ABSTRACT

CHALLENER, STEPHEN. Geological Setting of the Reed Gold Mine, North Carolina. (Under the direction of James P Hibbard).

The Reed Gold Mine (RGM) is a historically important mine in the Carolina terrane of central North Carolina. It is located in the Gold Hill shear zone (GHsz), a regional sinistral oblique thrust duplex that hosts numerous other historic gold mines and prospects. Although its discovery was the first documented find of gold in the United States, little is known about its geological setting; the focus of this study is to develop a clearer understanding of the geology of the deposit. A major motivation for this investigation is the renewed interest in gold in the Carolinas since the turn of the 21st century. Results of this study may aid in future gold exploration within either the GHsz or in similar gold fields worldwide.

A metagabbro body at the RGM is the primary host of auriferous quartz veins. The body is located in the core of a northeast-trending anticline in Neoproterozoic to earliest Cambrian strata of the Albemarle arc. As with other regional folds in the Carolina terrane, the anticline is attributed to the Late Ordovician to Early Silurian Cherokee orogeny. Whole rock geochemical analysis of the metagabbro indicates that it is a member of the regional Stony Mountain igneous suite, which represents c. 545-528 Ma magmatism during an arc rift event. Geochronological analysis of zircon from the metagabbro yielded no detectable uranium. New mapping reveals that the host metagabbro has an elliptical outcrop pattern with its long axis spatially coincident with the axis of the RGM anticline. In addition, structural analysis of the surrounding strata indicates that the RGM anticline is doubly plunging. These field observations in conjunction with magnetometric measurements are most consistent with the form of the metagabbro being a folded sill as opposed to a
subvertical dike as previously reported. Gold-bearing quartz veins in the metagabbro are shown to be orthogonal to the surface of the folded sill, indicating that they likely fill extensional cracks on the extrados of the sill resulting from neutral surface folding. Based on this structural relationship, mineralization at the mine site is interpreted to be synorogenic with the Cherokee orogeny. A review of the literature of gold deposits indicates that this new model for the geology of the RGM site appears to represent a previously undocumented setting for gold localization in both the GHsz of the Carolinas and worldwide.
DEDICATION

For my family, who put me on this path in the first place and supported me along the way.
BIOGRAPHY

Stephen Challener was born in Poughkeepsie, New York on 19 September, 1991, but grew up in Raleigh, NC. His family frequently travelled to the western US to visit relatives and collect rocks and minerals in the field. In retrospect the whole geology thing makes a lot of sense. He attended Raleigh Charter High School, graduating in 2010, and went on to attend UNC the following fall. Like every UNC freshman he intended to major in biology, but after taking the Field Geology of Eastern California first year seminar with Dr. Coleman there was no going back. He graduated with honors in 2014, completing undergraduate thesis work on ugly hornblende crystals under Dr. Glazner.

In fall of 2014 he started graduate work under Dr. Hibbard at NC State University. In 2016 he graduated with a Masters in Science from NC State University having completed his research on the geology of the Reed Gold Mine.

Stephen has a lifelong rock collecting habit which has developed into a strong interest in the lapidary arts, gemstones and jewelry. In partnership with his brother Tim he runs Angry Turtle Gems, an online jewelry business. He is also a digital artist, having contributed work to several indie game projects and to the multimedia webcomic Homestuck.
ACKNOWLEDGMENTS

First and foremost, I thank my adviser Dr. Hibbard. Not only has he provided constant help and support throughout the project, he has done so during his retirement which rightly should not involve editing any theses. Nevertheless he has shared his endless support and unmatched knowledge of southeastern geology.

I also thank the other members of my committee, Drs. Drew Coleman and Del Bohnenstiehl. Their support and expertise on specialized analysis methods, and unending patience when things didn’t work out quite right, have made this project possible. Thank you to both of you for so generously making your labs, equipment and time available.

Thank you to Connor Lawrence for the many hours spent helping me with zircon processing and dating.

Several others have generously offered their help on this project. Thanks to Phil Bradley, who has offered experience and advice about NC mapping in general and the Reed Gold Mine in specific. I would like to thank Dr. Jeff Pollock for his help in understanding the geochemistry of the Stony Mountain Suite. His help has been instrumental in understanding chemical analyses conducted in the course of this project. I’d also like to thank Dr. Brent Miller for his assistance in prepping geochemical samples and pointing me in the right direction for geochemical analysis.

I’d like to extend my appreciation to everyone who attended my field defense at the Reed Gold Mine and shared their time and expertise. Your comments have helped shape my analysis of the mine and directed my reading in exciting directions.
Thanks also to Ken Gillon and the geologists of the Haile Gold Mine. The extensive tour of the Haile Gold Mine provided during the GSA Southeast Section meeting and their ready sharing of modeling data was enlightening. Their comments on the Reed Gold Mine in the course of my field defense were also very helpful and encouraging.

Thanks to Larry Neal at the NC Department of Cultural Resources, Aaron Kepley and the entire staff at the Reed Gold Mine, who were always friendly and supportive of this research. Thanks also to Bird for having such short legs and brightening my days out there.

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Introduction

Focus of Study

The Reed Gold Mine (RGM) is a historically important mine in the Carolina terrane of central North Carolina. It is located in the Gold Hill shear zone (GHsz), a regional structure that hosts numerous other historic gold mines. However, in spite of its historical importance and location within the highly productive GHsz, the geology of the RGM is poorly understood. With the recent revival of interest in Carolina gold, understanding the geology of the RGM deposit is an essential step for directing future exploration within the region.

The most recent geological studies of the mine site (Osman, 1978; El-Samani, 1978) collectively formulated a basic model of the structure and geologic history of the RGM. However, that model is based on partially inaccurate map data; additionally, a wealth of information about the the broader regional context has only come to light over the past decade (e.g. Hibbard and Pollock, 2009; Hibbard et. al, 2010; Hibbard et. al, 2012). A wealth of research on analogous vein-hosted gold deposits has also been undertaken in the intervening decades. As such, the existing model for the RGM deposit is likely obsolete. It is the motivation and goal of this study to create a modern model for the geologic setting of the gold deposit that may help direct and inform future gold prospecting within the Gold Hill shear zone and the Carolina terrane.
**Historical Context**

The RGM is located on the former farmlands of John Reed, a Hessian defector from the British army during the Revolutionary War. Gold was first discovered on Reed’s land in 1799 when his son came across a 17 pound nugget in Little Meadow Creek (Fig. 1), a discovery that launched the North Carolina gold rush (Knapp, 1973). Early mining at the RGM focused on the alluvium in and around Little Meadow Creek, with haphazard panning eventually replaced by more sophisticated shakers used with quicksilver amalgam. By the early 1830s surface deposits were largely exhausted and the miners began subsurface excavations using methods that had been introduced to the state by Cornish miners. Several pits and shafts were sunk, targeting the gold-rich quartz veins in bedrock uncovered by farming activity (Partz, 1854). Diggings were largely limited to three hills surrounding Little Meadow Creek: Upper, Middle and Lower Hill, with minor activity on the adjacent Lake Hill (Fig 1).

Professional mining continued on an irregular basis until WWI, and amateur panning and prospecting continued in the following decades (Knapp, 1978). Although the total amount of gold produced at the site is unknown, it is estimated that 50,000 troy ounces (~1550 kg) of gold were recovered by 1830 (Koschmann and Bergendahl, 1998). By 1960, the total gold production of all North Carolina gold mines totaled to over a million troy ounces (~31,000 kg) (Koschmann and Bergendahl, 1998).

In 1971 the mine property was donated and made an NC state historic site (Knapp, 1978). The mine is located at 9621 Reed Mine Rd., Midland, NC (35°17'7.08"N,
80°28'0.04"W), and is open from Tuesday-Saturday from 9 to 5. Parking is available and the site has no entry fee. Walking paths provide ready access to most areas within the mine property, and the entire aboveground site is accessible. A portion of the underground workings, including Linker Adit (Fig. 1) and two cross-shafts, was shored up and wired for electricity to make them accessible to the public.

Figure 1: A map of the RGM mine site, with major roads, paths and landmarks overlaid on a 2015 orthophoto of the area (NC Onemap, 2015).

Recent elevated gold prices have led to a rekindling of interest in future exploitation of gold deposits in the Carolinas. The Haile gold mine in northern South Carolina has recently been reopened and will produce gold before the end of the year (K. Gillon, pers.)
Prospectors have also been actively seeking information on the geology of the GHsz, host structure to many North Carolina gold deposits (J. Hibbard, pers. com., 2014).

**Regional Geological Context**

The RGM is within Carolinia, a collection of terranes in the southern Appalachian Piedmont (Hibbard et al., 2012; Hibbard et al., 2002) (Fig. 2). The terranes that make up Carolinia are closely grouped spatially and all share a broadly similar lithologic assemblage of metavolcanic and associated epiclastic rocks (Hibbard et al., 2002). Based on a combination of isotopic dating, faunal affinity, and stratigraphic relations they have been determined to be exotic to Laurentia and peri-Gondwanan in origin (Hibbard et al., 2012). The RGM deposit is located in the center of Carolinia, near the western edge of the low grade Carolina terrane (Fig. 2), within the GHsz (Fig. 3) of North Carolina.
Figure 2. The Reed Gold Mine is centrally located in Carolinia, in the Gold Hill shear zone, near the western edge of the Carolina terrane. Adapted from Hibbard et al., 2012.
Figure 3: The RGM is located in the GHsz, near the boundary between the Albemarle arc and the Hyco arc. The GHsz is the site of numerous historical gold mines. Approximate locations of selected regional mines and prospects are pictured, taken from Nitze and Hanna (1896). Several regional folds cross-cut the GHsz, most of which are noncylindrical. One notable example is the New London Syncline (NLs); the outcrop pattern of the Albemarle arc felsic volcanics and the Yadkin Formation clearly show that it is doubly plunging. Adapted from Hibbard et al. (2012) and Pollock and Hibbard (2009).

Until recently, the GHsz was thought to locally mark the boundary between the Carolina and Charlotte terranes of Carolinia (e.g. Allen, 2005)(Fig. 3). However, recent work has shown that the shear zone is entirely within the Carolina terrane in central North Carolina. In this area, the shear zone instead marks the tectonic boundary between two major
constituent volcanic arcs in the terrane, the structurally higher and older Hyco arc (ca. 610-630 ma) to the west and the structurally lower and younger Albemarle arc (ca. 528-555) to the east (Hibbard et al., 2012). The GHsz has been interpreted as a sinistral oblique duplex beneath the Gold Hill fault that formed during the Late Ordovician Cherokee Orogeny, an event attributed to the accretion of Carolinia to Laurentia (Hibbard et al., 2012).

The Cherokee orogeny also produced several regional-scale folds in the arc sequences; these structures generally trend northeast, clockwise oblique to the shear zone, and are commonly non-cylindrical and doubly plunging (Fig. 3) (Stromquist et al. 1971; Stromquist and Sundelius, 1975; Sundelius and Stromquist, 1978; Goldsmith et al., 1988).

Rocks within the GHsz, including the RGM, form part of the Albemarle arc. Within the Carolina terrane, the Albemarle arc is an approximately 15 km thick sequence composed of mildly deformed volcanic and volcaniclastic rock (Stromquist and Sundelius, 1969; Allen, 2005; Pollock et al., 2010; Hibbard et al., 2012) deposited in an island arc environment (Butler and Ragland, 1969). Rocks within the arc range from 555-528 Ma in age (Hibbard et al., 2012). Although rocks within the Albemarle arc record greenschist facies metamorphic conditions (Stromquist and Sundelius, 1969), primary features are generally preserved and as such the prefix “meta-” has been omitted from volcaniclastic rock type names in the present study. The Albemarle arc includes the Uwharrie Formation at its base and the overlying Albemarle Group. The Albemarle Group has most recently been divided into the Tillery, Cid, Floyd Church and Yadkin formations (Milton, 1984). The stratigraphically lowest unit, the Tillery Formation, is defined by thinly laminated siltstone and claystone (Stromquist and
Sundelius, 1969). The overlying Cid Formation is composed of two distinct members separated by a thinly bedded shale. The lower member is composed of blocky, partially tuffaceous mudstone, and the top is defined by the distinctive Flat Swamp member, composed of mixed volcanioclastic rocks (Stromquist and Sundelius, 1969). The overlying Floyd Church Formation is composed of green argillite and siltstone (Stromquist and Sundelius, 1969). The uppermost unit, the Yadkin Formation, is largely composed of medium-bedded, fine- to medium-grained greywackes (Stromquist and Sundelius, 1969).

Although the RGM is within the Albemarle Group, it is unclear which formation it belongs to; El-Samani (1978) assigned it to the Cid Formation, whereas Sundelius and Stromquist (1978) considered it part of the Tillery Formation. Assignment of rocks in the GHsz to specific formations within the Albemarle Group is contentious and difficult because of structural disruption and the lack of stratigraphic context (Hibbard et al., 2012); as such, the mine site rocks are left as ‘unseparated Albemarle Group’ in the present study.

Gold-bearing quartz veins at the RGM are predominantly hosted in a metagabbro body, also referred to as a greenstone in older works (El-Samani, 1978). Observations during the present study indicate that the RGM metagabbro shows textural and mineralogical similarities to a regional suite of gabbros termed the Stony Mountain suite (SMs) (Ingram, 1999). The SMs comprises gabbro stocks, sills and dikes that intrude all units within the Albemarle Group. Sills are the most typical intrusion style (Pollock and Hibbard, 2009), but dikes and laccoliths have also been inferred from aeromagnetic data (Stromquist and
As with Albemarle Group strata, the gabbro bodies within the suite have been metamorphosed at greenschist facies (Pollock and Hibbard, 2009).

Because the Albemarle Group is the youngest unit in the Carolina terrane in North Carolina, the intrusion of the SMs is thought to be the last magmatic activity within the terrane before the greenschist grade metamorphism, which has been related to the accretion of Carolinia to Laurentia (Pollock and Hibbard, 2009; DeDecker et al., 2013). The SMs is thought to represent magmatism related to the arc rifting event responsible for the separation of the Carolina terrane from Gondwana and the opening the Rheic ocean (Pollock and Hibbard, 2009; Dedecker et al., 2013). Potentially correlative mafic units, dubbed the ‘departure’ gabbro, have been observed in the Carolina terrane of South Carolina (Secor et al., 2015).

**Previous Work**

Early information on the geology of the RGM is limited to cursory descriptions in regional reviews of North Carolina gold mining (Partz, 1854; Nitze and Hanna, 1896; Pardee and Park, 1946). These authors made only brief visits to the site and their reports largely focused on mining activity rather than geology. Of particular significance to the present study, two competing interpretations for the intrusive form of the metagabbro appear in these earlier works: Nitze and Hanna (1896) describe the metagabbro as a dike, whereas Pardee and Park (1946) describe it as a sill. Neither reference provides observations to support their respective interpretation.
The most recent geological investigations of the RGM site were conducted by Osman (1978) and El-Samani (1978). El-Samani (1978) produced a bedrock geological map of the site (Fig. 4) and described the general mine site geology, whereas Osman (1978) performed microscopy and rudimentary geochemical analysis on gold-hosting rock. El-Samani (1978) was the first to recognize a prominent fold in Albemarle Group strata within the RGM, herein termed the RGM fold, which he described as northeast-plunging and southeast verging. The location and trend of the RGM fold are readily observed in the local argillites on the basis of bedding-cleavage relationships. Bedding is subparallel to cleavage on the limbs and at a high angle to cleavage at the crest of the fold. Most measured bedding-cleavage intersections trend to the northeast; the northeast plunge was also readily inferred from northeast-dipping beds observed by El-Samani in the northeast area of the mine property. However, this interpretation of the fold conflicts with El-Samani’s mapping; the RGM M metamagabbro is shown outcropping at the core of the RGM fold, but its outcrop pattern closes off to the southwest and continues off the mine property to the northeast (Fig. 4); if the metamagabbro is concordant with bedding this pattern would be suggestive of a southwest-plunging anticline rather than a northeast-plunging structure.

El-Samani (1978) and Osman (1978) sidestepped this conflict by adopting the view of Nitze and Hanna (1896), modeling the metamagabbro as a subvertical dike intruded along the axis of the RGM fold after it had formed. In this interpretation, the southwestern closure was presumably considered to be the termination of the dike. El-Samani (1978) hypothesized that the gold deposit formed in three events. First, the local argillites were folded, forming the
RGM fold. Second, a gold-rich gabbro dike was intruded along the center of the fold axis. Finally, the entire area was brought to greenschist metamorphic conditions, and during the metamorphism gold and silica from within the gabbro was mobilized and redeposited in tension fractures (El-Samani 1978, Osman 1978).

Figure 4: RGM geologic map produced by El-Samani (1978) and adapted by Hibbard et. al (2013).
Methods and Approach

Lode gold at the RGM is hosted in quartz veins that are concentrated in the metagabbro body. Auriferous veins like these are precipitated from mineral-rich fluids (e.g. LaPoint and Moye, 2013). In order to fully understand the origin of the RGM deposit three main points need to be addressed: 1) the source of gold-bearing mineralizing fluids, 2) the paths that allowed the fluids to travel through the crust, and 3) the nature of the depositional sink where the veins were exsolved.

The pervasive low-grade foliation in rocks throughout the GHsz is suggestive of pressure solution as a source of fluids, and the concentration of numerous gold deposits in the GHsz suggest that this structure provides ample pathways for fluid migration within the GHsz. However, a full investigation of these first two points is beyond the scope of the present project. It is the final point, understanding the nature of the depositional sink, that is the focus of this study. By targeting the depositional sink a model can be created for gold localization, which is of greatest importance for locating economic deposits within a known gold field.

Because of the apparently contradictory nature of previous work, several questions must be answered to understand the nature of the depositional sink at the RGM. The first is the nature of the metagabbro intrusion. Although El-Samani and Osman modeled the metagabbro as a dike, it has also been interpreted to be a sill (Pardee and Park, 1946). The model of El-Samani and Osman also does not provide a compelling mechanism for the localization of mineralized veins within the metagabbro. Although El-Samani (1978) and
Osman (1978) both note that quartz veins are predominantly found in the RGM metagabbro, and that many veins strike to the southwest, they did not systematically examine the structure and orientation of the veins. As such, a structural analysis of the veins is necessary to model their formation. Finally, the origin and age of the RGM metagabbro, host to most of the mineralized quartz veins, are unknown. This information would provide an important constraint on the timing of mineralization and a stronger connection between the geology at the RGM and the broader geology of the region.

I have approached the nature of the depositional sink from several different directions, utilizing geologic mapping, geochemistry, geophysics and structural analysis.

First, I conducted new mapping of the bedrock to compare with the work done by El-Samani (1978). Second, geochemical analysis of the RGM metagabbro was performed to assess its relationship to the SMs. Third, U-Pb radiometric dating was attempted on zircons recovered from the RGM metagabbro in an attempt to establish a date of intrusion. Fourth, magnetometric mapping was performed at the site to distinguish between dike and sill intrusion styles for the RGM metagabbro. Fifth, structural mapping and analysis were conducted both on the RGM fold and on the quartz veins within the RGM metagabbro. Finally, the RGM is compared with other deposits in the GHsz and worldwide. The description of these approaches will constitute the next five sections of this study, and a concluding section will synthesize a model for the depositional sink for the RGM deposit.
Mapping Observations

In order to understand the nature of the RGM sink it is important to have an understanding of the rock varieties which make up the bedrock at the site and their distribution. Although mapping was previously conducted by El-Samani (1978), observations in the course of this study resulted in updated descriptions of previously identified rock types, the addition of newly identified rock types on the site, and a major revision to the outcrop pattern of the RGM metagabbro. These results will each be discussed in the following sections.

A Note about Geological Mapping

Mapping at the RGM is complicated by limited surface exposures of bedrock and pervasive overgrowth. Small exposures and open shafts are present in some areas, but in others underlying bedrock must be inferred from the contents of the root balls of overturned trees or of tailings piles. Although the mine area was once clear-cut farmland (Knapp, 1973) it is currently extensively forested with young growth trees. At the time that El-Samani (1978) was mapping surface exposures were more abundant—the majority of exposures marked on his map are now unexposed. As such, his map boundaries and tectonic features have been adopted where not in conflict with new mapping done in this study.

Rock Types

El-Samani (1978) described four mappable rock types at the RGM; however, some of his terminology is imprecise, and new observations in this study suggested that the rocks he interpreted as pyroclastic are in fact epiclastic. As such, several of his rock names were
adjusted to match the new observations. In the present study, five rock types were observed that were not mapped by El-Samani (1978). A summary of the changes to the names of mapped rock types is given in Table 1. The updated bedrock map of the RGM (Fig. 5) and descriptions of each rock type follow. Following these descriptions, the contact relationship between the metagabbro and the surrounding strata is discussed.

Table 1. Comparison and correlation of rock types recognized at the RGM by El-Samani (1978) and in this study.

<table>
<thead>
<tr>
<th>El-Samani</th>
<th>Present Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laminated Argillite</td>
<td>Laminated Argillite</td>
</tr>
<tr>
<td>Rhyodacite</td>
<td>Tuffaceous Argillite</td>
</tr>
<tr>
<td>Felsic Tuff</td>
<td></td>
</tr>
<tr>
<td>N/A</td>
<td>Massive Argillite</td>
</tr>
<tr>
<td>N/A</td>
<td>Chloritic Argillite</td>
</tr>
<tr>
<td>N/A</td>
<td>Slaty Argillite</td>
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<tr>
<td>N/A</td>
<td>Volcanlastic Conglomerate</td>
</tr>
<tr>
<td>Greenstone (Metagabbro)</td>
<td>Metagabbro</td>
</tr>
<tr>
<td>N/A</td>
<td>Diabase</td>
</tr>
</tbody>
</table>
Figure 5: An updated bedrock map of the RGM based on observations made during the present study; where there was no conflict with map data from this study, contacts were adapted from El-Samani (1978). Selected orientations of bedding and cleavage come from measurements made during this study as well as compiled from El-Samani (1978).

**RGM Metagabbro**

The RGM metagabbro (Fig. 5, Fig. 6) was generically termed a greenstone by earlier workers in the area, likely as a result of uncertainty over whether it was originally either an
intrusive or extrusive igneous rock. This uncertainty arose due to local obscuration of crystalline texture by any combination of metamorphism, alteration, and weathering. Examination by El Samani (1978) and observations made in this study, including its fine to medium grain size, igneous texture, overall homogeneity, and sharp contact with surrounding rocks, all serve to identify the protolith as a gabbro.

*Distribution of the RGM Metagabbro*

New mapping and revision of rock types present at the RGM during this study has led to a new perception of the outcrop pattern of the RGM metagabbro. Most notably, the northeast section of El Samani’s map (1978), which shows the RGM metagabbro with an elongated outcrop pattern that extends off the mine property (Fig. 4), is demonstrated to be inaccurate by new mapping (Fig. 5). Four prominent shafts were observed in the northeast section of Upper Hill, over 100 meters from the other workings. Although all other shafts observed at the RGM were sunk into metagabbro, the walls and tailings of these four shafts expose volcaniclastic rocks; two are in slaty argillite, and two in volcaniclastic conglomerate. None of the tailings piles contain any evidence of metagabbro. Similarly, the roots of fallen trees from the northeastern slope of Upper Hill contain flakes of weathered argillite but no metagabbro. These exposures provide definitive proof that the RGM metagabbro is not on the surface or close to the surface in this area. This observation requires a revision of the mapped outcrop pattern of the metagabbro, from an elongated structure to an oblate ovoid at the center of the RGM property, forming the tops of the hills at the site (Fig. 5). This change is significant to the structural analysis of the mine site.
The contradiction between my mapping and El-Samani (1978) is curious, given the obvious and easily-accessible nature of the shafts and their associated tailings piles. There may, however, be a historical explanation: at the time of his investigation, a purportedly cranky (W. Bell, pers. Com., 2016) groundskeeper lived in the northeast section of the mine property. It is possible that El-Samani could not access the area and simply extrapolated the metagabbro’s outcrop pattern based on his structural hypothesis.

Description

The metagabbro is medium to light grey on fresh surfaces and weathers to brown and tan. It shows a consistent medium-fine-grained plutonic igneous texture in all outcrops, although locally the texture is partially obscured by either weathering or alteration or both. In hand sample, feldspar grains of up to 2mm are visible in a greenish grey groundmass. Pyrite cubes from 0.5 to 6 mm are locally present, with prevalence ranging from samples with no visible pyrite to approximately 5% of some samples. Locally, pyrite is replaced by red iron oxides. White quartz veins from 0.5 mm to greater than a meter in width are present throughout the metagabbro. Some veins have either crystals of tan calcite intergrown with the quartz or angular voids where calcite has dissolved away (Fig. 6a).

Thin section examination reveals that the metagabbro is equigranular, with original grain boundaries largely intact despite alteration. Feldspar is present throughout, ranging from largely unaltered crystals showing lamellar twinning to fully saussuritized grains. Original pyroxene and other phases are extensively replaced with fine-grained sericite and chlorite. White skeletal opaque inclusions are present throughout the metagabbro, commonly
associated with weathered pyrite. El Samani (1978) identified this phase as leucoxene, a fine intergrowth of rutile and anatase that typically replaces ilmenite and commonly shows a skeletal morphology (Pichler and Schmitt-Riegraf, 2012). In one thin section from Lake Hill abundant blebs of what is likely gold are present in limonitized pyrite (Fig. 6c).

Some samples are intensely weathered and friable and others are heterogeneously silicified. Silicification expresses itself in color changes, with more silicified areas grading to light grey in color; texture remains consistent but is more difficult to discern in hand sample. Silicified samples also exhibit increased resilience and can be broken only with great effort.

Pollock (2007) has described the petrography of the SMs in detail. Members are gabbros that record greenschist facies metamorphism; they intrude every formation of the Albemarle Group, most typically as sills that tend to define the tops of hills and ridges (Pollock and Hibbard, 2009). Although some members of the suite are coarser grained and fresher, with more original mineralogy preserved through the greenschist facies overprint, overall the RGM metagabbro bears a striking petrographic similarity to the SMs.

Age of the RGM Metagabbro

There is no direct evidence for the age of the RGM metagabbro. However, a sample of SMs from Ridges Mountain, North Carolina, was dated using U-Pb zircon dating to 544.81±0.55 Ma (DeDecker et al., 2013); the SMs, however, has been found to intrude every unit of the Albemarle Group (Pollock and Hibbard, 2009). As such, intrusion of SMs
members is clearly time transgressive, ranging at least from 545 Ma to 528 Ma, the minimum age of the youngest Albemarle sedimentary rocks (Hibbard et al., 2012).

![Figure 6: RGM metagabbro. Hand sample approximately 15 cm across in (a), featuring two quartz veins. In (b), at 20x with uncrossed polars, extensive chloritization and skeletal black opaque phases are visible. In (c) a reflected light image at 40x reveals detail within the opaque phases. The skeletal white opaque minerals are likely leucoxene, the red likely limonite after pyrite, and the metallic blebs within the red are likely gold.](image)

**Unseparated Albemarle Group**

The majority of bedrock surrounding the RGM metagabbro is composed of a variety of volcaniclastic rocks (Fig. 5). They are known to be part of the Albemarle Group, but as noted above no attempt has been made to assign them to a specific formation. Within the RGM property separation of many of these Albemarle Group rocks can be difficult. All
appear to be epiclastic in origin, and different varieties are commonly interbedded with one another, an issue also noted by El-Samani (1978). Few fresh outcrops of Albemarle Group rocks are currently available on the site, and weathering quickly obscures many of their distinguishing features. As such, mapped areas of each variety represent the rock type which is most dominant in fresh outcrops. The term ‘argillite’ is broadly used in this study to describe any of the five fine-grained volcaniclastic rocks present at the RGM (Table 1).

The map patterns of Albemarle Group rocks from El-Samani’s map (1978) were largely preserved, although with different rock names. The majority of new rock types were identified and marked in areas previously mapped as laminated argillite or within the northeast area previously mapped as RGM metagabbro.

Some rock types are separated on the basis of differences in appearance which may be the result of secondary alteration rather than initial composition or depositional style. This is particularly true in the separation of tuffaceous argillite and slaty argillite. However, other rock type divisions such as chloritic argillite and massive argillite reflect obvious differences in composition or depositional style.

_Laminated Argillite_

Laminated argillite (Figs. 4, 7) is the most common volcaniclastic rock within the RGM property, and is observed in several small outcrops across the site. It is usually tan, fine-grained and friable; grain size ranges from clay to fine sand. Bedding laminae are well preserved, and graded beds of up to 2 cm thick are locally visible. Because of its intensely
weathered nature, thin sections of the laminated argillite were not made during the present study.

Figure 7: A typical outcrop of laminated argillite (a) along with readily-removed cleavage flakes (b). Main access road to the Reed Gold Mine state historic site.

Tuffaceous Argillite

Tuffaceous argillite forms several thin bodies elongated parallel to the strike of the RGM fold (Fig.5). It is superficially similar in appearance to laminated argillite, with a tan to green-grey color and grain sizes that range from clay to silt. However, the tuffaceous argillite can be distinguished by its superior competence resulting in a subconchoidal fracture and prominent crystals of pyrite ranging from 1-3 mm. Bedding is visible in some outcrops, particularly in exposures forming the walls of Linker Adit. There, beds range up to approximately 10 cm in thickness.

Massive Argillite

Massive argillite (Figs. 5, 8) is most commonly seen interbedded with other argillite varieties, but in a small area southwest of the RGM metagabbro it is the most prominent rock
type. There it is grey to white, and typified by its flinty, subconchoidal fracture, indistinct cleavage and lack of visible bedding.

In thin section it has a uniform, fine-grained texture of quartz and feldspar. White, opaque grains of leucoxene with an irregular, rounded outline are scattered throughout. Foliation is defined by dark seams (Fig. 8b). The argillite has abundant microscopic veins of quartz; in the single thin section viewed in this study the veins were predominantly oriented approximately 30 degrees from cleavage.

Figure 8: (a), massive argillite shows a subconchoidal fracture, indistinct cleavage and a lack of bedding features. Sample shown is approximately 20 cm across. In (b), at 40x with crossed polars, the fine-grained nature of the massive argillite is apparent. Foliation is defined by the dark seams. Micro quartz veins crosscut the matrix. Some of the black patches are opaque leucoxene, and others are apparently sericitized inclusions that were plucked out of the thin section during the polishing process, leaving voids. In (c) one of the intact inclusions is seen at 100x with crossed polars. It is largely quartz and feldspar with a patch of sericite in the center, and a small pyrite cube on one edge. The inclusion is cross-cut by a fine quartz vein. Above it is one of the foliation seams seen in (b); at higher magnification the seam is red and resembles oxidized biotite.
Slaty Argillite

Dark grey slaty argillite (Figs. 4, 9) is observed exclusively in two shaft walls and tailings piles to the northeast of Upper Hill. It is the most dense and most competent variety of argillite, with pronounced planar cleavage. Pyrite cubes up to 6 mm and quartz veins up to 5mm across are present throughout. Bedding up to approximately 6cm thick can be readily observed and at this locality it is at a high angle to cleavage.

In thin section individual silt-sized clasts can be seen to make up the majority of the rock. Bedding is defined by subtle transitions in grain size. Foliation is marked by planar stringers of opaque minerals. Microscopic cubes of altered pyrite are scattered throughout the rock, along with irregular blobs of leucoxene similar to those seen in the massive argillite.

Slaty argillite may be a less weathered or more silicified example of tuffaceous argillite, which shows a similar prevalence of pyrite and bedding on a similar scale. However, the quantity and width of quartz veins and size of pyrite cubes are significantly greater in the slaty argillite than in the tuffaceous argillite.
Figure 9: Slaty Argillite. A typical hand sample (a) is fine-grained aside from large pyrite cubes, and displays pronounced cleavage. bedding features are readily observed. In thin section view (b) fine lines of dark red oxidized biotite and irregular blobs of opaque leucoxene are observed.

**Chloritic Argillite**

Chloritic argillite (Figs. 5, 10) is observed in a single minor pit on Mansion Hill in the southeast corner of the mine property. It is medium grey-green and extensively altered, with rusty iron oxides and hydroxides present in cracks and voids in the rock (Fig. 10a). Cleavage is well developed, but is wavy and generally less planar than in slaty argillite. Hand samples commonly have a knobbled surface texture with diffuse lumps of pea size or smaller present throughout the rock.

In thin section, the majority of the rock can be seen to be composed of chlorite (Fig. 10b). The lumps seen in hand sample appear to be angular lithic clasts which deflect the
fabric of the surrounding chlorite (Fig. 10b). Feldspar crystal fragments are present but most have been extensively sericitized (Fig. 10c). White leucoxene is present throughout in the form of irregular blobs similar to those in the massive and slaty argillite.

Figure 10: In hand sample (a) chloritic argillite is a dull grey-green with red to orange iron oxide deposits. In (b) at 100x with crossed polars, with a single clast centered in frame (outlined in black). Despite indistinct edges it can be identified by its coarser texture and disruption of the surrounding rock fabric defined by oriented chlorite crystals. In (c) at 40x with uncrossed polars the clastic nature of the rock becomes apparent, although almost all minerals have been largely chloritized.

*Volcaniclastic Conglomerate*

Volcaniclastic conglomerate is locally interbedded with laminated, massive and tuffaceous argillite, but it is most prominent in the walls and tailings piles of two shafts in the north-eastern area of the mine, where it is the only rock type exposed (Figs. 5, 11). It is readily identified by grey to brown, angular to subangular clasts up to 5cm, including crystals
of white feldspar that range up to 3mm in length, within a medium grey-green fine-grained groundmass. Quartz veins up to 4cm in width are prevalent throughout the rock.

In thin section, broken, angular feldspar crystals and larger lithic clasts can be seen to make up the majority of the rock (Figs. 11b, 11c). Some feldspars are largely intact and unaltered with lamellar twinning but others are almost entirely saussuritized. Lithic clasts are rounded to angular in shape, and appear to be mainly epiclastic. Some clasts are volcanic, displaying a variety of textures and compositions, that appear to range from mafic to felsic. Some clasts can be readily distinguished, but others partially blend into the matrix (Fig. 11c). As with the RGM argillites, opaque white grains of leucoxene are present throughout the rock, although they are larger and more prominent in some clasts than in the matrix.

Figure 11: At first glance, the feldspar clasts give the volcaniclastic conglomerate a porphyritic appearance. On closer inspection, however, the rock is composed of diverse angular to rounded volcanic clasts. (b) At 40x a variety of clasts can be seen. Although many clasts are largely altered, some feldspars are intact and some clasts preserve original volcanic textures. (c) A prominent clast with trachytic texture viewed at 100x with crossed polars.


**Diabase**

The root ball of a single fallen tree on Mansion Hill contains spheroidally weathered clasts of diabase. It is a dark black with a fine-grained crystalline texture and is unmetamorphosed, suggesting that it is a Mesozoic diabase dike typical to the Piedmont of North Carolina (e.g. Allen, 2005).

**Contact Relationship between RGM Metagabbro and Unseparated Albemarle Group Rocks**

To better understand the intrusion style of the RGM metagabbro, the contact between the metagabbro and the surrounding Albemarle Group strata was examined. The contact is only exposed in one place, in the walls of Linker Adit in the underground portion of the mine. In this exposure the metagabbro is in contact with bedded tuffaceous argillite (Fig. 12). Bedding in the argillite is at a high angle to the contact where it is visible, which gives the contact the appearance of a bedding-discordant intrusive contact. It is likely on this basis that El-Samani described the metagabbro as a dike. However, definitive interpretation of the nature of the contact is complicated by a few factors. First, weathering along the contact is significantly more intense than any other area of the adit. Rock in the vicinity of the contact is intensely saprolitized, where it is a light tan color and can be readily removed and crumbled by hand (Fig. 12b); extra wood supports were needed to shore up the immediately adjacent wall. Tuffaceous argillite near the contact is well bedded, although bedding is indistinct in the saprolite in this zone. As such, the contact between the metagabbro and tuffaceous argillite is difficult to determine. Though bedding in the tuffaceous argillite is at a
high angle to the contact, it deflects upwards as it approaches the contact (Fig. 12a), suggesting drag along the contact. Slippage along this contact might be expected during tectonism because of the apparent strong rheological discontinuity between the RGM metagabbro and the argillite. These factors, in addition to the extreme saprolitization (which is common in faulted rocks in the Carolina terrane) suggest that it is a tectonic contact rather than a primary intrusive contact. Because of these factors and the small exposed area of the contact, it is not possible to come to a firm conclusion on the initial nature of the contact between the metagabbro and surrounding stratified Albemarle group rocks on the basis of this exposure.

Figure 12: (a) A schematic view of the contact between tuffaceous argillite and the RGM metagabbro in the wall of Linker Adit, with the rock visible between wooden slats (in brown). The image is adapted from photos taken in the course of underground mapping. Bedding in the argillite deflects upward as it approaches the contact. Within the heavily weathered zone around the contact primary texture and sedimentary features are almost entirely obscured and both rock types are a light tan color; as such the two are difficult to distinguish. The metagabbro adjacent to the contact (b) is saprolitic and can easily be crumbled into silt- and clay-sized particles.
Geochemistry.

To better understand the relationship of the RGM metagabbro to the SMs, a geochemical study of the metagabbro was conducted. First, a whole rock analysis of major, trace and rare earth elements was performed on three samples from the RGM. Second, U-Pb dating of zircons from the RGM metagabbro was attempted. Dating was unsuccessful, but the details of the attempt are included here for completeness.

Whole Rock Major and Trace Element Analysis

The RGM metagabbro bears a striking petrographic similarity to members of the SMs. In order to better understand their interrelationship, I undertook whole rock chemical analyses on three samples of RGM metagabbro (Fig. 13). In this section I will briefly give the sampling and analytical methods, followed by a comparison of selected discrimination diagrams of the RGM and SMs metagabbros.

Sampling and Preparation

Because of the limited number of surface outcrops with minimally weathered metagabbro, only three samples collected from two sites at the RGM were selected for analysis (Fig. 13). The samples were removed from surface outcrops adjacent to shallow pits, two from Lake Hill and one from Middle Hill. All three appeared identical in hand sample, however in thin section the pyrites cubes were altered in the samples from Lake Hill and unaltered in the sample from Middle Hill. All visible quartz veins were removed from each sample by hammering, and the remaining portion was crushed and powdered in a disc mill at Texas A&M University.
Figure 13: Locales for geochemical sampling at the RGM. Samples for whole rock elemental analysis were collected at site a on Lake Hill and site b on Middle Hill. Zircons for dating were separated from samples collected at site a.

Analytical methods

All major and trace element analyses were conducted by ActLabs in Ancaster, Ontario; whole rock elemental composition was measured using lithium metaborate/tetraborate fusion ICP, and trace elements were measured using ICP-MS. Data for the three samples are given in Table 2, and provide a basis for comparison with the SMs in selected discrimination diagrams.
Because the geochemistry of the SMs is already well-characterized (Pollock and Hibbard, 2009), a direct comparison with the RGM metagabbro should easily determine whether the RGM metagabbro is geochemically related to the SMs. An alkali-silica plot is included to assess alteration of the RGM metagabbro relative to the SMs (Fig. 14). However, to avoid other anomalies caused by localized weathering and alteration immobile element plots (Figs. 16 and 17) are used for primary characterization of the RGM metagabbro.

\[ \text{Table 2: Geochemical Data from the RGM Greenstone and a typical SMs member} \]

\[
\begin{array}{cccccccccccc}
\text{Sample} & \text{SiO}_2 & \text{Al}_2\text{O}_3 & \text{Fe}_2\text{O}_3 & \text{MnO} & \text{MgO} & \text{CaO} & \text{Na}_2\text{O} & \text{K}_2\text{O} & \text{TiO}_2 & \text{P}_2\text{O}_5 & \text{Cr} & \text{Ni} & \text{Sc} & \text{V} \\
\text{Lake} & & & & & & & & & & & & & \\
\text{Hill 1} & 47.86 & 19.74 & 13.51 & 0.118 & 7.79 & 0.3 & 1.45 & 2.29 & 0.928 & 0.21 & 230 & 120 & 45 & 453 \\
\text{Hill 2} & 47.31 & 19.93 & 13.85 & 0.112 & 7.88 & 0.37 & 1.27 & 2.4 & 0.989 & 0.25 & 240 & 120 & 45 & 475 \\
\text{Middle} & & & & & & & & & & & & & \\
\text{Hill 2} & 52.86 & 13.57 & 10.33 & 0.215 & 2.06 & 5.59 & 3.61 & 1.32 & 1.294 & 0.59 & <0.20 & <0.20 & 26 & 190 \\
\text{SMs} & 36.74 & 9.63 & 12.91 & 0.18 & 23.65 & 8 & 0.15 & 0.45 & 0.31 & 0.05 & 1566.7 & 433.54 & 22.21 & 164.74 \\
\text{Sample} & \text{Cu} & \text{Ga} & \text{As} & \text{Rb} & \text{Sr} & \text{Y} & \text{Zr} & \text{Nb} & \text{Ba} & \text{Ce} & \text{Th} & \text{U} & \text{La} & \text{Pr} \\
\text{Lake} & & & & & & & & & & & & & \\
\text{Hill 1} & 40 & 26 & 51 & 93 & 22 & 14.3 & 45 & 1.9 & 440 & 22.9 & 3.12 & 0.6 & 9.33 & 3.09 \\
\text{Hill 2} & 60 & 26 & 49 & 96 & 22 & 16.2 & 41 & 2 & 454 & 23.7 & 3.04 & 0.62 & 10.9 & 3.36 \\
\text{Middle} & & & & & & & & & & & & & \\
\text{Hill 2} & 310 & 20 & 20 & 40 & 188 & 38.1 & 108 & 4.6 & 381 & 63.5 & 11.4 & 2.48 & 28.2 & 8.27 \\
\text{SMs} & 15.94 & 8.43 & 1.83 & 27.14 & 79.49 & 7.33 & 15.97 & 0.86 & 74.64 & 12.42 & 2.79 & 3.2 & 1.63 & 0.59 \\
\text{Sample} & \text{Nd} & \text{Sm} & \text{Eu} & \text{Gd} & \text{Tb} & \text{Dy} & \text{Ho} & \text{Er} & \text{Tm} & \text{Yb} & \text{Lu} & \text{Hf} & \text{Ta} & \text{Ti} \\
\text{Lake} & & & & & & & & & & & & & \\
\text{Hill 1} & 13.5 & 2.96 & 0.652 & 2.87 & 0.45 & 2.65 & 0.54 & 1.58 & 0.235 & 1.42 & 0.201 & 1.3 & 0.13 & 0.4 \\
\text{Hill 2} & 14.5 & 3.13 & 0.744 & 3.37 & 0.5 & 2.88 & 0.56 & 1.67 & 0.241 & 1.44 & 0.211 & 1.2 & 0.12 & 0.48 \\
\text{Middle} & & & & & & & & & & & & & \\
\text{Hill 2} & 35.1 & 8.03 & 2.26 & 7.21 & 1.16 & 6.91 & 1.37 & 3.93 & 0.573 & 4.01 & 0.615 & 3.2 & 0.36 & 0.3 \\
\text{SMs} & 3.05 & 1.01 & 0.37 & 1.38 & 0.23 & 1.57 & 0.33 & 0.98 & 0.14 & 0.91 & 0.14 & 0.6 & 0.03 & 0.35 \\
\text{Analyses} & & & & & & & & & & & & & \\
\end{array}
\]

\(^{9}\text{Sample 205 from Pollock and Hibbard (2009).}\)
There is an approximately linear relationship between the alkalinity of SMs metagabbros and their silica content (Fig. 14). RGM metagabbro plots within the field of SMs metagabbros on the high-SiO$_2$ end of the spectrum, potentially suggesting that they are less hydrothermally altered than most other sampled SMs metagabbros (Pollock and Hibbard, 2009). Although minimally altered samples of RGM metagabbro were selected for analysis, the silicification noted in several RGM outcrops may offer an alternative explanation for the high silica values. On a K$_2$O+Na$_2$O vs K$_2$O/(K$_2$O+Na$_2$O) diagram of Hughes (1973), the two samples from Lake Hill (Fig. 13a) plot away from the SMs samples and outside of the igneous spectrum (Fig. 15), but the single sample from Middle Hill (Fig.13b) is well within
the igneous spectrum. This suggests that there has been significant mobilization of K and Na by local alteration at the Lake Hill outcrop which did not affect the outcrop on Middle Hill.

Figure 15: RGM metagabbro samples from Lake Hill (Fig. 13a) plot outside the igneous spectrum (Hughes, 1973), indicating mobilization of K and Na after the initial intrusion. The sample from Middle Hill (Fig.13b) is within the igneous spectrum with values similar to members of the SMs, indicating that mobilization was related to local alteration rather than regional metamorphism. Adapted from Pollock and Hibbard (2009) Fig. 6.

Although the RGM metagabbro and SMs metagabbros are heterogeneously altered, immobile elements can shed light on the original character of the rocks. The four elements plotted in Figure 15, Zr, Ti, Nb and Y, are all relatively immobile under normal metamorphic conditions (Pollock and Hibbard, 2009); Zr/TiO$_2$ can be used as a proxy for igneous affinity.
and Nb/Y is a proxy for alkalinity. The SMs metagabbros show basaltic affinities (Zr/TiO$_2$<0.1) and low alkalinities (Nb/Y < 0.8). RGM metagabbro samples plot directly in the center of the SMs cluster (Figure 16).

![Figure 16: Immobile element proxies for basaltic affinity (Zr/TiO$_2$) and alkalinity (Nb/Y) plotted against one another. SMs metagabbros cluster strongly in the basalt field (Pollock and Hibbard, 2009, Fig. 7). RGM metagabbro plots at the center of this cluster as well.](image)

In order to best compare the chemical fingerprints of the SMs and RGM metagabbro, selected immobile elements were plotted (Fig. 17). The trends seen in the SMs and the RGM metagabbro are essentially identical, suggesting that the RGM and SMs are derived from the same magmatic setting.
In summary, immobile elements within the RGM metagabbro are geochemically indistinguishable from SMs. In conjunction with the similarities in mode of occurrence and lithic attributes, these data provide strong evidence that the RGM metagabbro is a member of the SMs.

**U-Pb Dating of RGM Metagabbro Zircon**

In order to establish the age of intrusion and elucidate the timing of mineralization, U-Pb dating was attempted on zircon grains collected from the RGM metagabbro. Previous U-Pb dating of a single SMs sample yielded an age of approximately 545 Ma (DeDecker et al.); however, as previously noted the SMs intrudes every unit of the Albemarle Group, suggesting intrusive ages as young or younger than 528 Ma.
The procedure followed was similar to that given in DeDecker et. al (2013) and the description is adapted from that work. Approximately 10 kg of RGM metagabbro, collected from a surface exposure in a pit at the top of Lake Hill (Fig. 13a), was crushed in a jaw crusher and powdered in a disc mill. Heavy minerals were extracted using a Rodgers gravity separation table. Abundant magnetic grains were separated first by use of a hand magnet and then by a Frantz magnetic separator. Initial attempts with the electromagnet set to high voltage yielded no zircons as they were swept up with the abundant magnetic inclusions, and the separation had to be repeated at a lower setting. Finally, separation with heavy liquids was used to remove light mineral grains. Zircons were hand-picked using a binocular microscope and then annealed at 950 °C for 48 hours. Approximately 20 grains of zircon were collected from the concentrate. All were small crystal fragments up to 30 µm in length, and clear and colorless (Fig. 18).

![Figure 18: Two typical colorless zircon grains (outlined in red) from the RGM metagabbro.](image)
Because of both the low number and small size of the grains, chemical abrasion in HF-HNO₃ solution was restricted to 4 hours. Most grains showed little visible change, although one grain appeared to turn black from internal etching. Because of their small size, and despite great care being taken, standard zircon transfer procedures resulted in larger-than-usual losses. By the final step only three zircons remained. These grains were each spiked with a mixed ⁰⁵⁰Pb-²³³U-²³⁶U tracer and dissolved in HF in an individual microcapsule at 220 °C for 48 hours, and then converted to chloride salts by dissolution in 6N HCl in a microcapsule at 180 °C for 16 hours. The chloride salts were dried down and dissolved in H₃PO₄ for column chromatography separation of Pb and U. Lead and U were loaded onto Re filaments for analysis of isotope ratios using a VG Sector 54 thermal ion mass spectrometer.

The resultant measurements showed no detectable uranium from the zircons, and as such no date could be assigned to the zircons. Although disappointing, this result is not entirely unexpected. The clear and colorless nature of the crystals from the RGM gabbro indicates they experienced little to no damage from radioactive decay, and zircons from the Stony Mountain gabbro suite in particular are known to be generally low in U (DeDecker et al., 2013).
Geophysical Observations.

Magnetometry

In order to better understand the subsurface geometry of the RGM metagabbro magnetometric measurements were collected at the RGM site. The metagabbro is an iron-rich metagabbro, and numerous magnetic grains were separated during zircon extraction. In contrast, the surrounding volcaniclastic rocks are largely felsic and should be significantly less magnetic. In the case of a vertical or subvertical dike, a strong magnetic signal would be expected above the surface exposure of the metagabbro with a sharp decrease on either side above the various RGM argillites. In contrast, a folded sill would be expected to have a more distributed signal, with the strongest response at the center of the metagabbro exposure gradually decreasing on either side as the metagabbro, down the dip of the limbs.

Measurements were collected with a Scintrex SM5 backpack-mounted magnetometer. Two full traverses were walked approximately northwest to southeast, perpendicular to the axial trend of the RGM fold. An additional traverse was walked near the entrance to Linker Adit with a short along-strike component. The measurements were despiked and projected onto a map of the mine area (Fig 19).

The magnetic signature of the RGM property is dominated by numerous small-scale anomalies rather than either the strong, visible magnetic anomaly expected from a dike or the gradual rise and decline expected from a sill. There is, however, a slight trend towards higher magnetic values in the eastern portion of the property. Although neither a dike nor sill
geometry is definitively supported by these results, the vertical dike model is cast in doubt by the absence of a distinct ‘peak’ signal.

Figure 19: Geomagnetometric data collected at the RGM, plotted over a 2015 orthophoto of the area (NC Onemap, 2015) with the outcrop pattern of the metagabbro superimposed over it. After processing and despiking, numerous small anomalies are visible with a broad trend towards higher values in the eastern area of the property. If the RGM metagabbro had intruded as a vertical dike a relatively strong magnetic signal would be expected with a sharp magnetic drop off on either end.
Structural Analysis.

Introduction

Because gold at the RGM is found in quartz veins, which require geologic structures to provide space for ponding and precipitation of mineralizing fluids, understanding the structural geology of the mine is vital for understanding the nature and formation of the deposit. Three targets were selected for structural analysis. First, the form of the RGM metagabbro and the character of the surrounding RGM fold is clarified. Second, the intrusion style of the metagabbro is addressed by use of local and regional structural context. Finally, the geometry of RGM quartz veins is described and a mechanism for the localization of mineralization is modeled from this geometry in conjunction with the overarching structure of the RGM metagabbro.

Form of the RGM Metagabbro Body

The RGM metagabbro occupies the core of the RGM fold. Its outcrop pattern is an ellipsoid elongated along the strike of the RGM fold, and magnetometric measurements did not show a strong magnetic anomaly above the exposed area. These features are inconsistent with previous descriptions of the RGM metagabbro as a vertical dike; instead, they are suggestive of a domal structure.

The apparent domal form of the RGM metagabbro and its location at the core of the RGM fold is suggestive that the RGM fold might be doubly plunging. A northeast plunge to the fold was reported by El-Samani (1978), and it is readily observed in this study from bedding and cleavage orientations measured in stratified rocks in the northeastern area of the
mine property. The northeast plunge can be inferred both from locally northeast-dipping beds (Fig. 5) and from the northeast-plunging line of intersection between bedding and cleavage measurements in the same area (Fig. 20).

![Diagram showing bedding and cleavage orientations](image)

**Figure 20:** The line of intersection of bedding and cleavage orientations from stratified rocks in the northeastern area of the RGM property intersect dips to the northeast, indicating a northeast plunge to the fold in that area.

The outcrop pattern of the metagabbro also closes to the southwest, suggesting that contrary to El-Samani’s (1978) interpretation of the RGM fold as plunging only to the northeast, the fold also plunges to the southwest. The southwest area of the property has
gentle topography and is generally unfavorable for the formation of bedrock exposures, and as such only one bedding/cleavage pair could be measured in the present study, and only three were recorded by El-Samani (1978). However, the line of intersection between all four pairs plunges to the southwest, indicating that the fold plunges to the southwest in this area (Fig. 21).

In addition to the bedding-cleavage relationships, a minor fold, parasitic to the RGM fold, was observed in an outcrop in the southwestern portion of the property (Fig. 22) that also plunges to the southwest (Fig. 21). Thus, existing evidence in this portion of the property supports a southwest plunge to the RGM fold in the stratified rocks of this area. In conjunction with structural data from the northeast portion of the site, the RGM fold appears to be a shallowly doubly plunging fold in the unseparated Albemarle Group strata.
Figure 21: Four pairs of bedding orientations (in black) and cleavage orientations (in blue) from the southwestern portion of the RGM from the present study and El-Samani (1978). The line of intersection between each bedding and cleavage pair (marked with white circles) plunges shallowly to the southwest, indicating that the fold plunges to the southwest in this area. The axis of a single parasitic fold measured in the same area, marked with an X, plots close to the intersection.
Regional context offers additional support for the doubly plunging or periclinal natural of the RGM fold. Large-scale regional folds that flank the GHsz, such as the New London syncline, are also doubly plunging (Stromquist et al. 1971; Stromquist and Sundelius, 1975; Sundelius and Stromquist, 1978; Goldsmith et al., 1988). Lithostratigraphic units in their cores produce northeast-trending ovoid outcrop patterns strikingly similar to the RGM metagabbro (Fig. 2). Smaller folds also attributed to Cherokee deformation in the adjacent Charlotte terrane to the west are also typically doubly plunging (Allen, 2005).

As such, both the RGM metagabbro outcrop pattern and structural data from the surrounding Albemarle Group strata are most consistent with each having a domal structure. The spatial coincidence of these two lines of evidence strongly suggests that there is a
concordant relationship between the metagabbro and Albemarle Group rocks at the site. Thus, the RGM metagabbro is herein interpreted to have the form of a folded sill.

**Structural Geometry of Quartz Veins**

In order to better understand the nature of the RGM sink and to see if the veining is related to any other local or regional structures, I examined the orientation of the Au-bearing quartz veins. It is herein estimated on the basis of field observations that the metagabbro hosts at least 90 vol% of the vein quartz at the RGM. Economic workings were restricted to the metagabbro near the crest of the RGM fold, particularly on Middle and Upper Hill. The relatively competent volcaniclastic units also locally host quartz veins to a much lesser degree, particularly near the crest of the fold. At least four test shafts were sunk into volcaniclastic material northeast of the metagabbro, but quantities of gold were apparently uneconomic as the shafts were terminated at shallow levels.

Because of the accessibility of the subsurface portions of the mine, orientations of quartz veins are measured directly in the tunnel walls. The opening to the subsurface workings is at Linker Adit (Fig. 5) and the exit is on Upper Hill; as such, all of the mapped quartz veins are in the northwestern limb of the fold, near the crest. All quartz veins have an approximately planar geometry. The poles to quartz veins plot along a great circle, with a pole that plunges to the southeast (Fig. 23). This great circle is subparallel to bedding measurements taken in immediately adjacent sedimentary rocks. This geometry indicates that the quartz veins are oriented suborthogonal to the RGM fold surface in this area, and thus subperpendicular to the metagabbro sill.
This plot also reveals that the quartz veins define a folded surface; however, because the detailed location of the quartz veins was not recorded, the nature of this folded surface is uncertain. Such a folded surface could have resulted from perturbations during the formation of the pericline.

The veins being orthogonal to the fold surface suggests a relationship between the veins and the folded layer. Specifically, the vein distribution is consistent with fracture
formation during neutral surface folding. This mechanism of folding is typical for a rheologically strong layer folded with less competent surrounding layers; in this case, the more competent metagabbro is interlayered with weaker Albemarle Group strata. Neutral surface folding requires extension on the outer portion (extrados) of the folded competent layer and shortening on the inner portion (intrados) of the folded layer; the extrados also shows an increase in volume (Lisle et al., 2009). In many cases, the extension is accommodated by brittle fracturing on the outside of the fold, and in the field these fractures are commonly filled by quartz veins (Lisle et al., 2009) (Fig. 24a).

Considering the high concentration of quartz veins in the RGM metagabbro, its apparent concordancy with the stratified Albemarle Group rocks, and the orientation of the quartz veins in the metagabbro, the RGM metagabbro is most consistent with a folded sill model as depicted in Fig. 23b.
Figure 24: Visualization of the folded sill model for the RGM sink. In (a) zones of extension and shortening, and the neutral surface that experiences neither, are marked. Extension is accommodated by fractures that host auriferous quartz veins. In (b) a three-dimensional rendering shows the two fold axes in black that define the strike of the doubly plunging fold. White quartz veins are orthogonal to the tighter northeast-trending fold. In (a) and (b) parallel grey lines denote axial planar cleavage.

This model has important implications for the timing of mineralization at the RGM. The extensional cracks that allowed vein formation in the metagabbro are geometrically linked to the RGM fold; it is also impossible that extensional cracks would remain open at depth (e.g. Yardley, 1986), so precipitation of minerals must have occurred as the cracks formed. The RGM fold, along with other folds within the GHsz, is attributed to the Late Orodvician-Silurian Cherokee Orogeny (Hibbard et al., 2013). As such, mineralization must be syorogenic with the Cherokee Orogeny, c. 460-430 Ma (Hibbard et al., 2013).
Comparison of the RGM with Similar Deposits

Though the RGM and similar deposits within the GHsz have not been the subject of focused geological study, extensive research has been conducted on broadly similar gold deposits worldwide. Whereas direct investigation of the source of mineralizing fluids at the RGM is outside the scope of this project, findings in similar deposits provide a basis for informed speculation. Similarly, styles of localization have been recorded at mines within the GHsz and worldwide and can provide insight into the RGM gold deposit. This section will offer a brief review of some key research and speculate on similarities between fluid sourcing and gold localization at the RGM and other gold deposits.

Gold deposits associated with convergent boundaries can be broadly divided into three categories: volcanogenic massive sulfide (VMS) deposits, epithermal deposits and orogenic gold deposits (e.g. Foley and Ayuso, 2012). All three types occur in the GHsz and surrounding Carolina terrane, but the RGM is readily classified as an orogenic deposit on the basis of its structurally-controlled auriferous veins (LaPoint and Moye, 2013). Orogenic style deposits form from Au-rich fluids released during regional shortening events (e.g. LaPoint and Moye, 2013). These fluids are widely considered to be released by metamorphic dewatering (e.g. Fitches et. al., 1985; Cox et al., 1991; Windh, 1995), a conclusion supported by analysis of stable isotopes (e.g. Jia et al., 2001). As such, formation of these deposits is synorogenic. Most authors suggest that the gold is extracted from the entire depositional pile by metamorphic fluids (Fitches et. al., 1985; Cox et al., 1991; Windh, 1995; Sibson and Scott, 1998), although others suggest magmatic fluids or particularly gold-rich organic
sediments as contributors in some cases (Ho et al., 1992; Large et al., 2010). Remobilization of epithermal gold at the Haile mine has resulted in quartz veins hosting visible gold, in contrast to the normally microscopic nature of gold particles at the mine (K. Gillon, pers. Com., 2016). This observation may suggest scavenging of an underlying epithermal gold deposit as another potential source of gold for mineralizing fluids in the GHsz.

Although orogenic deposits within a particular gold field are fed by the same fluids and form during the same orogeny, the structure of vein formation varies significantly from deposit to deposit (e.g. Cox et al. 1991; Bottrell et al., 1988; Sibson and Scott, 1998). By comparing recorded structures at other deposits to those seen at the RGM, the latter can be given better context and be better understood.

Numerous other orogenic gold deposits occur nearby in the GHsz (Foley and Ayuso, 2012, LaPoint and Moye, 2013). However, most of these mines ceased production during the 1800s (Carpenter, 1976), and had low total productions of gold (Foley and Ayuso, 2012). Records from mining are almost entirely lost (Green, 1937), and little modern attention has been paid to these deposits; instead, workings and research have largely focused on Carolina VMS and epithermal deposits (Foley and Ayuso, 2012, LaPoint and Moye, 2013). It has, however, been noted that large-scale rheological discontinuities appear to have affected the movement of mineralizing fluids within the GHsz (Moye et al., 2016). On the basis of the regional trend and of previous observations at the RGM, it has also been speculated that rheological discontinuities are important for the formation of gold deposits (Moye et al., 2016). However, in the scarce available information no other gold mine in the GHsz is
recorded as having auriferous veins primarily hosted in a metagabbro or folded sill of any kind (Carpenter, 1976; El-Samani, 1978). The vast majority feature quartz veins hosted in metavolcanic or metasedimentary rocks (Carpenter, 1976). Two deposits, the Pioneer Mills Mine and the Snyder Mine in Cabarrus County, NC, are recorded as having auriferous quartz veins hosted in a diorite, although no additional information about their geometry is known (Carpenter, 1976).

Although details of GHsz mines are not well known, other analogous orogenic deposits have been the subject of more intense study. Orogenic deposits with similar settings and Paleozoic ages (e.g. Hutchinson, 1987) exist around the world, including in Australia (Cox et al., 1991; Windh, 1995), Wales (Bottrell et al., 1988), New Zealand (Sibson and Scott, 1998) and Nova Scotia (Mawer, 1987). Like the RGM, all are hosted in areas underlain by thick, metavolcaniclastic piles that have undergone orogenic shortening. Comparison with these deposits will offer potential answers to the source and movement of mineralizing fluids and the details of vein formation at the RGM.

As with deposits in the GHsz, these deposits typically feature auriferous quartz veins hosted in metavolcaniclastic rocks. Veins are typically emplaced between sedimentary beds and in places concentrated at the tops of anticlines, with only minor ‘leader vein’ offshoots that crosscut bedding (Windh, 1995); most lack major rheological discontinuities, although where discontinuities exist they can be important for the formation of bedding-parallel veins (Windh, 1995, Bottrell et al., 1988). Voids for vein formation appear to be the result of flexural flow (Bottrel et al., 1988) and flexural slip (Cox et. al, 1991). As in the GHsz, no
recorded deposit in these fields features gold veins hosted in a metagabbro or localized by extensional cracks formed during neutral surface folding. As such, the RGM appears to feature a unique style of gold localization.
Conclusions

This study yielded multiple new findings. In this section, the findings of the study are summarized and then synthesized into a comprehensive, chronological model for the formation of the RGM gold deposit. Finally, outstanding problems and potential future directions of study are suggested.

New Findings

- On the basis of similarities in petrography, geochemistry, and mode of occurrence, the RGM metagabbro has been shown to be a member of the Stony Mountain suite.
- New mapping established that the outcrop pattern of the RGM metagabbro is an elongated ellipsoid.
- Structural analysis has shown that the RGM fold is doubly plunging.
- Based on mapping, structural and magnetometric data, the form of the RGM metagabbro is most compatible with a folded sill morphology.
- Auriferous quartz veins within the RGM metagabbro are structurally related to the RGM fold - they have orientations orthogonal to the folded sill.
- The geometric relationship between auriferous veins and the folded RGM metagabbro indicate that the Au mineralization is syntectonic with respect to the Cherokee Orogeny.
- An unusual style of gold localization, with auriferous quartz veins forming in extensional cracks on the outside of a folded metagabbro sill has been
described at the RGM. This form of a mineralized fluid sink appears to be previously undescribed.

**Chronological Model for the Formation of the RGM**

As part of the Albemarle Group, the volcaniclastic rocks of the RGM likely range in age from c. 555-528 Ma (Hibbard et al., 2012). Relatively soon after these rocks were deposited, the RGM metagabbro was intruded mainly in the early Cambrian as a bedding concordant sill. Although it could not be directly dated, the RGM metagabbro is a member of the Stony Mountain suite. The intrusion of the Stony Mountain suite was a time-transgressive event, ranging from at least 545 Ma to 528 Ma (DeDecker et al., 2013).

From the Late Ordovician to the Early Silurian, c. 460-430 Ma, Carolinia docked with Laurentia during the Cherokee Orogeny, forming the GHsz (Hibbard et al., 2010; Hibbard et al., 2013). Based on the structural relationship between auriferous veins and the RGM fold, the localization of gold at the RGM appears to have been synorogenic. Shortening during the orogeny formed the RGM fold and at the same time released Au-rich mineralizing fluids, which were the source of gold for all orogenic style gold deposits in the GHsz. The fluids are likely the result of metamorphic dewatering and pressure solution in the Albemarle arc pile. The competent RGM metagabbro sill was folded amongst surrounding Albemarle Group sedimentary rocks, likely by the mechanism of neutral surface folding; folding generated extensional cracks on the extrados of the sill which provided space for mineralizing fluids to exsolve auriferous quartz veins.
Outstanding Problems and Future Work

- The structure of the RGM demonstrates that concentrations of gold may be expected at the core of anticlines that fold intrusive sills of the Stony Mountain suite gabbros. In the past, gold deposits in the southeastern US have been recognized by the appearance of placer gold on the surface. Even the Haile Gold Mine in South Carolina, where subsurface gold is disseminated through the rock at low levels and only rarely attains visible concentrations, was recognized on the basis of gold nuggets found at the surface (Hayward, 1992). Future prospecting could seek out structures similar to the RGM sink, either in the GHsz or worldwide.

- A systematic study of vein localization styles in the various GHsz orogenic deposits would better contextualize the RGM, and may reveal further previously undescribed styles of vein localization. In particular, the Pioneer Mills and Snyder mines in Cabarrus County feature veins hosted in diorite, and may have RGM-like vein localization.

- Further study could be directed to explore the origins and interconnections of orogenic gold deposits in the GHsz. One approach could be a study of stable isotope ratios at the RGM and other orogenic deposits—such a study would help distinguish between different sources of mineralizing fluids and help make connections between deposits.
• The unusually large size of gold nuggets found at the RGM is worthy of future study. The largest nugget produced at the RGM was more than ten times the weight of the largest at any other mine in NC (Hurley, 1900). Gold nugget formation has been the subject of recent research, and in some locations their formation has been shown to be biologically mediated (e.g. Reith and Rogers, 2006). It is possible that the RGM site was particularly suited for gold mobilization and precipitation by bacteria. Alternatively, the unusual style of vein localization may have preferentially produced large nuggets.
REFERENCES


APPENDICES
Appendix A – *Measurements of Quartz Vein Orientations and Thicknesses in RGM*

**Subsurface Workings**

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Appendix B – *Measurements of Fault Orientation and Displacement in RGM Subsurface Workings*

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