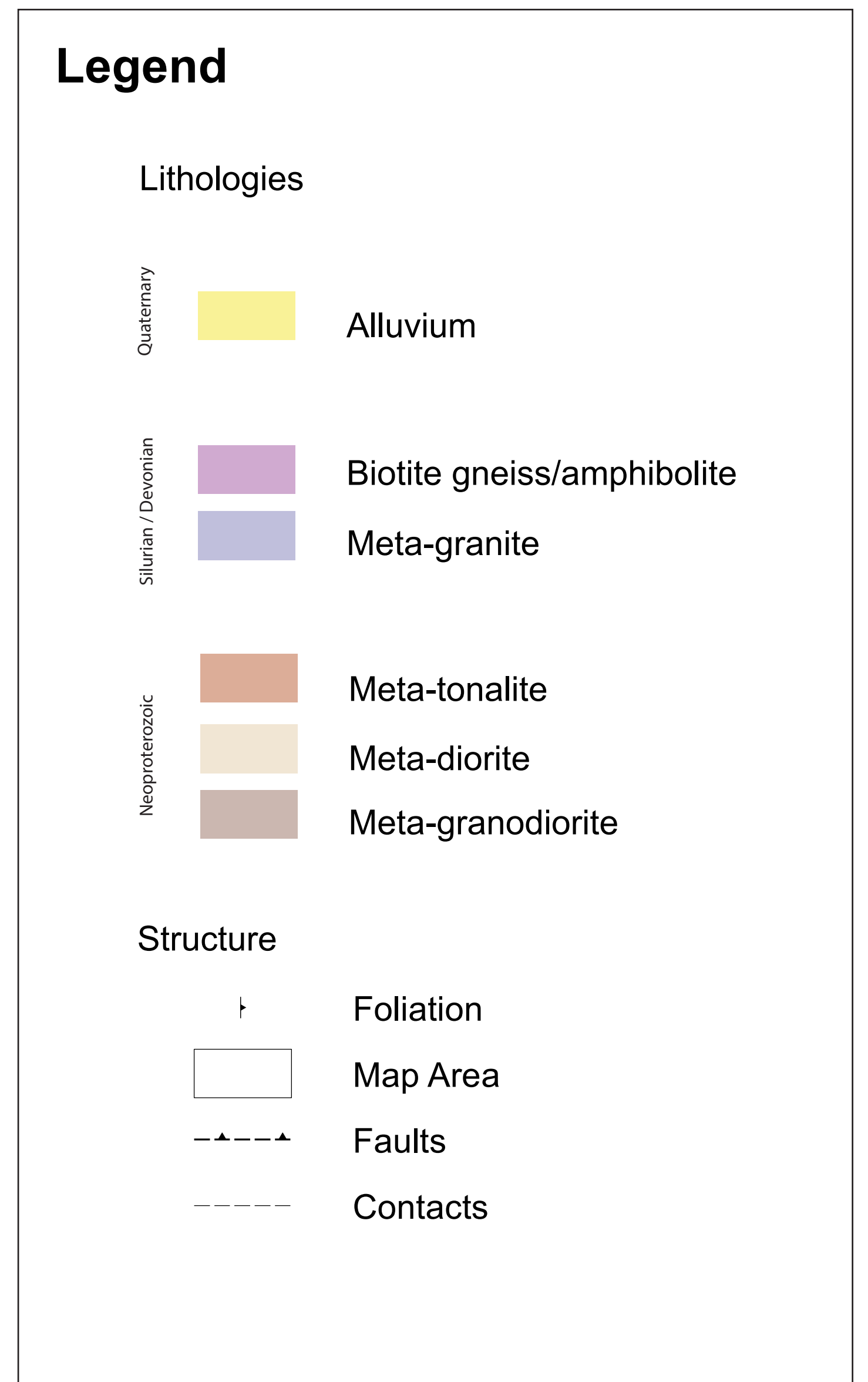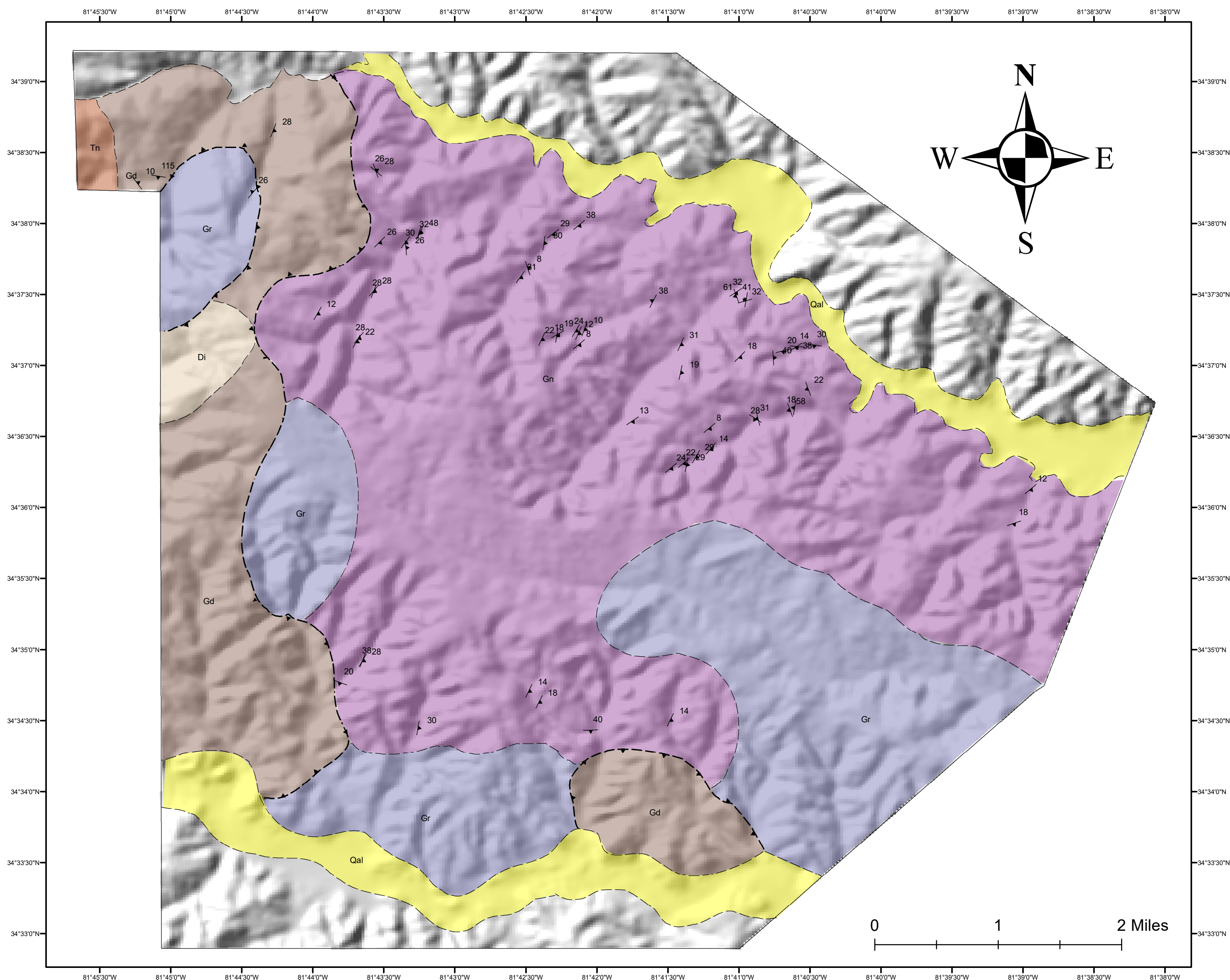
Geology of the Calhoun Critical Zone Observatory

by Bear Jordan

This map was produced in conjuction with the University of Georgia and the Calhoun Critical Zone Observatory. Further information about the mapped area can be found in "Geology of the Calhoun Critical Zone Observatory" by Bear Jordan.

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1785

Legend

Lithologies

Quaternary

Alluvium	

Silurian / Devonian

Biotite gneiss/amphibolite	
Meta-granite	

Neoproterozoic

Meta-tonalite	
Meta-diorite	
Meta-granodiorite	

Structure

Foliation

Map Area

Faults

Contacts

0   1   2 Miles

N W E S

Adapted from Hatcher et al. 2007

0   30   60 Miles   ☐ Study Area
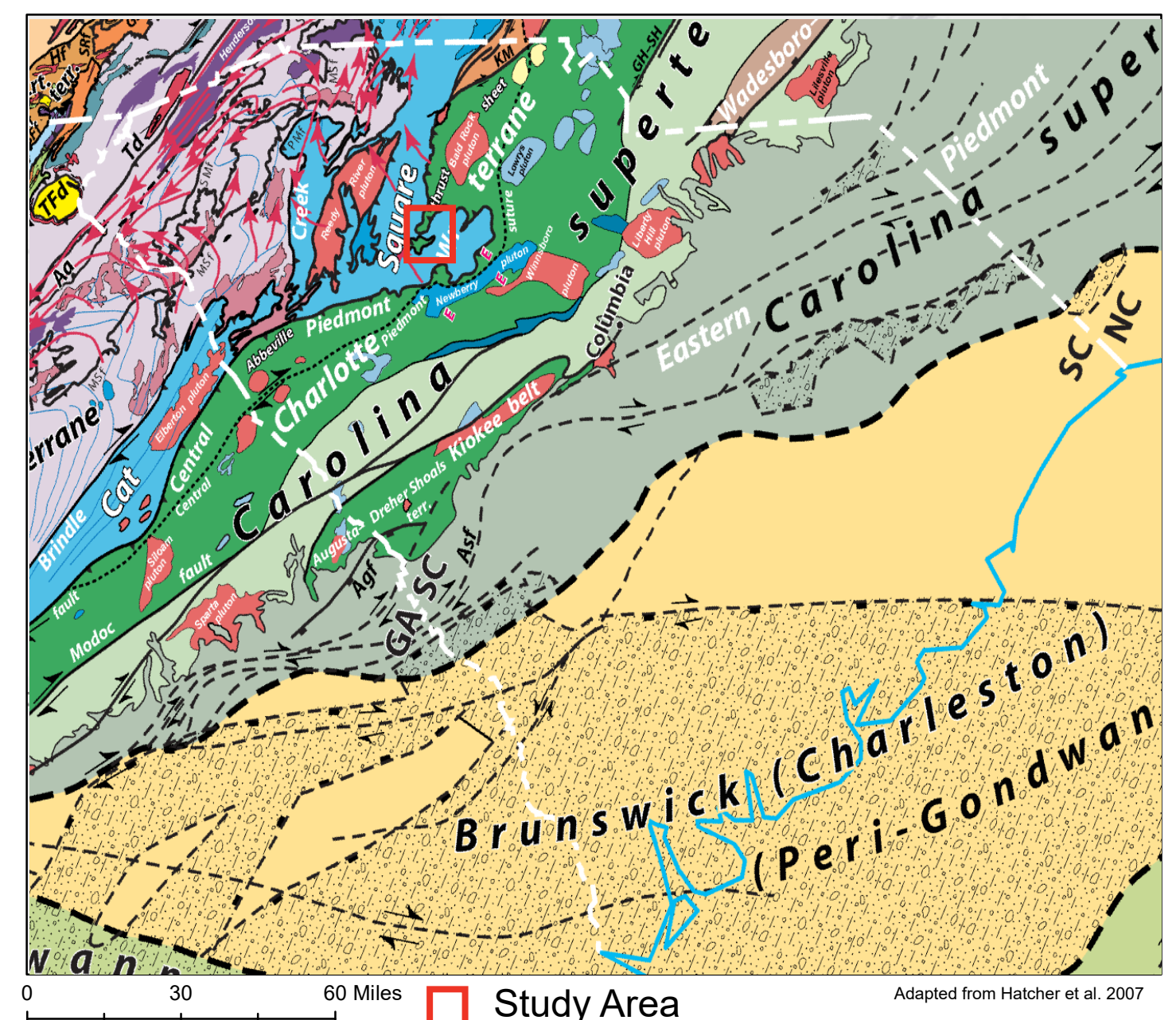
APPENDIX B:

X-RAY DIFFRACTION DATA

Biotite Meta-Granodiorite

Legend:
- ■ PDF 41-1480 (Na,Ca)Al(Si,Al)3O8 Albite, calcian, ordered
- ■ PDF 42-1437 K(Mg,Fe+2)3(Al,Fe+3)Si3O10(OH,F)2 Biotite-1M
- ■ PDF 84-1455 (K.95Na.05)AlSi3O8 Microcline Pellotsalo - K-rich phase - from Lake Ladoga,USSR
- ■ PDF 78-2315 SiO2 Quartz

Counts vs 2Theta WL=1.7890

Biotite Meta-Granodiorite

S-Q

PDF 42-1437 = 16.4 %

PDF 41-1480 = 20.3 %

PDF 84-1455 = 24.5 %

PDF 78-2315 = 38.8 %

Biotite Gneiss/Amphibolite

Legend:
- PDF 71-1060 Na.9K.4Ca1.6Mg2.9Fe1.4Ti.5Al2.4Si6O24 Hornblende
- PDF 33-1161 SiO2 Quartz, syn
- PDF 71-0748 (Na.5Ca.5)(Al1.5Si2.5O8) Labradorite
- PDF 19-0926 KAlSi3O8 Microcline, ordered

x-axis: 2Theta WL=1.7890

y-axis: Counts

S-Q

PDF 71-1060 = 51.7 %

PDF 19-0926 = 2.6 %

PDF 33-1161 = 6.6 %

PDF 71-0748 = 39.1 %

APPENDIX C:

GEOCHEMICAL DATA

Terrane	Granitoid	Sample	Age	SiO2	Al2O3	Fe2O3	MnO	MgO	CaO	Na2O	K2O	TiO2	P2O5
Carolina	Gold Hill	NC-318	368	75.6	12.7	1.24	-	0.28	1.15	4.19	3.32	0.2	-
Carolina	Salisbury	96	411	75.5	13.4	0.97	0.18	0.06	0.47	4.47	4.12	0.06	-
Carolina	Southmont	744	486	74.47	12.9	1.3	-	0.03	0.69	4.06	4.93	0.07	-
Carolina	Southmont	928	486	74.69	12.38	1.56	-	0.04	0.79	3.96	4.75	0.08	-
Carolina	Southmont	930	486	75.09	12.35	1.41	-	0.05	0.53	4.05	4.59	0.09	-
Carolina	Southmont	931	486	74.96	12.82	1.47	-	0.05	0.82	4.1	4.69	0.16	-
Carolina	Southmont	932	486	75.8	12.62	1.56	-	0.03	0.56	3.97	4.82	0.06	-
Carolina	Southmont	743*	486	74.92	12.64	1.54	-	0.04	0.7	3.92	4.96	0.08	-
Carolina	Southmont	745*	486	71.54	13.71	2.25	-	0.09	1	4.19	4.55	0.2	-
Carolina	Southmont	746*	486	75.85	12.14	1.35	-	0.03	0.59	3.89	4.78	0.07	-
Carolina	Southmont	927*	486	75.85	11.99	1.17	-	0.03	0.57	3.9	4.8	0.07	-
Carolina	Southmont	929*	486	75.95	12.75	1.42	-	0.03	0.5	4.01	5.02	0.07	-
Carolina	Southmont	933*	486	75.22	12.72	1.35	-	0.02	0.12	4.12	5.02	0.03	-
Carolina	Southmont	NC-62*	486	75	13.2	1.49	-	0.06	0.52	3.87	4.77	0.11	-
Carolina	Yadkin	747	461	74.54	12.99	0.94	-	0.01	0.53	4.5	4.62	0.04	-
Carolina	Yadkin	748	461	74.68	13.26	1.12	-	0.02	0.1	4.65	4.1	0.04	-
Carolina	Yadkin	749	461	74.58	12.53	0.52	-	0.01	0.12	4.42	4.37	0.04	-
Carolina	Yadkin	750	461	75.25	12.43	0.73	-	0.02	0.1	4.69	3.89	0.03	-
Carolina	Yadkin	751	461	75.58	12.86	0.88	-	0.01	0.12	4.38	4.43	0.03	-
Carolina	Yadkin	752	461	75.73	12.57	0.75	-	0.01	0.09	4.39	4.39	0	-
Carolina	Yadkin	920	461	75.66	13.78	1.24	-	0.02	0.08	4.57	4.48	0.02	-
Carolina	Yadkin	921	461	76.75	12.97	0.83	-	0.02	0.2	4.61	3.59	0.01	-
Carolina	Yadkin	922	461	75.14	13.78	1.05	-	0.01	0.09	4.72	4.35	0.01	-
Carolina	Yadkin	923	461	76.41	13.78	0.84	-	0.01	0.22	4.59	4.67	0.01	-
Carolina	Yadkin	924	461	77.76	13.16	1.21	-	0.02	0.06	4.31	4.39	0.01	-
Carolina	Yadkin	925	461	76.06	13.39	0.91	-	0.01	0.26	4.61	4.31	0.02	-
Carolina	Yadkin	926	461	76.12	12.63	0.95	-	0.01	0.11	4.46	4.35	0.03	-
Carolina	Yadkin	NC-97	461	75.6	13.4	1.49	-	0.02	0.52	4.49	4.12	0.04	-
Cat Square	Anderson Mil	AMG	415	71	14.3	2.99	0.07	0.67	2.61	2.99	3.61	0.3	0.07
Cat Square	Cherryville	C-10	355	72	14.93	0.96	0.02	0.22	0.19	2.84	5.16	0.17	0.17
Cat Square	Gray Court	GC-1	357	74	13.78	1.44	0.03	0.3	1.38	3.28	4.8	0.17	0.1
Cat Square	High Falls	FRHF	372	68.3	15.38	2.86	0.06	0.9	2.28	3.68	4.76	0.47	0.19
Cat Square	High Falls	HF862	378	61.6	18.89	5.38	0.09	1.14	2.99	3.82	4.76	0.72	0.15

Terrane	Granitoid	Sample	Age	SiO2	Al2O3	Fe2O3	MnO	MgO	CaO	Na2O	K2O	TiO2	P2O5
Cat Square	High Falls	HFSP	399	56.56	21.17	5.31	0.08	1.26	3.48	4.27	5.35	0.76	0.27
Cat Square	High Falls	IS370	378	65.8	15.83	5.38	0.12	1.14	2.4	2.74	4.15	0.69	0.23
Cat Square	High Falls	S123	383	71.57	13.88	3.41	0.27	0.69	0.89	2.08	5.94	0.35	0.05
Cat Square	Toluca	CH117	383	71.65	14.85	3.01	0.1	0.47	2.19	3.16	3.73	0.19	0.06
Cat Square	Toluca	TOL-1	383	73.1	15.04	2.1	0.04	0.26	2.22	3.56	3.63	0.12	0.03
Cat Square	Toluca	TOL-10	383	70.1	15.1	2.43	0.02	0.74	1.35	3.04	5.25	0.37	0.19
Cat Square	Toluca	TOL-11	383	68.9	14.93	2.78	0.02	0.74	1.35	3.04	5.28	0.63	0.19
Cat Square	Walker Top	B9WT	357	64.67	15.01	7.21	0.12	1.84	3.22	2.56	3.47	0.99	0.33
Cat Square	Walker Top	GL-1	357	66.36	15.74	4.54	0.09	1.99	3.47	2.69	4.16	0.76	0.26
Cat Square	Walker Top	GL-1B	357	65.03	15.77	4.56	0.09	2.03	3.57	2.96	4.16	0.75	0.26
Cat Square	Walker Top	GL-2	357	64.66	15.85	4.67	0.09	2.09	3.59	2.98	4.17	0.77	0.26
Cat Square	Walker Top	MV-19	408	67.96	15.18	3.48	0.06	1.33	2.55	3.1	3.96	0.58	0.22
Cat Square	Walker Top	MV-19B	357	68.37	15.35	3.45	0.06	1.34	2.57	3.28	4.26	0.56	0.21
Cat Square	Walker Top	MV-249	357	68.05	15.38	3.38	0.06	1.3	2.55	3.26	4.38	0.54	0.22
Cat Square	Walker Top	MV-564	357	71.48	15.09	2.3	0.05	0.51	1.17	2.89	4.86	0.32	0.24
Cat Square	Walker Top	MV-566	357	73.13	14.64	2.22	0.04	0.5	1.16	2.76	4.37	0.32	0.24
Cat Square	Walker Top	MV-566B	357	71.79	15.01	2.29	0.05	0.5	1.17	2.91	4.84	0.32	0.24
Cat Square	Walker Top	RP281	357	64.81	15.35	5.9	0.09	1.41	3.11	2.5	4	0.95	0.3
CCZO	CCZO	BR02	-	68.28	15.89	1.96	0.035	0.5	2.24	4.05	4.59	0.298	0.08
CCZO	CCZO	HC02	-	72.67	14.12	1.66	0.028	0.41	1.62	3.52	4.8	0.208	0.06

Terrane	Granitoid	Sample	Age	V	Cr	Cu	Zn	Rb	Sr	Y	Zr	Nb
Cat Square	Anderson Mill	AMG	415	35	3	1.1	60.4	148	133	20	158	13
Cat Square	Cherryville	C-10	355	6	3.2	1.37	54.6	298	52	6	197	41.8
Cat Square	Gray Court	GC-1	357	11	2.1	3.9	39.4	204	132	13	194	12.3
Cat Square	High Falls	FRHF	372	44	13.3	4	61	194	337	11	186	10
Cat Square	High Falls	HF862	378	63	14.9	2	91	155	190	34	303	14.6
Cat Square	High Falls	HFSP	399	67	30	-	84	194	208	42	329	17
Cat Square	High Falls	IS370	378	63	21.7	17	91	144	187	31	260	14.7
Cat Square	High Falls	S123	383	31	-	-	41	198	133	77	201	7.7
Cat Square	Toluca	CH117	383	13	8	37	40	113	204	30	190	5.6
Cat Square	Toluca	TOL-1	383	8	0.5	-	31.2	102	199	8	126	4.24
Cat Square	Toluca	TOL-10	383	37	9.7	2.35	46.8	157	244	18	254	14.4
Cat Square	Toluca	TOL-11	383	44	2.9	8.08	90.2	165	280	5	536	13
Cat Square	Walker Top	B9WT	357	78	33.1	13	110	150	184	71	388	25.7
Cat Square	Walker Top	GL-1	357	94	73.6	10	71	200	297	23	247	14.7
Cat Square	Walker Top	GL-1B	357	96	58.3	10	63	195	304	24	235	14.1
Cat Square	Walker Top	GL-2	357	97	61.3	9	64	195	305	24	253	14.3
Cat Square	Walker Top	MV-19	408	64	50.1	2	61	167	195	22	157	13.5
Cat Square	Walker Top	MV-19B	357	62	42.3	4	51	176	202	27	203	13.6
Cat Square	Walker Top	MV-249	357	61	32.2	4	49	170	204	28	235	12.7
Cat Square	Walker Top	MV-564	357	19	3.9	1	56	244	162	19	156	15.6
Cat Square	Walker Top	MV-566	357	22	8.6	1	65	209	155	18	136	15.1
Cat Square	Walker Top	MV-566B	357	19	6.2	2	58	234	163	19	148	15.7
Cat Square	Walker Top	RP281	357	75	31	20	77	120	217	44	484	13.4
CCZO	CCZO	BR02	-	28	-	20	40	96	644	3	157	2
CCZO	CCZO	HC02	-	21	-	40	40	120	381	4	88	4

Terrane	Granitoid	Sample	Age	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb
Cat Square	Anderson Mill	AMG	415	564	28.9	59.3	6.3	28	5.2	0.99	4.4	0.5
Cat Square	Cherryville	C-10	355	233	28.71	55.74	6.64	26.17	5.61	0.77	5.11	0.62
Cat Square	Gray Court	GC-1	357	355	29.15	63.59	6.07	23.48	4.56	0.74	4.1	0.64
Cat Square	High Falls	FRHF	372	1066	65.4	130	14.1	47	6.89	1.19	4.06	0.5
Cat Square	High Falls	HF862	378	851	55.7	116	13.4	52.3	10.2	1.89	7.48	1.1
Cat Square	High Falls	HFSP	399	1036	65.1	137	16.6	60.5	12.1	2.36	10.3	1.55
Cat Square	High Falls	IS370	378	905	49	105	12.2	49.4	10.3	1.68	7.73	1.15
Cat Square	High Falls	S123	383	765	44.7	98.5	11.5	41.2	8.48	1.23	6.77	1.3
Cat Square	Toluca	CH117	383	477	42.8	88.7	10.9	37.3	7.77	1.46	6.57	1.03
Cat Square	Toluca	TOL-1	383	661	28.78	57.88	6.36	24.12	4.21	1.47	2.89	0.39
Cat Square	Toluca	TOL-10	383	832	52.56	111	10.2	38.07	6.29	1.53	5.16	0.72
Cat Square	Toluca	TOL-11	383	1642	160	316	28.24	97.36	10.81	1.68	5.14	0.3
Cat Square	Walker Top	B9WT	357	679	74.8	159	17.8	63.1	12.7	1.61	10.4	1.7
Cat Square	Walker Top	GL-1	357	719	38.6	81.5	9.48	34.6	6.99	1.64	6.07	0.86
Cat Square	Walker Top	GL-1B	357	676	54.3	109	12.2	43.4	8.24	1.68	7.01	0.96
Cat Square	Walker Top	GL-2	357	664	35.7	73.4	8.31	31.5	6.75	1.61	6.18	0.9
Cat Square	Walker Top	MV-19	408	572	44.2	93.1	10.3	38.6	7.71	1.28	6.24	0.9
Cat Square	Walker Top	MV-19B	357	603	43.3	88.9	9.92	35.6	7.36	1.27	6.26	0.92
Cat Square	Walker Top	MV-249	357	628	44.9	91.4	10.1	36.4	7.54	1.26	6.36	0.94
Cat Square	Walker Top	MV-564	357	429	35.7	77	8.78	33.2	7.51	0.82	6.11	0.84
Cat Square	Walker Top	MV-566	357	389	37.1	83.8	9.49	36	8.16	0.8	6.23	0.87
Cat Square	Walker Top	MV-566B	357	416	36.8	81.3	9.21	34.7	7.82	0.82	6.31	0.84
Cat Square	Walker Top	RP281	357	869	91.7	183	24.8	81.7	14.8	2.26	11.2	1.71
CCZO	CCZO	BR02	-	1512	9.8	25.6	2.18	7.1	1	0.53	0.6	0.1
CCZO	CCZO	HC02	-	882	9.7	26	2.22	7.7	1.4	0.51	0.9	0.1

Terrane	Granitoid	Sample	Age	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	Pb
Cat Square	Anderson Mill	AMG	415	3.8	0.65	2.4	0.3	2.3	0.3	4	1	17
Cat Square	Cherryville	C-10	355	2.39	0.29	0.68	0.09	0.58	0.08	3.86	1.37	48.6
Cat Square	Gray Court	GC-1	357	3.07	0.53	1.47	0.2	1.27	0.2	4.83	0.57	39.5
Cat Square	High Falls	FRHF	372	2.38	0.4	1.05	0.14	0.89	0.13	4.6	0.88	32
Cat Square	High Falls	HF862	378	6.12	1.22	3.46	0.51	3.3	0.53	8.4	1	35
Cat Square	High Falls	HFSP	399	8.32	1.59	4.24	0.62	3.7	0.56	8.6	1.27	35
Cat Square	High Falls	IS370	378	6.01	1.14	3.15	0.47	3.14	0.52	7.1	1	30
Cat Square	High Falls	S123	383	9.98	2.91	11.1	2.32	17.6	2.59	5.6	0.53	51
Cat Square	Toluca	CH117	383	5.98	1.1	3	0.42	2.61	0.36	5.7	0.2	39
Cat Square	Toluca	TOL-1	383	1.74	0.28	0.73	0.09	0.61	0.08	4.19	0.08	29.3
Cat Square	Toluca	TOL-10	383	3.87	0.72	2.07	0.29	1.87	0.29	6.96	0.97	32.5
Cat Square	Toluca	TOL-11	383	1.57	0.19	0.42	0.06	0.38	0.05	12.84	0.36	25.7
Cat Square	Walker Top	B9WT	357	11	2.52	8.21	1.23	7.31	1.03	9.6	1	27
Cat Square	Walker Top	GL-1	357	4.65	0.82	2.27	0.32	1.92	0.27	6	0.89	28
Cat Square	Walker Top	GL-1B	357	4.91	0.9	2.38	0.33	2.02	0.28	5.9	1	26
Cat Square	Walker Top	GL-2	357	4.71	0.87	2.42	0.34	2.06	0.29	6.4	1	20
Cat Square	Walker Top	MV-19	408	4.74	0.82	2.11	0.28	1.62	0.22	4.4	0.89	39
Cat Square	Walker Top	MV-19B	357	5.03	0.93	2.49	0.34	2	0.28	5.1	0.9	32
Cat Square	Walker Top	MV-249	357	5.03	0.91	2.34	0.33	1.93	0.25	6	0.8	32
Cat Square	Walker Top	MV-564	357	3.89	0.69	1.84	0.28	1.76	0.24	4.2	0.9	25
Cat Square	Walker Top	MV-566	357	4.06	0.64	1.59	0.22	1.36	0.18	4.1	0.88	27
Cat Square	Walker Top	MV-566B	357	3.97	0.65	1.7	0.25	1.56	0.21	4	1.2	24
Cat Square	Walker Top	RP281	357	9.06	1.69	4.76	0.68	3.99	0.55	11.1	0.5	27
CCZO	CCZO	BR02	-	0.6	0.1	0.4	0.07	0.5	0.08	3.9	0.2	27
CCZO	CCZO	HC02	-	0.7	0.1	0.4	0.05	0.3	0.05	2.5	0.6	32

Terrane	Granitoid	Sample	Age	Th	U
Cat Square	Anderson Mill	AMG	415	15.6	2.9
Cat Square	Cherryville	C-10	355	14.9	12.87
Cat Square	Gray Court	GC-1	357	18.6	5.77
Cat Square	High Falls	FRHF	372	22.5	1.53
Cat Square	High Falls	HF862	378	24.1	2.29
Cat Square	High Falls	HFSP	399	25.3	2.74
Cat Square	High Falls	IS370	378	20.1	2.53
Cat Square	High Falls	S123	383	25.2	3.44
Cat Square	Toluca	CH117	383	18.5	2.93
Cat Square	Toluca	TOL-1	383	10.6	0.95
Cat Square	Toluca	TOL-10	383	23.3	2.47
Cat Square	Toluca	TOL-11	383	47.8	0.85
Cat Square	Walker Top	B9WT	357	29.9	1.72
Cat Square	Walker Top	GL-1	357	9.31	1.82
Cat Square	Walker Top	GL-1B	357	15.6	2.21
Cat Square	Walker Top	GL-2	357	8.11	1.82
Cat Square	Walker Top	MV-19	408	23.6	2.13
Cat Square	Walker Top	MV-19B	357	21.9	2.41
Cat Square	Walker Top	MV-249	357	22.8	3.21
Cat Square	Walker Top	MV-564	357	17.4	4.26
Cat Square	Walker Top	MV-566	357	17.7	4.35
Cat Square	Walker Top	MV-566B	357	18.3	4.61
Cat Square	Walker Top	RP281	357	30.4	1.06
CCZO	CCZO	BR02	-	14.5	1.4
CCZO	CCZO	HC02	-	16.3	1.8

APPENDIX D:

STRUCTURAL MEASUREMENTS

Measurement	Latitude	Longitdue	Strike	Dip	Dip Direction
Joint	34.6131	-81.6959	305	60	E
Joint	34.6131	-81.6959	43	72	E
Joint	34.6131	-81.6959	40	85	E
Joint	34.6131	-81.6959	355	75	E
Joint	34.6191	-81.6900	315	30	E
Joint	34.6191	-81.6900	267	31	W
Joint	34.6114	-81.6775	240	80	W
Joint	34.6114	-81.6775	233	82	W
Joint	34.6112	-81.6776	246	73	W
Joint	34.6106	-81.6786	62	72	E
Joint	34.6106	-81.6786	65	72	E
Joint	34.6105	-81.6798	60	80	E
Joint	34.6055	-81.6912	101	82	W
Joint	34.6055	-81.6912	100	80	W
Joint	34.6052	-81.6893	290	89	E
Joint	34.6038	-81.6892	112	90	-
Joint	34.6038	-81.6892	123	90	-
Joint	34.6056	-81.6890	115	90	-
Joint	34.6059	-81.6882	304	89	E
Joint	34.6067	-81.6874	252	92	W
Joint	34.6068	-81.6865	330	82	E
Joint	34.6068	-81.6865	333	72	E
Joint	34.6068	-81.6865	340	70	E
Joint	34.6068	-81.6865	231	86	W
Joint	34.6068	-81.6865	240	82	W
Joint	34.6068	-81.6865	250	90	-
Joint	34.6226	-81.6972	260	64	W
Joint	34.6190	-81.7020	308	70	E
Joint	34.6190	-81.7020	270	78	S
Joint	34.6190	-81.7020	150	89	W
Joint	34.6190	-81.7020	122	82	W
Joint	34.6190	-81.7020	144	80	W
Joint	34.6190	-81.7020	112	90	-
Joint	34.6245	-81.6935	310	64	E
Joint	34.6180	-81.6910	124	90	-
Joint	34.6371	-81.7405	204	74	W
Joint	34.6387	-81.7515	106	80	W
Joint	34.6387	-81.7515	94	84	W
Joint	34.5857	-81.7301	303	74	E
Joint	34.5795	-81.7085	89	80	E
Joint	34.5795	-81.7085	109	84	W
Joint	34.5795	-81.7085	105	80	W
Joint	34.5749	-81.7053	288	74	E
Joint	34.5749	-81.7053	85	82	E
Joint	34.5719	-81.6898	104	90	-
Joint	34.5719	-81.6898	281	80	E

Measurement	Latitude	Longitdue	Strike	Dip	Dip Direction
Joint	34.5719	-81.6898	197	77	W
Joint	34.6310	-81.7060	54	90	-
Joint	34.6194	-81.7280	100	88	W
Joint	34.6194	-81.7280	190	82	W
Joint	34.6194	-81.7280	67	90	-
Dike	34.6257	-81.6839	240	89	W
Dike	34.6244	-81.6827	190	40	W
Dike	34.6187	-81.6765	280	38	E
Dike	34.6139	-81.6754	310	59	E
Dike	34.6092	-81.6867	70	76	E
Dike	34.6160	-81.6947	210	70	W
Dike	34.6160	-81.6947	140	82	W
Dike	34.5867	-81.7295	260	74	W
Dike	34.5793	-81.7302	320	82	E
Dike	34.5741	-81.7208	166	82	W
Dike	34.6310	-81.7060	236	74	W
Fold Arm	34.6131	-81.6959	59	74	E
Fold Arm	34.6131	-81.6959	56	66	E
Fold Arm	34.6131	-81.6959	180	62	W
Fold Arm	34.6131	-81.6959	195	70	W
Fold Arm	34.6160	-81.6947	215	84	W
Fold Arm	34.6160	-81.6947	224	81	W
Foliation	34.6100	-81.6957	56	13	E
Foliation	34.6158	-81.6900	12	19	E
Foliation	34.6176	-81.6831	18	26	E
Foliation	34.6176	-81.6831	45	18	E
Foliation	34.6191	-81.6900	24	31	E
Foliation	34.6248	-81.6838	160	61	W
Foliation	34.6251	-81.6836	57	32	E
Foliation	34.6244	-81.6827	254	41	W
Foliation	34.6244	-81.6827	190	32	W
Foliation	34.6176	-81.6791	356	40	E
Foliation	34.6182	-81.6781	76	20	E
Foliation	34.6187	-81.6765	57	38	E
Foliation	34.6187	-81.6765	95	14	W
Foliation	34.6185	-81.6762	130	20	W
Foliation	34.6185	-81.6762	128	22	W
Foliation	34.6189	-81.6745	97	30	W
Foliation	34.6139	-81.6754	160	22	W
Foliation	34.6117	-81.6770	190	18	W
Foliation	34.6114	-81.6775	160	58	W
Foliation	34.6114	-81.6775	158	40	W
Foliation	34.6114	-81.6775	165	46	W
Foliation	34.6104	-81.6813	166	28	W
Foliation	34.6103	-81.6815	123	31	W

Measurement	Latitude	Longitdue	Strike	Dip	Dip Direction
Foliation	34.6045	-81.6912	50	24	E
Foliation	34.6045	-81.6912	30	14	E
Foliation	34.6055	-81.6912	310	12	E
Foliation	34.6051	-81.6897	50	22	E
Foliation	34.6052	-81.6893	17	8	E
Foliation	34.6050	-81.6893	10	29	E
Foliation	34.6056	-81.6890	4	28	E
Foliation	34.6059	-81.6882	30	29	E
Foliation	34.6067	-81.6874	57	26	E
Foliation	34.6068	-81.6865	50	10	E
Foliation	34.6068	-81.6865	40	14	E
Foliation	34.6092	-81.6867	50	8	E
Foliation	34.6197	-81.7063	25	22	E
Foliation	34.6202	-81.7045	10	18	E
Foliation	34.6202	-81.7045	60	19	E
Foliation	34.6207	-81.7023	30	24	E
Foliation	34.6204	-81.7020	24	12	E
Foliation	34.6209	-81.7013	20	10	E
Foliation	34.6190	-81.7020	50	8	E
Foliation	34.6243	-81.6936	207	38	W
Foliation	34.6371	-81.7405	220	26	W
Foliation	34.6442	-81.7378	21	28	E
Foliation	34.6382	-81.7538	323	10	E
Foliation	34.6387	-81.7515	99	115	W
Foliation	34.6396	-81.7258	310	26	E
Foliation	34.6396	-81.7258	341	28	E
Foliation	34.5820	-81.7273	30	38	E
Foliation	34.5820	-81.7273	21	28	E
Foliation	34.5793	-81.7302	110	20	W
Foliation	34.5741	-81.7208	10	30	E
Foliation	34.5784	-81.7078	25	14	E
Foliation	34.5771	-81.7066	27	18	E
Foliation	34.5737	-81.7007	87	40	E
Foliation	34.5750	-81.6912	53	29	E
Foliation	34.5750	-81.6912	26	14	E
Foliation	34.6322	-81.7207	18	32	E
Foliation	34.6227	-81.7326	30	12	E
Foliation	34.6330	-81.7020	50	38	E
Foliation	34.6330	-81.7020	55	32	E
Foliation	34.6320	-81.7050	53	29	E
Foliation	34.6310	-81.7060	8	30	E
Foliation	34.6282	-81.7080	342	8	E
Foliation	34.6270	-81.7088	36	31	E
Foliation	34.6323	-81.7206	24	48	E
Foliation	34.6310	-81.7223	37	30	E

Measurement	Latitude	Longitdue	Strike	Dip	Dip Direction
Foliation	34.6305	-81.7222	355	26	E
Foliation	34.6310	-81.7254	45	26	E
Foliation	34.6253	-81.7260	21	28	E
Foliation	34.6254	-81.7260	40	28	E
Foliation	34.6198	-81.7278	40	28	E
Foliation	34.6194	-81.7280	29	22	E
Foliation	34.6194	-81.7280	44	52	E
Foliation	34.5980	-81.6510	71	18	E
Foliation	34.6000	-81.6500	330	24	E
Foliation	34.6020	-81.6490	50	12	E

APPENDIX E:

FIELD GUIDE

Geology of the Calhoun Critical Zone Observatory: Field Guide

By Bear Jordan

February 28, 2020

Index

Preface

Thank you all for attending my field defense. Today is the result of 100s of hours of time in the field and in the offices of many professors, and I appreciate the support I have received in excess within the department. In particular, I would like to thank my committee members Dr. Paul Schroeder, Dr. Mike Roden, and Dr. Christian Klimczak for their patience and guidance.

The purpose of this field trip is to explore and review field observations produced during the past two years in order to validate the geologic map I have produced. With that understanding, the explanations and observations given today will focus on ideas that are observable with boots, a hand lens, and a compass. Detailed petrographic and geochemical analysis will be reserved to present during my oral defense later this Spring. Thank you all once again, and I'm looking forward to sharing my work with you.

Sincerely,

Bear Jordan

Itinerary
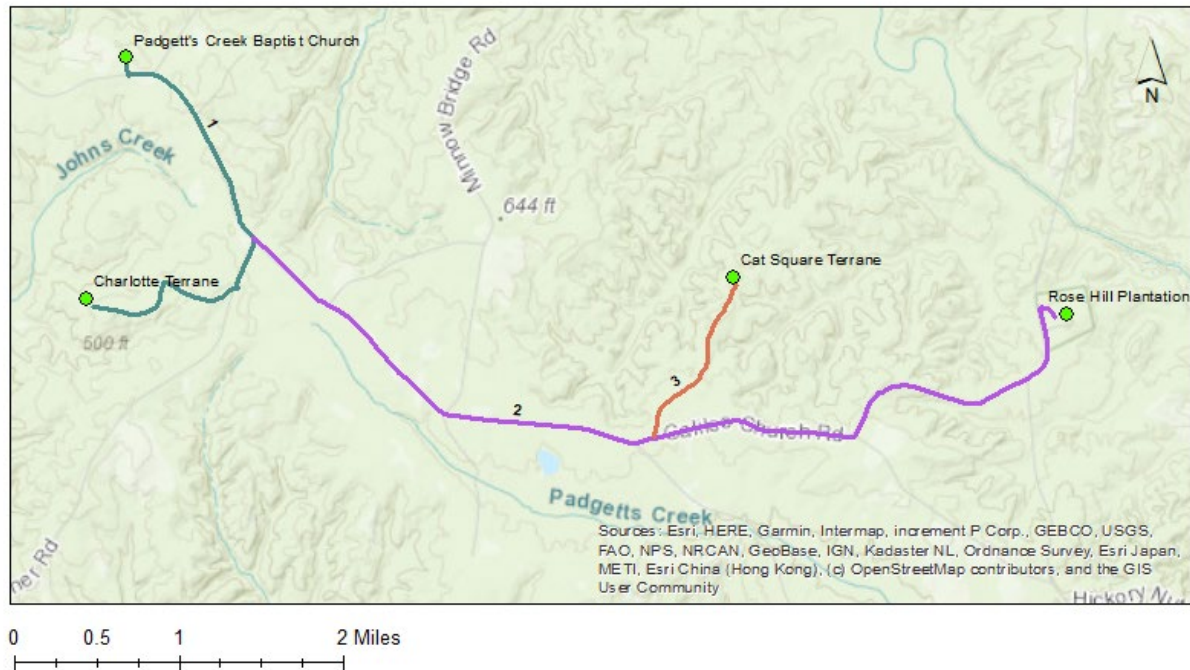
Goals

Stop 1: Examine type lithologies for the Charlotte Terrane

Stop 2: Eat lunch

Stop 3: Examine type lithologies of the Cat Square Terrane and observe structural trends

Directions

1. Padgett's Creek to Charlotte Terrane
   Left onto Old Buncombe Rd
   First right onto Forest Service Road

2. Charlotte Terrane to Rose Hill
   Exit towards Old Buncombe Rd
   Left at fork to SR-S-44-64
   Right into Rose Hill Plantation

3. Rose Hill Plantation to Cat Square Terrane
   Exit towards Old Buncombe Rd
   Right turn on Galilee Baptist Rd

Introduction
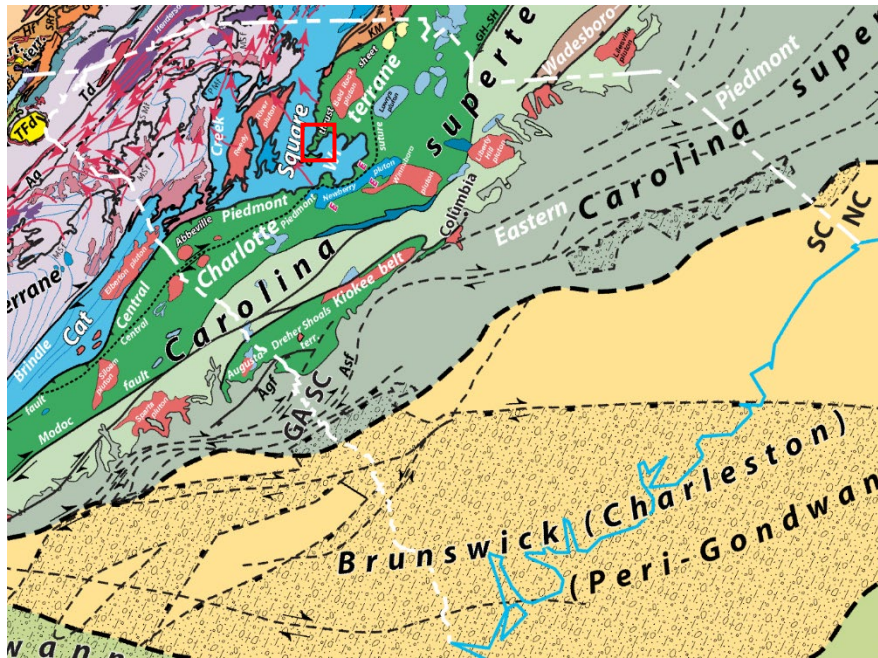
Figure 1: Regional geology of South Carolina with field site highlighted in red (adapted from Hatcher et al. 2007)
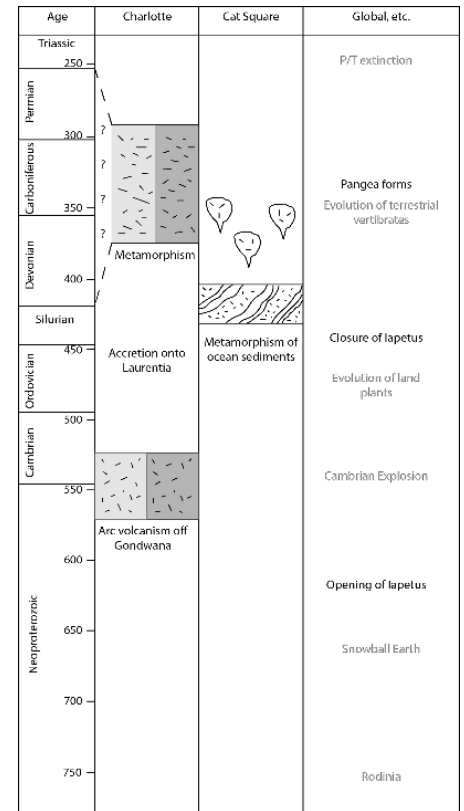
Figure 2: Correlated history of Cat Square and Charlotte Terranes (adapted from Pollock 2011)
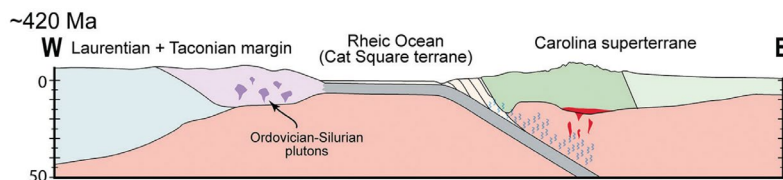
Figure 3: Tectonic setting for the formation of the Cat Square and Charlotte Terranes
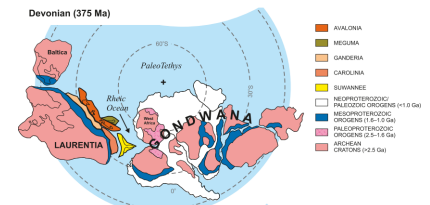
The geologic history of the CCZO spans across a billion years of earth history involving the formation and break up of two super-continents. From 1.3-1.0 Ga, the Grenvillian orogeny occurred along proto-Laurentia's margin whose weathered sediments accumulated in the subsequent ocean basin formed during Neoproterozoic rifting (Thomas, 2006). As the new oceanic crust grew, it was subsequently subducted at the Gondwanan margin during the Neoproterozoic-Cambrain transition resulting in island arc volcanism forming Carolinia (Pollock, 2011). These ocean basins closed in the middle Paleozoic as Gondwana and Laurentia began to converge. Gondwana thrusted over Laurentia zippering from north to south with a dextral strike slip component accreting the ocean basin sediments and Carolinia onto Laurentia and forming the Appalachian Mountains (Hatcher, 2010). By the end of the Mesozoic, Pangea would fully rift, developing the Atlantic Ocean and leaving behind dikes and joints. Over the past 60 Ma, extensive weathering has torn down the Appalachians to form the Piedmont and the modern setting in which we find the CCZO.

Geologic Map
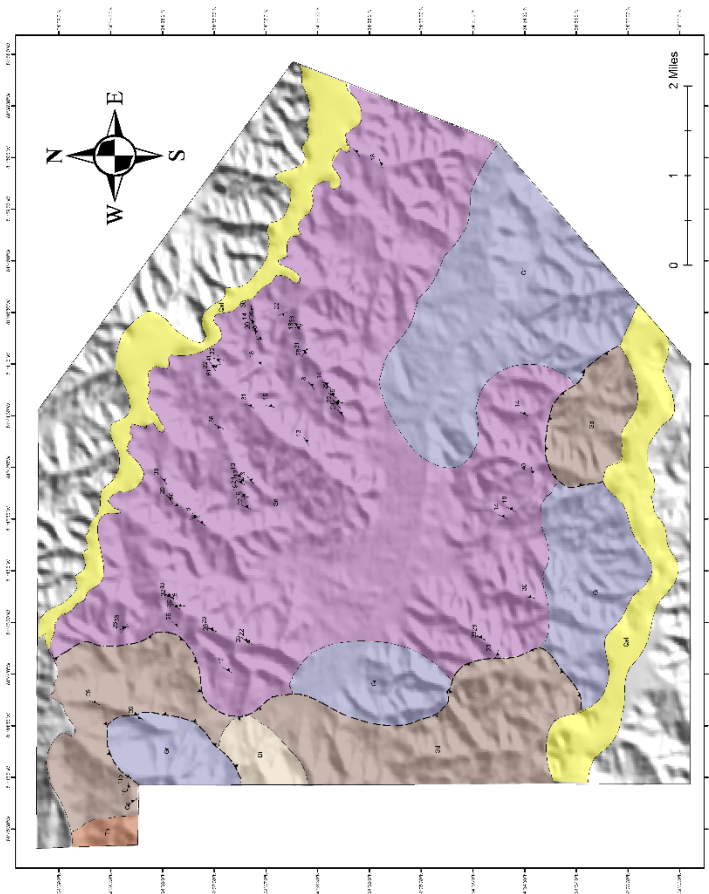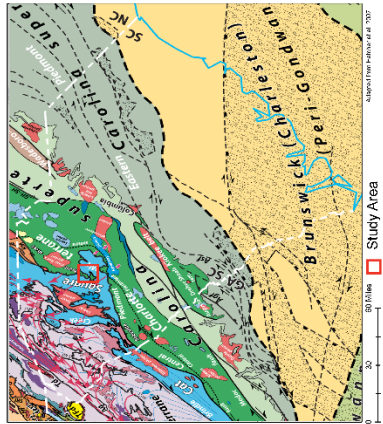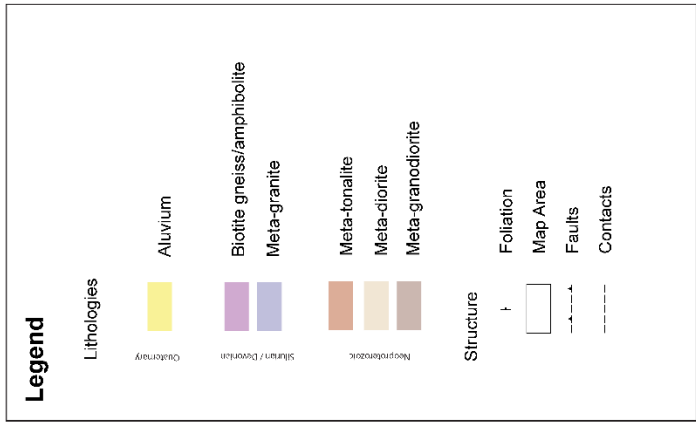
Legend

Lithologies

Quaternary
- Aluvium

Silurian / Devonian
- Biotite gneiss/amphibolite
- Meta-granite

Neoproterozoic
- Meta-tonalite
- Meta-diorite
- Meta-granodiorite

Structure
- Foliation
- Map Area
- Faults
- Contacts

Study Area

Geology of the Calhoun Critical Zone Observatory

by Bear Jordan

This map was produced in conjuction with the University of Georgia and the Calhoun Critical Zone Observatory. Further information about the mapped area can be found in "Geology of the Calhoun Critical Zone Observatory" by Bear Jordan.

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Department of Geology
Franklin College of Arts and Sciences
UNIVERSITY OF GEORGIA

Charlotte Terrane
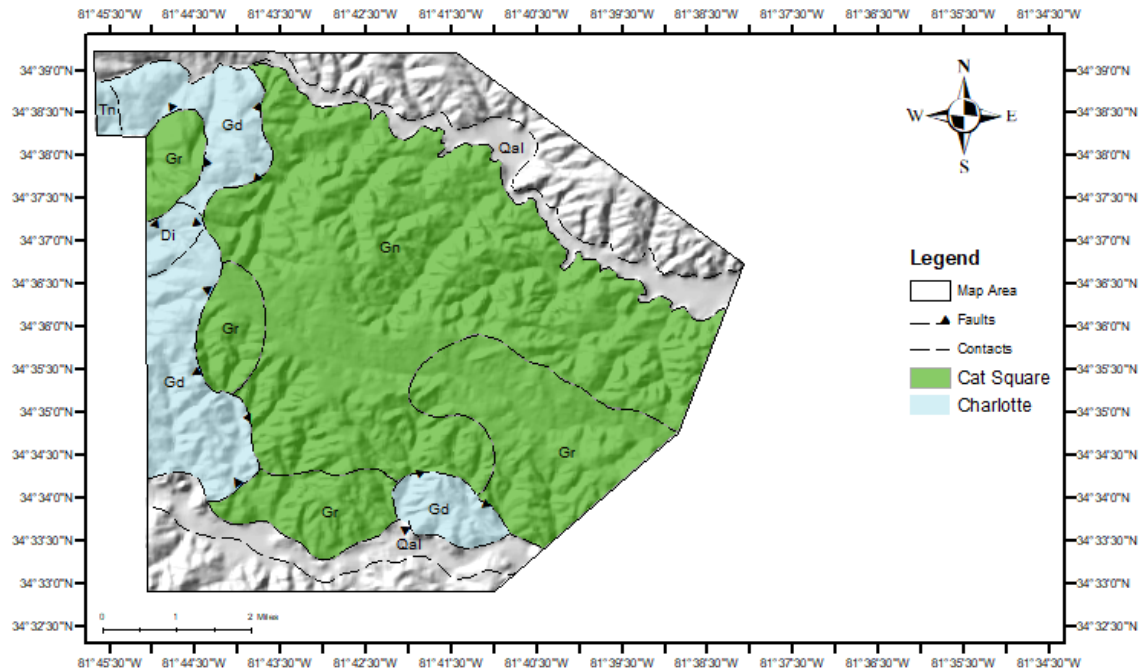
The Charlotte Terrane is observed along the western and southern boundaries of the field site. Both volcanic and plutonic rocks are present demonstrating various degrees of metamorphism presented in hand sample as incipient shape preferred orientation. Preservation is typically poor except for the meta-granodiorite units observed frequently as spheroidally weathered boulders in streambeds. The Charlotte Terrane's abundance of mafic and ultramafic rock types distinguishes it from the Cat Square Terrane.

Hand Samples

Meta-granodiorite (SC04)	Meta-tonalite (BR04)	Meta-diorite (PC06)
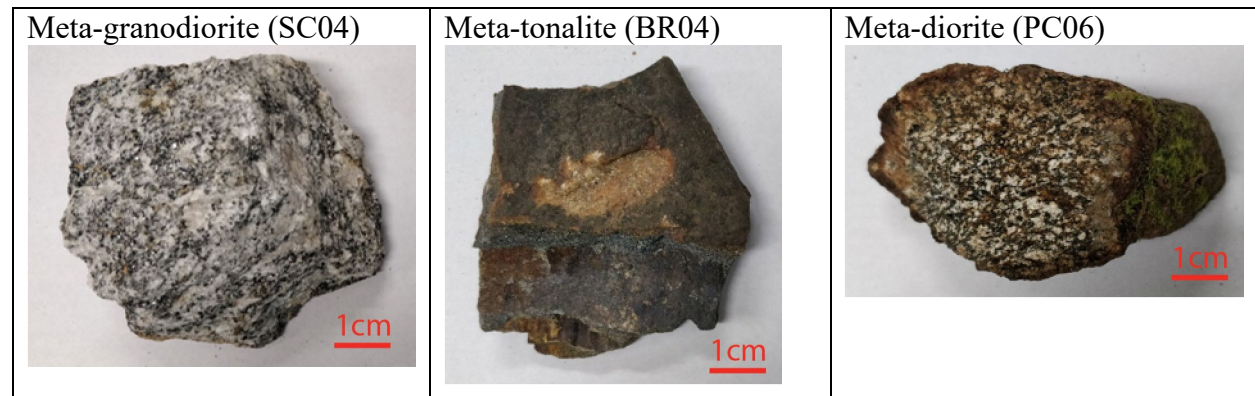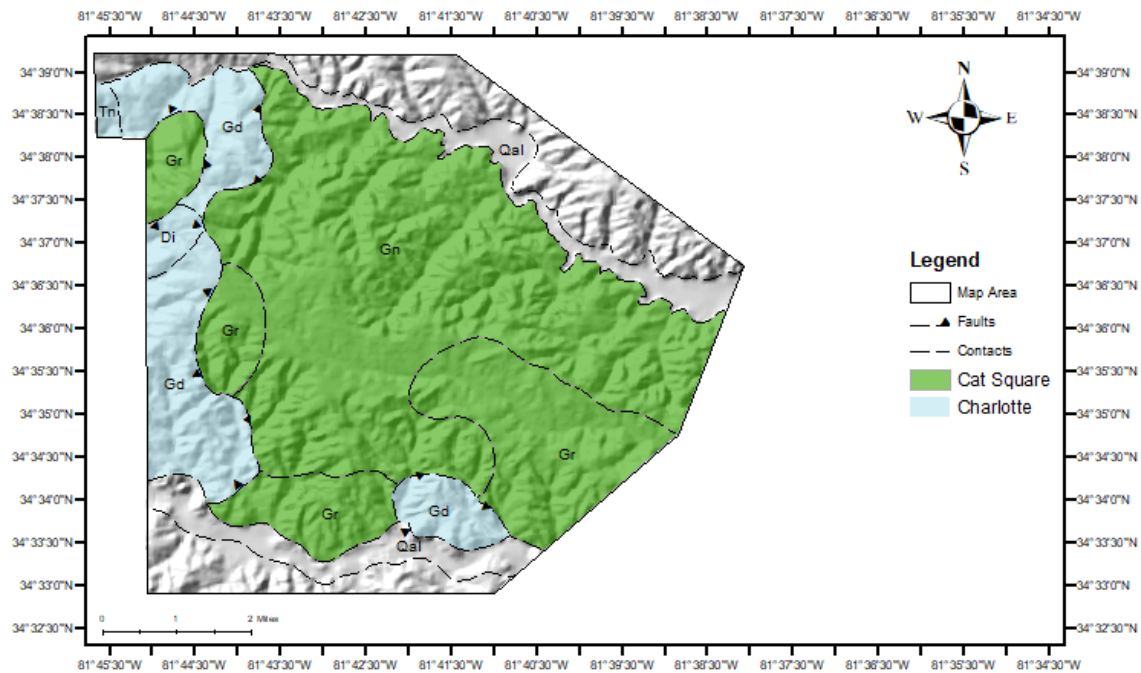
Cat Square Terrane

The Cat Square Terrane is mainly observed in the eastern portion of the field site with well preserved outcrops of gneiss and meta-granites in streambeds. Within the gneissic unit, rare inclusions of garnet quartzite and chlorite schists are observed. The extents of these regions are not large enough to include on the map.

Biotite gneiss (HB21)	Meta-granite (PC04)	Amphibolite lens (HB08)
Garnet quartzite (HB02)	Chlorite schist (HB23)	

Structure

On display at this outcrop within Holcombe's Branch is an extensive record of deformational events that preserve the CCZO's long geologic history. To reiterate, this outcrop shows scars from the Pangean supercontiental cycle consistent with regional structural trends.

Least recent

M1 – Development of foliation (pictured in alternating light and dark bands)

D1 – Folding

D2 – Jointing

Most recent

References

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Pollock, J. C., et al. (2011). "A paleogeographical review of the peri-Gondwanan realm of the Appalachian orogen." <u>Canadian Journal of Earth Sciences</u> **49**(1): 259-288.

Thomas, W. A. (2006). "Tectonic inheritance at a continental margin." <u>GSA today</u> **16**(2): 4-11.

APPENDIX F:

SAMPLE LOCATIONS

Latitude	Longitude	ID
34.6098	-81.6939	HB01
34.6095	-81.695	HB02, HB02-S
34.61	-81.6957	HB03, HB03-S
34.61	-81.6966	HB04
34.6088	-81.6932	HB05
34.6113	-81.6967	HB06
34.6131	-81.6959	HB07
34.6176	-81.692	HB08
34.6168	-81.6896	HB09
34.6153	-81.6898	HB10
34.6233	-81.6849	HB11
34.6244	-81.6827	HB12
34.6244	-81.6827	HB13
34.6237	-81.6794	HB14
34.6187	-81.6765	HB15
34.6159	-81.6726	HB15
34.6189	-81.6745	HB16
34.6133	-81.6837	HB18
34.6198	-81.7054	ORT01
34.618	-81.691	HB21
34.6324	-81.7426	BR01
34.6371	-81.7405	BR02
34.6408	-81.7575	BR04
34.6395	-81.7564	BR05
34.6396	-81.7565	BR06
34.6177	-81.749	PC02
34.6212	-81.7484	PC03
34.6063	-81.753	PC05
34.6053	-81.7591	PC06
34.6097	-81.7523	PC07
34.5944	-81.7509	PC08
34.5956	-81.7654	PC09
34.5944	-81.7618	PC10
34.5951	-81.7395	HC01
34.5925	-81.7388	HC02
34.5867	-81.7468	HC03
34.5857	-81.7301	HC04
34.5866	-81.7297	HC05, HC06
34.5867	-81.7295	HC07
34.582	-81.7273	HC08
34.5719	-81.7093	RH01
34.5749	-81.7053	RH02
34.5737	-81.7011	RH03, RH04
34.5802	-81.6964	RH05

34.5718	-81.6898	RH06
34.5719	-81.6898	RH07
34.5719	-81.6898	RH08
34.5762	-81.6768	RH09
34.57	-81.6798	RH10, RH11
34.6312	-81.725	SC01
34.6264	-81.7286	SC02
34.6264	-81.7288	SC03
34.629	-81.7305	SC05

APPENDIX G:

ACT LABS RESULTS

Analyte Symbol	SiO2	Al2O3	Fe2O3(T)
Unit Symbol	%	%	%
Detection Limit	0.01	0.01	0.01
Analysis Method	FUS-ICP	FUS-ICP	FUS-ICP
BR02	68.28	15.89	1.96
HC02	72.67	14.12	1.66

Analyte Symbol	CaO	Na2O	K2O
Unit Symbol	%	%	%
Detection Limit	0.01	0.01	0.01
Analysis Method	FUS-ICP	FUS-ICP	FUS-ICP
BR02	2.24	4.05	4.59
HC02	1.62	3.52	4.8

Analyte Symbol	LOI	Total	
Unit Symbol	%	%	
Detection Limit		0.01	
Analysis Method	GRAV	FUS-ICP	
BR02	0.36	98.28	
HC02	0.24	99.33	

Analyte Symbol	Sc	Be	V
Unit Symbol	ppm	ppm	ppm
Detection Limit	1	1	5
Analysis Method	FUS-ICP	FUS-ICP	FUS-ICP
BR02	3	2	28
HC02	3	2	21

Analyte Symbol	Ni	Cu	Zn
Unit Symbol	ppm	ppm	ppm
Detection Limit	20	10	30
Analysis Method	FUS-MS	FUS-MS	FUS-MS
BR02	< 20	20	40
HC02	< 20	40	40

Analyte Symbol	As	Rb	Sr
Unit Symbol	ppm	ppm	ppm
Detection Limit	5	2	2
Analysis Method	FUS-MS	FUS-MS	FUS-ICP
BR02	< 5	96	644
HC02	< 5	120	381

Analyte Symbol	Nb	Mo	Ag
Unit Symbol	ppm	ppm	ppm
Detection Limit	1	2	0.5
Analysis Method	FUS-MS	FUS-MS	FUS-MS
BR02	2	< 2	0.5

Analyte Symbol	SiO2	Al2O3	Fe2O3(T)
Unit Symbol	%	%	%
Detection Limit	0.01	0.01	0.01
Analysis Method	FUS-ICP	FUS-ICP	FUS-ICP
HC02	4	< 2	< 0.5

Analyte Symbol	Sb	Cs	Ba
Unit Symbol	ppm	ppm	ppm
Detection Limit	0.5	0.5	2
Analysis Method	FUS-MS	FUS-MS	FUS-ICP
BR02	< 0.5	2.5	1512
HC02	< 0.5	1.3	882

Analyte Symbol	Pr	Nd	Sm
Unit Symbol	ppm	ppm	ppm
Detection Limit	0.05	0.1	0.1
Analysis Method	FUS-MS	FUS-MS	FUS-MS
BR02	2.18	7.1	1
HC02	2.22	7.7	1.4

Analyte Symbol	Tb	Dy	Ho
Unit Symbol	ppm	ppm	ppm
Detection Limit	0.1	0.1	0.1
Analysis Method	FUS-MS	FUS-MS	FUS-MS
BR02	0.1	0.6	0.1
HC02	0.1	0.7	0.1

Analyte Symbol	Yb	Lu	Hf
Unit Symbol	ppm	ppm	ppm
Detection Limit	0.1	0.01	0.2
Analysis Method	FUS-MS	FUS-MS	FUS-MS
BR02	0.5	0.08	3.9
HC02	0.3	0.05	2.5

Analyte Symbol	Tl	Pb	Bi
Unit Symbol	ppm	ppm	ppm
Detection Limit	0.1	5	0.4
Analysis Method	FUS-MS	FUS-MS	FUS-MS
BR02	0.5	27	< 0.4
HC02	0.7	32	< 0.4

Report Number: A19-15874

Report Date: 28/11/2019

Analyte Symbol	MnO	MgO
Unit Symbol	%	%
Detection Limit	0.001	0.01
Analysis Method	FUS-ICP	FUS-ICP
BR02	0.035	0.5
HC02	0.028	0.41

Analyte Symbol	TiO2	P2O5
Unit Symbol	%	%
Detection Limit	0.001	0.01
Analysis Method	FUS-ICP	FUS-ICP
BR02	0.298	0.08
HC02	0.208	0.06

Analyte Symbol		
Unit Symbol		
Detection Limit		
Analysis Method		
BR02		
HC02		

Analyte Symbol	Cr	Co
Unit Symbol	ppm	ppm
Detection Limit	20	1
Analysis Method	FUS-MS	FUS-MS
BR02	< 20	4
HC02	< 20	3

Analyte Symbol	Ga	Ge
Unit Symbol	ppm	ppm
Detection Limit	1	1
Analysis Method	FUS-MS	FUS-MS
BR02	19	< 1
HC02	20	1

Analyte Symbol	Y	Zr
Unit Symbol	ppm	ppm
Detection Limit	1	2
Analysis Method	FUS-ICP	FUS-ICP
BR02	3	157
HC02	4	88

Analyte Symbol	In	Sn
Unit Symbol	ppm	ppm
Detection Limit	0.2	1
Analysis Method	FUS-MS	FUS-MS
BR02	< 0.2	1

Final Report
Activation Laboratories

Analyte Symbol	MnO	MgO
Unit Symbol	%	%
Detection Limit	0.001	0.01
Analysis Method	FUS-ICP	FUS-ICP
HC02	< 0.2	1

Analyte Symbol	La	Ce
Unit Symbol	ppm	ppm
Detection Limit	0.1	0.1
Analysis Method	FUS-MS	FUS-MS
BR02	9.8	25.6
HC02	9.7	26

Analyte Symbol	Eu	Gd
Unit Symbol	ppm	ppm
Detection Limit	0.05	0.1
Analysis Method	FUS-MS	FUS-MS
BR02	0.53	0.6
HC02	0.51	0.9

Analyte Symbol	Er	Tm
Unit Symbol	ppm	ppm
Detection Limit	0.1	0.05
Analysis Method	FUS-MS	FUS-MS
BR02	0.4	0.07
HC02	0.4	0.05

Analyte Symbol	Ta	W
Unit Symbol	ppm	ppm
Detection Limit	0.1	1
Analysis Method	FUS-MS	FUS-MS
BR02	0.2	6
HC02	0.6	< 1

Analyte Symbol	Th	U
Unit Symbol	ppm	ppm
Detection Limit	0.1	0.1
Analysis Method	FUS-MS	FUS-MS
BR02	14.5	1.4
HC02	16.3	1.8