GEOLOGICAL SETTING OF THE REED GOLD MINE, NORTH CAROLINA

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FOREWORD

This special publication is a condensation of the MS studies and thesis of Stephen Challener (Challener, 2016) that were undertaken at North Carolina State University under the supervision of Dr. James Hibbard, and committee members Dr. Del Bohnenstiehl (NCSU), and Dr. Drew Coleman (UNC-CH). The field and lab studies were undertaken mainly during the summers of 2014 and 2015.

ABSTRACT

The Reed Gold Mine is an historically important mine in the Carolina terrane of central North Carolina. It is located in the Gold Hill shear zone, 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 gabbro body that hosts auriferous quartz veins of the deposit and its structural setting. New whole rock geochemical analyses of the gabbro indicate that it is part of the regional Stony Mountain intrusive suite, which represents c. 545-528 Ma arc rift magmatism. The gabbro body is located in the core of a northeast-trending anticline in Neoproterozoic - Early Cambrian strata of the Albemarle arc. As with other regional folds in the Carolina terrane, the anticline is attributed to the Late Ordovician - Early Silurian Cherokee orogeny. New geological mapping reveals that the host gabbro has an elliptical outcrop pattern with its long axis coincident with the hinge of the anticline. In addition, structural analysis of the surrounding strata indicates that the anticline is doubly plunging. These field observations in conjunction with magnetometric measurements are most consistent with gabbro body being a folded sill as opposed to a subvertical dike as previously reported. Gold-bearing quartz veins in the metagabbro are orthogonal to the surface of the folded sill, indicating that they likely fill extensional cracks on the extrados of the sill. These fractures were likely a product of a neutral surface fold mechanism in the sill. On the basis of this structural relationship, mineralization at the mine site is interpreted to be synchronous with the Cherokee orogeny. This new model for the geology of the Reed Gold Mine site appears to represent a previously undocumented setting for gold localization in both the Gold Hill shear zone of the Carolinas and worldwide.

INTRODUCTION

The Reed Gold Mine (RGM) is an historically important mine in the Carolina terrane of central North Carolina (Figure 1). The RGM is located in the Gold Hill shear zone (GHsz), a regional structure that hosts numerous historic gold mines and prospects (Figure 2). In spite of its historical importance and location within the productive GHsz, the geology of the RGM is poorly understood. The gold occurs as both placer deposits at the surface and in quartz veins that are concentrated in a gabbro body within Neoproterozoic–Early Cambrian volcaniclastic strata. With the 21st century revival of interest in Carolina gold, understanding

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the geology of the RGM deposit is an important step for directing future exploration within the region.
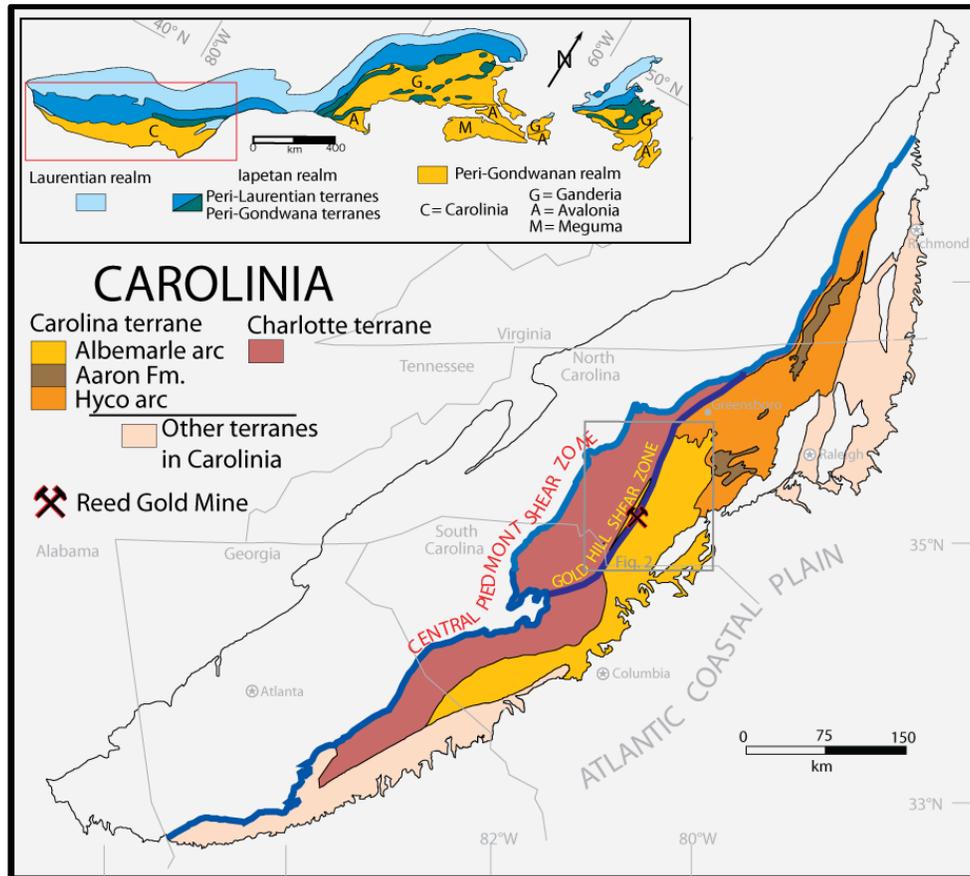
Figure 1: The Reed Gold Mine is centrally located in Carolinia, in the Gold Hill shear zone, near the western edge of the Carolina terrane (adapted from Hibbard et al., 2006, 2012).

The most recent geological studies of the mine site (El-Samani, 1978; Osman, 1978) collectively formulated a model of the structure and geologic history of the RGM; however, that model is based on partially inaccurate map data. Additionally, since the formulation of that model, a wealth of new information about the regional context of the RGM has come to light (e.g. Pollock and Hibbard, 2010; Hibbard et. al, 2010; Hibbard et. al, 2012; Hibbard and Pollock, 2013) and a considerable volume of new research has been undertaken on vein-hosted gold deposits in general. As such, the existing model for the RGM deposit is outdated. The motivation and goal of this study are to create a modern model for the geologic setting of the gold deposit that may help inform future gold prospecting within the Gold Hill shear zone, the Carolina terrane, and similar settings, globally. Following an introduction to the historical and regional geological contexts of the mine, and a review of relevant previous work, we

present our new observations, from which we formulate a new model for gold mineralization at the RGM.
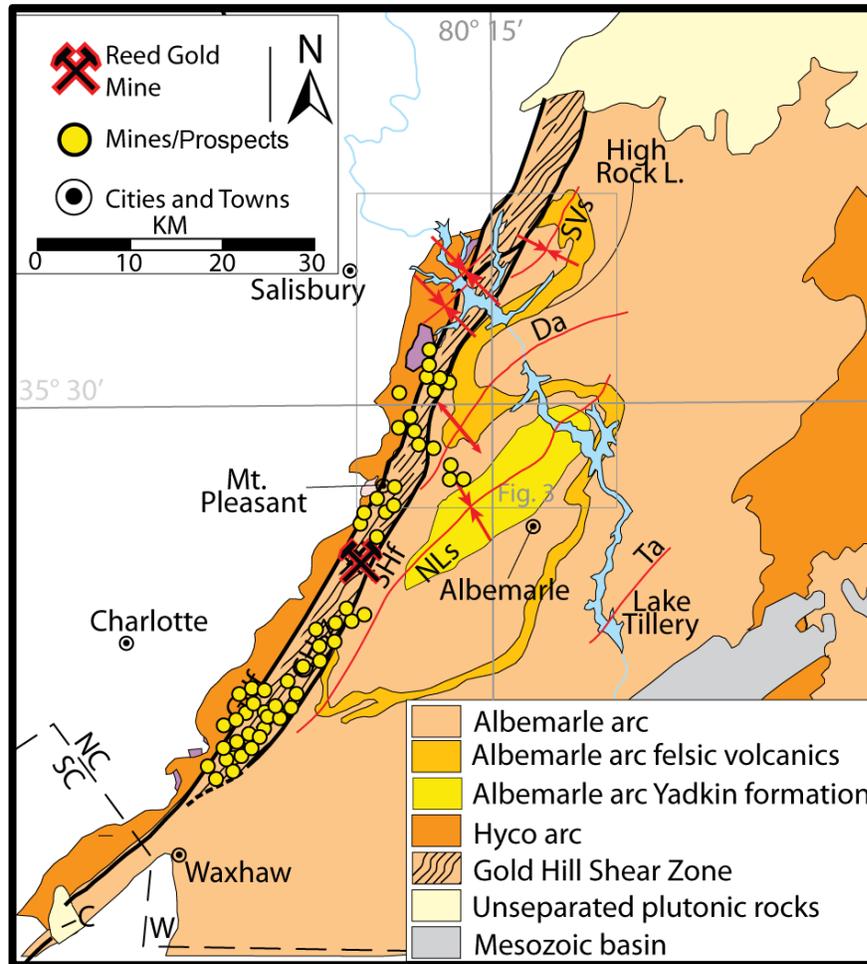
Figure 2: The RGM is located in the GHsz, along the boundary between the Albemarle and Hyco arcs. The GHsz is the site of numerous historical gold mines and prospects; approximate locations of selected regional mines and prospects from Nitze and Hanna (1896). Most of the regional folds associated with the GHsz, 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 Pollock and Hibbard, 2010; Hibbard et al., 2012).

Historical Context

The RGM is located on the former farmlands of John Reed (née Johannes Reidt, 1757-1845), 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 lb. nugget in Little Meadow Creek (Figure 3), 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

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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 in a gabbro body, targeting the gold-rich quartz veins in bedrock uncovered by farming activity (Partz, 1854). Diggings were largely limited to three hills adjacent to Little Meadow Creek — Upper, Middle and Lower Hill — with minor activity on the adjacent Lake Hill (Figure 3).
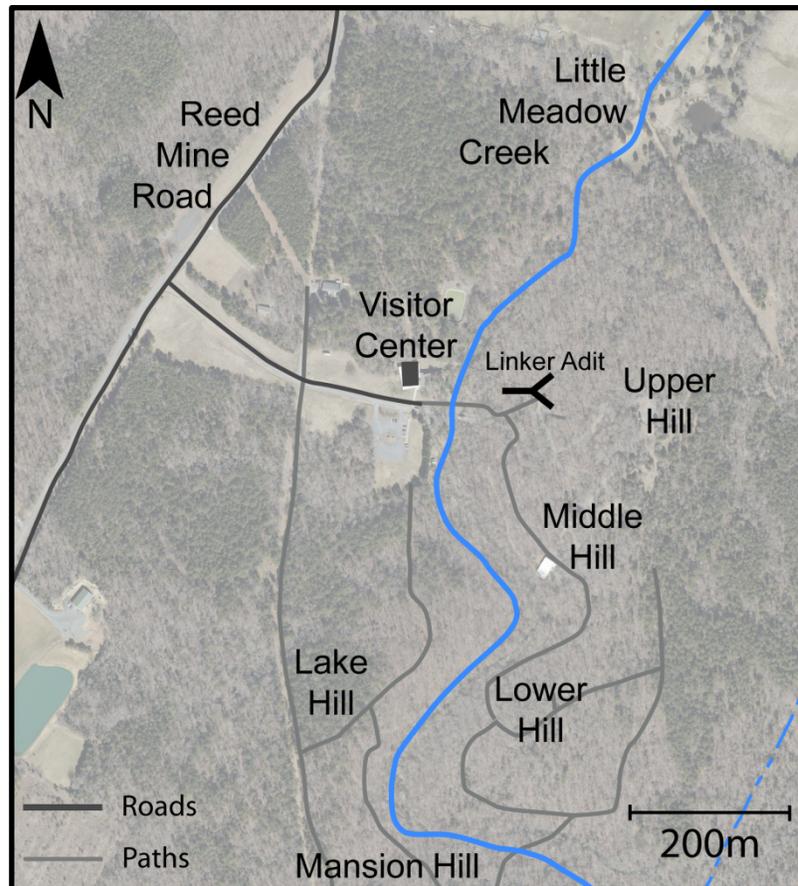
Figure 3: The RGM mine site, with major roads, paths and landmarks overlaid on a 2015 orthophoto of the area (NC OneMap, 2015).

Mining continued on an irregular basis until World War I, and amateur panning and prospecting continued in the following decades (Knapp, 1973). 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).

In 1971 the mine property was donated to the state and made a North Carolina State Historic site (Knapp, 1973). The mine is located at 9621 Reed Mine Rd., Midland, NC (35°17'7.08" N, 80°28'0.04" W). 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 the Linker adit (Figure 3) and two cross-shafts, was shored up and wired for electricity to make them accessible to the public.

<center>**Regional Geological Context**</center>

The RGM lies within Carolinia, a collection of southern Appalachian terranes (Hibbard et al., 2002; Hibbard et al., 2012) (Figure 1) that share a broadly similar lithologic assemblage of metamorphosed magmatic and associated epiclastic rocks and a peri-Gondwanan paleogeographic heritage (Hibbard et. al, 2002). The RGM is located in the center of Carolinia, near the western edge of the low-grade Carolina terrane (Figure 1), within the GHsz (Figure 2) of North Carolina. The GHsz was thought to locally mark the boundary between the Carolina and Charlotte terranes of Carolinia (e.g. Allen, 2005) (Figure 2), 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 marks the tectonic boundary between two major 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. 528-550) to the east (Hibbard et al., 2012). The GHsz is a sinistral oblique contractional duplex beneath the Gold Hill fault that formed during the Late Ordovician – Early Silurian 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 (Figure 2) (Stromquist et al. 1971; Stromquist and Sundelius, 1975; Sundelius and Stromquist, 1978; Goldsmith et al., 1988).

Rocks within the GHsz, including those at 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 ca. 555Ma to younger than 528 Ma in age (Hibbard et al., 2012). Although rocks within the Albemarle arc record greenschist facies metamorphism (Stromquist and Sundelius, 1969), primary features are generally well preserved and as such the prefix "meta-" is omitted from rock type names in the present study. The Albemarle arc includes the Uwharrie Formation at its base and the

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overlying Albemarle Group. The Albemarle Group comprises, in order from oldest to youngest, the Tillery, Cid, Floyd Church and Yadkin formations (Milton, 1984). The formations are defined mainly on the basis of stratigraphic position and the dominant facies of volcaniclastic rocks, although the dominant facies of individual units occur throughout the group. The Tillery Formation, is characterized by mainly thinly laminated siltstone and claystone (Stromquist and Sundelius, 1969). The overlying Cid Formation is composed of two distinct members separated by thinly bedded shale. The lower member is composed largely of blocky, locally tuffaceous, mudstone, and the top is defined by the distinctive Flat Swamp member, composed of mainly felsic volcanic and volcaniclastic rocks (Stromquist and Sundelius, 1969). The Floyd Church Formation is composed predominantly of medium-bedded 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). We agree with many previous workers that RGM strata are part of the Albemarle Group; however, it is unclear which formation they represent. El-Samani (1978) assigned them to the Cid Formation, whereas Sundelius and Stromquist (1978) considered them part of the Tillery Formation. Assignment of Albemarle Group strata in the GHsz to specific formations is contentious and difficult because of structural disruption and the lack of stratigraphic context in the zone (Hibbard et al., 2012); as such, the mine site strata are left as 'unseparated Albemarle Group' in the present study.

The entire Albemarle Group is intruded by the Stony Mountain intrusive suite (SMis) (Ingram, 1999), a collection of gabbro stocks, sills and dikes. Sills are the most typical intrusion style (Pollock and Hibbard, 2010), but dikes and laccoliths have been also been inferred from aeromagnetic data (Stromquist and Sundelius, 1975). As with Albemarle Group strata, the gabbro bodies within the suite have been metamorphosed at greenschist facies (Pollock and Hibbard, 2010). Gabbro of the suite at Ridges Mtn., NC, has yielded a single U-Pb TIMS zircon age date of 544 ± 0.55 Ma (DeDecker et al., 2013).

The SMis represents the last magmatic activity within the Carolina terrane before regional deformation and greenschist grade metamorphism (Pollock and Hibbard, 2010). This tectonism has been related to the accretion of Carolinia to Laurentia (Pollock and Hibbard, 2010; Hibbard et al., 2012; DeDecker et. al, 2013). Given the timing of its formation, the SMis appears to represent magmatism related to the arc rifting event responsible for the

separation of the Carolina terrane from Gondwana and the opening of the Rheic ocean (Pollock and Hibbard, 2010; Dedecker et. al, 2013).

Previous Work at the Reed Gold Mine

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). Most of the early workers referred to the gabbro body that hosts the auriferous quartz veins as a greenstone. Of particular significance to the present study, two competing interpretations for the intrusive form of this greenstone appear in these earlier works; Nitze and Hanna (1896) describe it 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 El-Samani (1978) and Osman (1978). El-Samani (1978) produced a bedrock geological map of the site and described the general mine site geology, whereas Osman (1978) performed microscopy and rudimentary geochemical analysis on gold-hosting rock. Although they recognized the greenstone of earlier workers to be a metamorphosed gabbro body, they continued to use the greenstone terminology. El-Samani (1978) was the first to recognize a prominent fold in Albemarle Group strata within the RGM, herein termed the Reed Gold Mine, or RGM, fold, which he described as northeast-plunging and southeast verging. El-Samani (1978) and Osman (1978) adopted the view of Nitze and Hanna (1896), modeling the gabbro as a subvertical dike intruded along the axis of the RGM fold after it had formed. El-Samani (1978) hypothesized that the gold deposit formed in three events including 1) folding of the local argillites to form the RGM fold, 2) intrusion of a gold-rich gabbro dike along the axial surface of the fold, and 3) regional greenschist metamorphism during which gold and silica from within the gabbro was mobilized and redeposited in veins (El-Samani 1978, Osman 1978).

SCOPE OF STUDY

In order to fully understand the origin of the RGM deposit three main points would need to be addressed: the source of gold-bearing mineralizing fluids, the paths that the fluids followed through the crust, and the nature, both chemical and physical, of the depositional sink where the veins were precipitated. However, a full investigation of all of these points is

beyond the scope of the present project. It is the final point, understanding the physical 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.

Several questions must be answered to understand the physical nature of the depositional sink at the RGM. The first is the nature of the gabbro intrusion. Although El-Samani (1978) and Osman (1978) modeled the gabbro as a dike, their model does not provide a compelling mechanism for the localization of mineralized veins within the gabbro. El-Samani (1978) and Osman (1978) both note that quartz veins occur predominantly in the RGM gabbro, and that many veins strike to the southwest, but 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 gabbro, 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 that of the broader region.

We have approached the physical nature of the depositional sink, i.e. the gabbro, from several different directions, utilizing multiple paths of study, including i) new geological mapping of the bedrock of the RGM property, ii) geochemical analysis of the RGM gabbro in order to assess its relationship to other magmatic rocks in the Carolina terrane, iii) attempted U-Pb radiometric dating of zircons recovered from the RGM gabbro in an effort to establish the timing of its intrusion, iv) magnetometric mapping to attempt to distinguish between dike and sill intrusion styles for the RGM gabbro, and v) structural mapping and analysis of both the RGM fold and the quartz veins within the RGM gabbro. The descriptions of these approaches constitute the following sections of this study, and a concluding section will summarize available data and 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 types that underlie the site and their distribution. Although mapping was previously conducted by El-Samani (1978), observations in the course of this study have resulted in the addition of newly identified stratified rock types on the site and a

major revision to the outcrop pattern of the RGM gabbro. 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, we have adopted some of his rock units, map boundaries, and tectonic features where not in conflict with new mapping done in this study. This section describes our updated bedrock map of the RGM including the major stratified rock types of the Albemarle Group and the RGM gabbro (Figure 4).
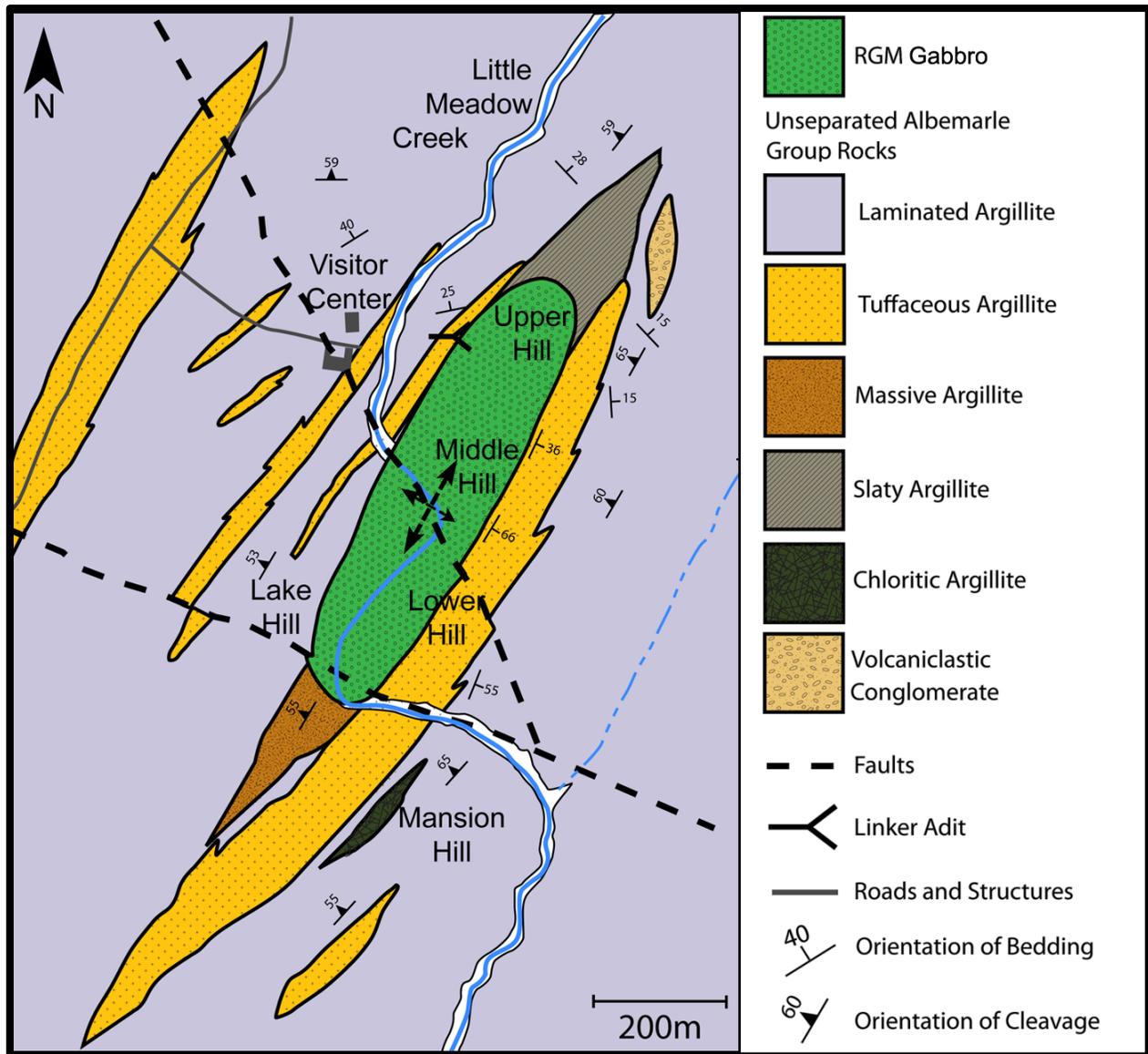

Figure 4: Geological map of the RGM based on observations made during the present study; where there was no conflict with map data from this study, contacts were adapted from El-Samani (1978). Selected orientations of bedding and cleavage come from measurements made during this study as well as those compiled from El-Samani (1978).

Unseparated Albemarle Group

The bedrock surrounding the RGM gabbro is composed of a variety of volcaniclastic rocks (Figure 4) that are part of the Albemarle Group; as noted above no attempt has been made to assign them to a specific formation. Few fresh outcrops of Albemarle Group rocks are currently exposed on the RGM site, and weathering quickly obscures many of their distinguishing features. As such, mapped areas of each variety represent the rock type that is dominant in fresh outcrops. The major mappable stratified rock types identified on the RMG property include laminated argillite, tuffaceous argillite, massive argillite, chloritic argillite, slaty argillite, and volcaniclastic conglomerate. Stratigraphically, the laminated argillite conformably encompasses mappable lenses of all of the other major stratified rock types such that they appear to be local facies variations within a 'sea' of laminated argillite.

Laminated argillite (Figures 4, 5) is the most common volcaniclastic rock within the RGM property, and it 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 present.

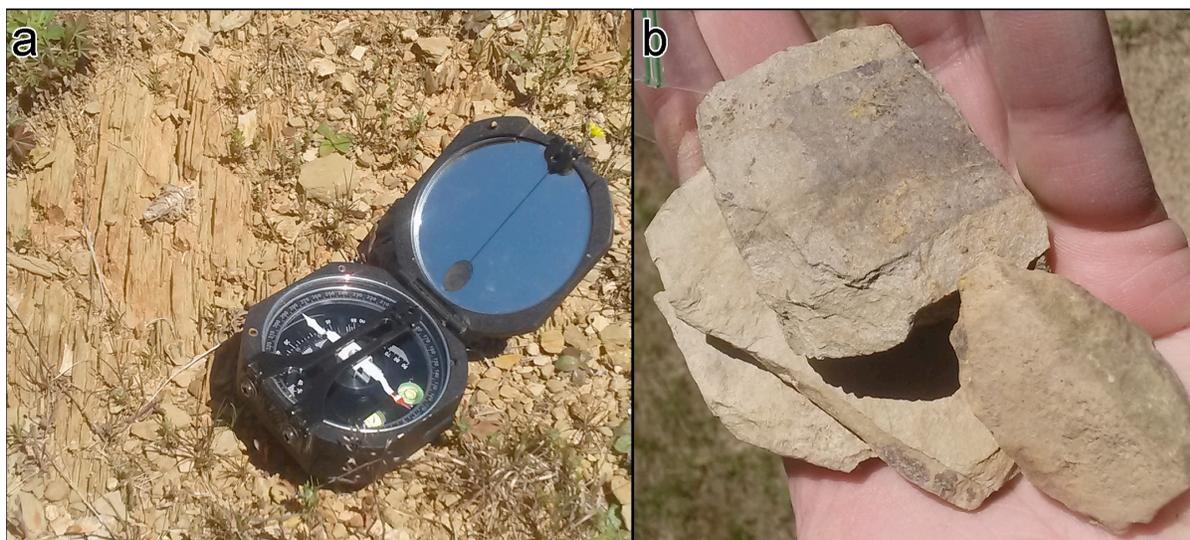**Figure 5:** A typical outcrop of laminated argillite (a) along with cleavage flakes (b). Main access road to the Reed Gold Mine state historic site.

Tuffaceous argillite forms several thin bodies elongated parallel to the trend of the RGM fold (Figure 4). 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, it can be visually

distinguished by its superior competence resulting in a subconchoidal fracture and prominent crystals of pyrite ranging from 1-3 mm. Bedding is present in some outcrops, particularly in exposures forming the walls of Linker adit. There, beds range up to approximately 10 cm in thickness.

Massive argillite (Figures 4, 6) is most commonly interbedded with other argillite varieties, but in a small area southwest of the RGM gabbro 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.
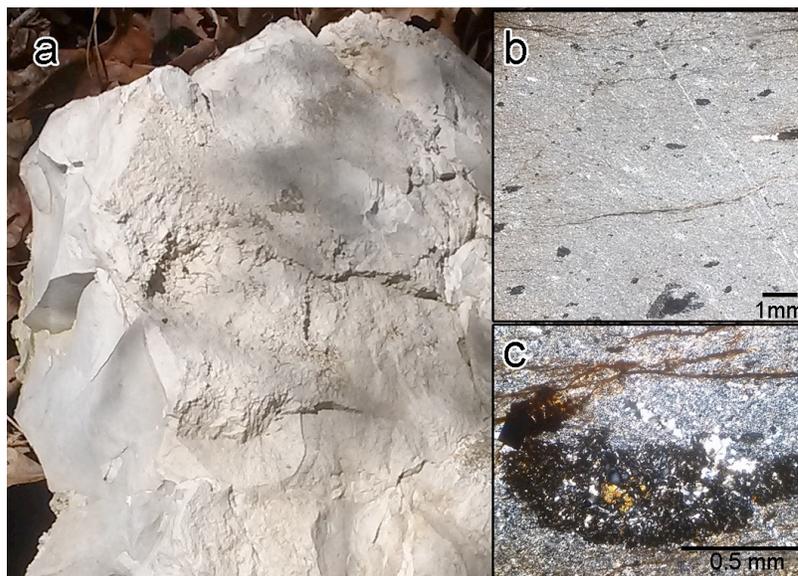

Figure 6: In hand sample (a), massive argillite shows a subconchoidal fracture, indistinct cleavage and a lack of bedding features. Sample shown is approximately 20 cm across. In (b), at 40x with crossed polars, the fine-grained nature of the massive argillite is apparent. Foliation is defined by the dark seams. Micro quartz veins crosscut the matrix. Some of the black patches are opaque leucoxene, and others are apparently sericitized inclusions that pulled 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. It is cross-cut by a fine quartz vein. Above it is one of the foliation seams seen in (b); at higher magnification it is red and resembles oxidized biotite.

Slaty argillite is exclusively observed in two shaft walls and in tailings piles to the northeast of Upper Hill. It is dark grey (Figures. 4, 7) and represents the densest 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 is present. 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.
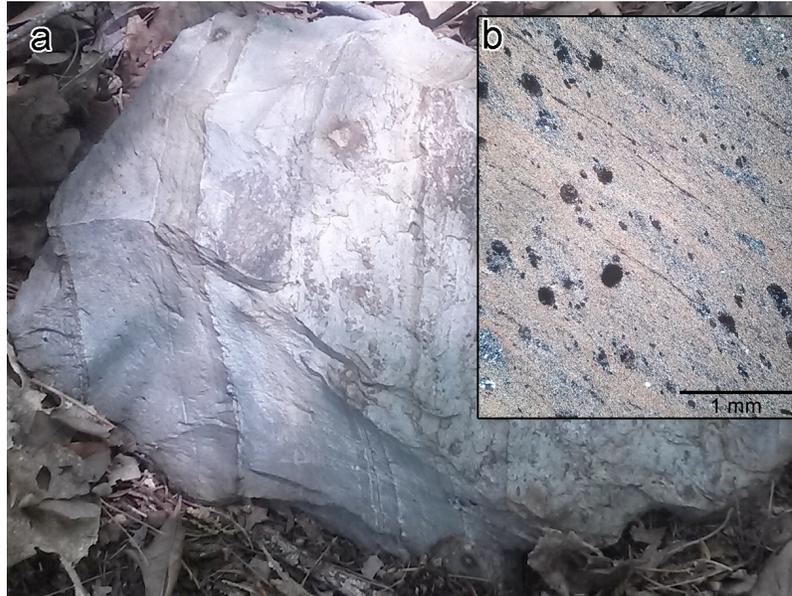

Figure 7: Slaty Argillite. A typical hand sample (a) is fine grained aside from large pyrite cubes, and displays pronounced cleavage. Bedding features are readily observed. In thin section view (b) parallel extinction, fine lines of dark red oxidized biotite and irregular blobs of leuxcoxene are observed.

Chloritic argillite (Figures 4, 8) is exposed in a single minor pit on Mansion Hill in the southeast corner of the mine property. It is a medium grey-green and extensively altered, with rusty iron oxides and hydroxides present in cracks and voids in the rock (Figure 8a). Cleavage is in this unit 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 less present throughout the rock. In thin section, it is seen that the majority of the rock is composed of chlorite (Figure 8b) and the lumps seen in hand sample are angular lithic clasts that deflect the fabric of the surrounding chlorite (Figure 8b).

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. 4, 9). It is readily identified by grey to brown, angular to rounded lithic clasts up to 5cm, including epiclastic clasts, mafic and felsic volcanic clasts, and 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.

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Figure 8: 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.
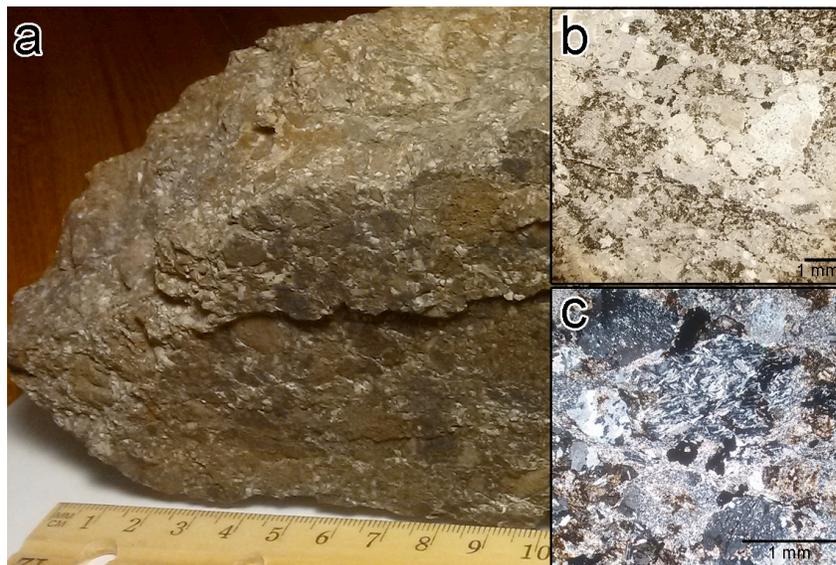
Figure 9: At first glance, the feldspar clasts give the volcaniclastic conglomerate a porphyritic appearance. On closer inspection, however, the rock is composed of diverse angular to rounded volcanic clasts. (b) At 40x a variety of clasts can be seen. Although many clasts are largely altered, some feldspars are largely intact and some clasts preserve original volcanic textures. (c) A prominent clast with trachytic texture viewed at 100x with crossed polars.

Reed Gold Mine Gabbro

The RGM gabbro (Figure 4, 10) 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

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or extrusive igneous rock. This uncertainty arose due to the local obscuring of crystalline texture by any combination of metamorphism, alteration, and weathering. El Samani (1978) noted its fine to medium grain size, igneous texture, overall homogeneity, and sharp contact with surrounding rocks, and interpreted the protolith as gabbro; a conclusion with which we agree.

Figure 10: RGM gabbro. Hand sample approximately 15 cm across in (a), featuring two quartz veins. In (b), at 20x with uncrossed polars, extensive chloritization and skeletal black opaques are visible. In (c) a reflected light image at 40x reveals detail within the 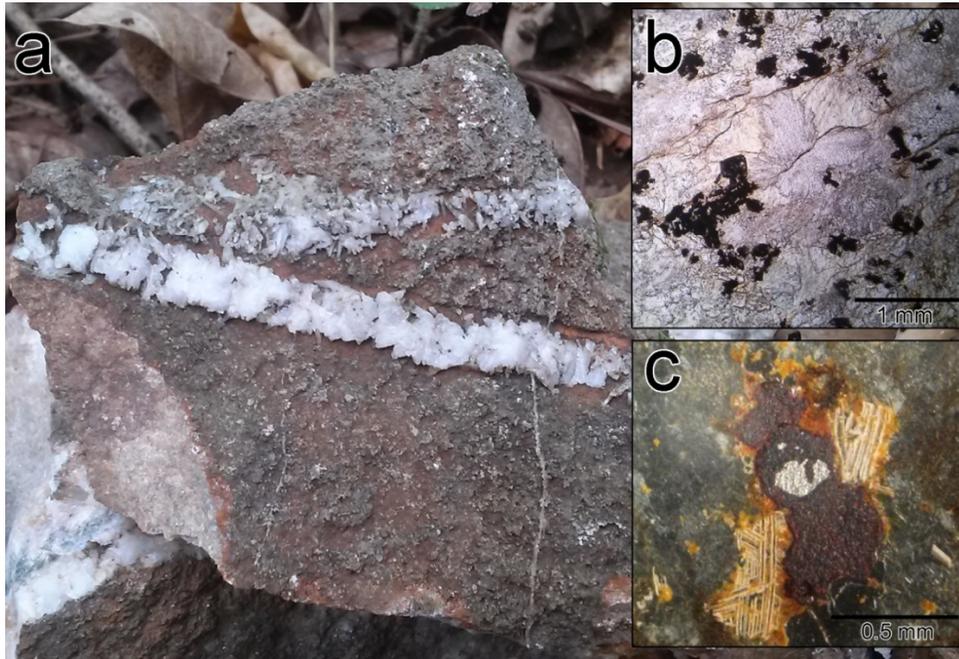opaques. The skeletal white opaques are likely leucoxene, the red likely limonite after pyrite, and the metallic blebs within the red are likely gold.

Distribution: Our new mapping has led to a new perception of the outcrop pattern of the RGM gabbro. Most notably, El Samani's (1978) map, showing the RGM gabbro with an elongated outcrop pattern that extends to the northeast off the mine property, is demonstrated to be inaccurate (Figure 4). Four prominent shafts were observed in the northeast section of Upper Hill, more than 100 meters from the other workings in an area depicted as gabbro by El Samani (1978). Although all other shafts observed at the RGM were sunk into gabbro, 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 for the shafts contain any evidence of gabbro. Similarly, the roots of fallen trees from the northeastern slope of Upper Hill contain flakes of weathered argillite but no gabbro. These exposures provide definitive evidence that the RGM gabbro is neither at or near the surface in this area. This observation

requires a major change to the mapped outcrop pattern of the gabbro, from a dike-like elongated structure to an ellipse at the center of the RGM property, forming the tops of the hills at the site (Figure 4). This change has significant ramifications for the structural interpretation of the mine site, as described in a succeeding section.

Description: The gabbro is medium to light grey on fresh surfaces and weathers to brown and tan. It has a consistent, medium- to fine-grained igneous texture in all outcrops, although locally the texture is partially obscured by either weathering or alteration or both. In hand sample, feldspar grains up to 2mm long are present 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 gabbro.

In thin section, the gabbro is equigranular, with original grain boundaries largely intact despite alteration. Plagioclase 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 of leucoxene (El Samani, 1978) are present throughout the gabbro, commonly associated with weathered pyrite. In one thin section from Lake Hill, the limonitized pyrite contains abundant blebs identified optically as gold (Figure 10c).

Some exposures are intensely weathered and friable and others are heterogeneously silicified. Silicification is expressed 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.

Age and correlation: the RMG gabbro lies within the region where gabbro bodies now assigned to the SMis have been mapped in the past (e.g. Stromquist and Sundelius, 1975). The suite is composed of gabbro that records greenschist facies metamorphism; it intrudes every formation of the Albemarle Group, most typically as sills that tend to define the tops of hills and ridges (Pollock and Hibbard, 2010). Pollock (2007) has described the petrography of the SMis in detail and overall, the RGM gabbro bears a striking petrographic similarity to the SMis, although some SMis bodies are coarse-grained and less altered, with more original mineralogy preserved through the greenschist facies overprint. Potentially correlative mafic

units, dubbed the 'departure' gabbro, have also been observed in the Carolina terrane of South Carolina (Secor et al., 2015).

There is no direct evidence for the age of the RGM gabbro. In this study, U-Pb dating was attempted on zircon grains collected from the RGM gabbro. Mineral separation of a gabbro sample from the top of Lake Hill (Figure 11) ultimately yielded three small colorless, clear zircon grains (Challener, 2016). These grains were processed and analyzed in a thermal ionization mass spectrometer; the resultant measurements indicated no detectable uranium from the zircons, and as such no date could be assigned to the zircons.

As noted, the RMG gabbro is petrographically similar to bodies in the SMis and spatially occurs within the distribution area of the suite. A sample from the SMis at Ridges Mountain, North Carolina, was dated by U-Pb TIMS method on zircon at 544.81±0.55 Ma (DeDecker et al., 2013); the SMis also intrudes every unit of the Albemarle Group (Pollock and Hibbard, 2010). As such, intrusion of SMis is likely time transgressive, ranging at least from 545 Ma to 528 Ma, the minimum age of the youngest Albemarle sedimentary rocks (Hibbard et al., 2012). On the basis of the similarities between the RMG and the SMis, the age of the RMG likely falls within this broad range.

<p style="text-align:center">Geochemistry of the RGM Gabbro</p>

As noted in the previous section, the RGM gabbro may be related to gabbro of the SMis. The SMis is well characterized as a distinct and coherent geochemical unit (Pollock and Hibbard, 2010); in order to confirm if the RGM is geochemically related to the SMis, we undertook whole rock chemical analyses of major, trace and rare-earth elements on three samples of RGM gabbro. Here, we briefly present the sampling and analytical methods, followed by a comparison of selected discrimination diagrams of the two gabbro units.

Sampling and Preparation

Due to the limited number of surface outcrops with minimally weathered gabbro, only three samples collected from two sites at the RGM were selected for analyses (Figure 11). 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 pyrite 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.
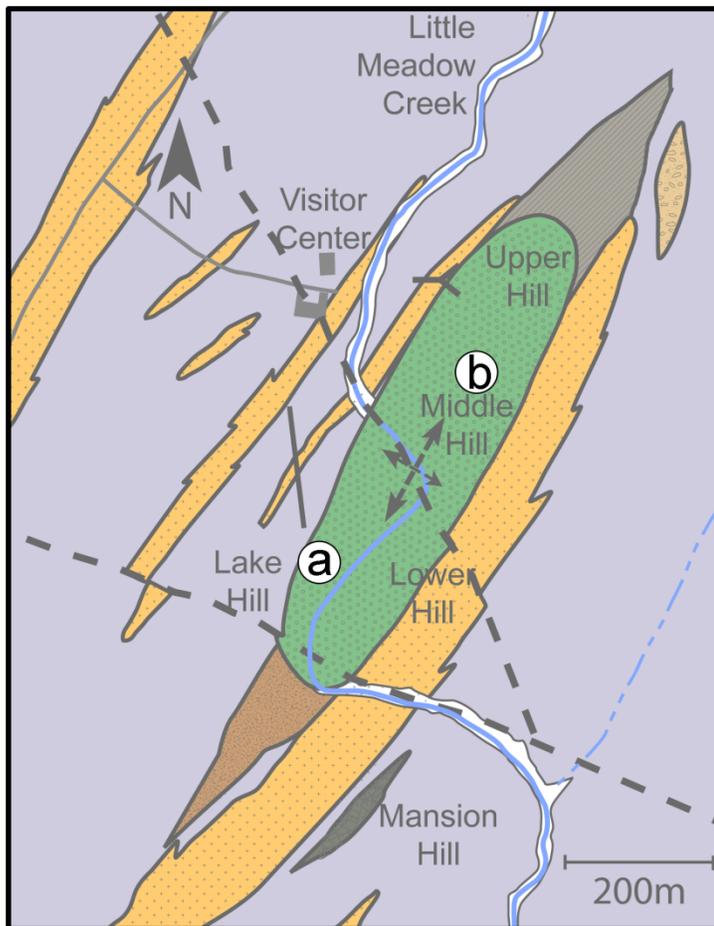
Figure 11: Locales for geochemical sampling at the RGM. Samples for whole rock elemental analysis were collected at site a on Lake Hill and site b on Middle Hill. Zircons for dating were separated from samples collected at site a.

Analytical Methods and Results

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 1, and provide a basis for comparison with the SMis in selected discrimination diagrams.

An alkali-silica plot is included to assess alteration of the RGM gabbro relative to the SMis. However, to avoid other anomalies caused by localized weathering and alteration, immobile-element plots are used for primary characterization of the RGM gabbro.

Table 1
Geochemical Data from the RGM Greenstone and a typical SMs member

Sample	SiO$_2$	Al$_2$O$_3$	Fe$_2$O$_3$	MnO	MgO	CaO	Na$_2$O	K$_2$O	TiO$_2$	P$_2$O$_5$	Cr	Ni	Sc	V
Lake 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
Lake 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
Middle Hill	52.86	13.57	10.33	0.215	2.06	5.59	3.61	1.32	1.294	0.59	< 20	< 20	26	190
SMs[a]	36.74	9.63	12.91	0.18	23.65	8	0.15	0.45	0.31	0.05	1366.7	433.54	22.21	164.74

Sample	Cu	Ga	As	Rb	Sr	Y	Zr	Nb	Ba	Ce	Th	U	La	Pr
Lake Hill 1	40	26	51	93	22	14.3	45	1.9	440	22.9	3.12	0.6	9.33	3.09
Lake Hill 2	60	26	49	98	22	16.2	41	2	454	23.7	3.04	0.62	10.9	3.36
Middle Hill	310	20	20	40	168	38.1	108	4.6	381	63.5	11.4	2.48	28.2	8.27
SMs	15.94	8.43	1.83	27.14	79.49	7.33	13.97	0.86	74.64	12.42	2.79	3.2	1.63	0.59

Sample	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	Tl
Lake 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
Lake 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
Middle Hill	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
SMs	3.05	1.01	0.37	1.38	0.23	1.57	0.33	0.96	0.14	0.91	0.14	0.6	0.03	0.35

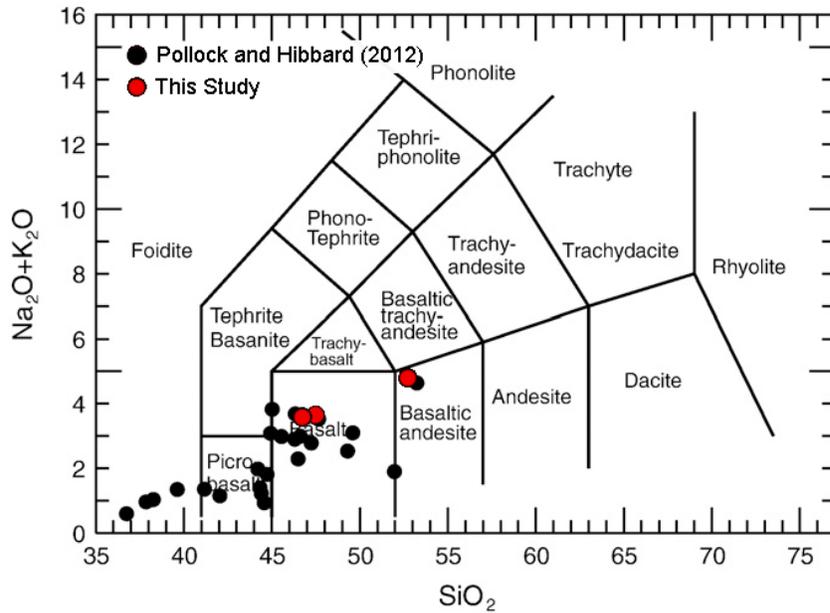[a] Sample 205 from Pollock and Hibbard (2009).

Figure 12: RGM samples fall with the higher silica range of the SMis samples on an alkalinity vs silica chart.

There is a positive linear correlation between the alkalinity of SMis gabbros and their silica content (Figure 12). RGM gabbro plots within the field of SMis gabbros on the high-Si end of the spectrum, potentially suggesting that they are less hydrothermally altered than most other sampled SMis gabbros (Pollock and Hibbard, 2010). However, although minimally altered samples of RGM gabbro were selected for analysis, the silicification noted

in several RGM outcrops may offer an alternative explanation for the high silica values. On a K_2O+Na_2O vs $K_2O/(K_2O+Na_2O)$ diagram of Hughes (1972), the two samples from Lake Hill (Figure 13a) plot away from the SMis samples and outside of the igneous spectrum (Figure 13), but the single sample from Middle Hill (Figure 11b) is well within the igneous spectrum. This observation 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.
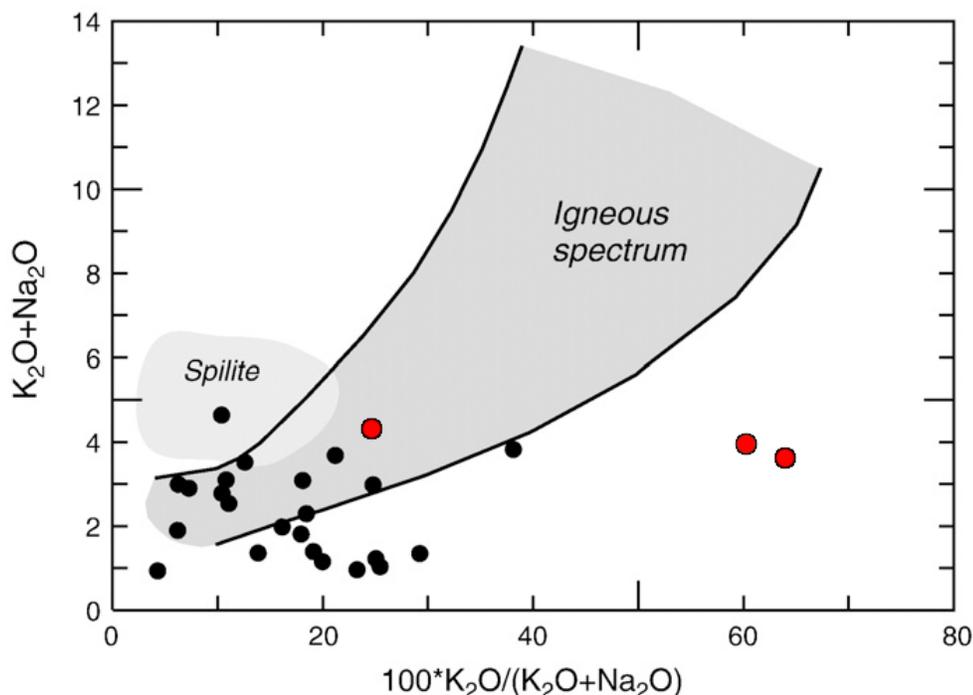

Figure 13: RGM gabbro samples from Lake Hill (fig. 11a) plot outside the igneous spectrum (Hughes, 1972), indicating mobilization of K and Na after the initial intrusion. The sample from Middle Hill (Fig.11b) is within the igneous spectrum with values similar to members of the SMis, indicating that mobilization was related to local alteration rather than regional metamorphism (adapted from Pollock and Hibbard, 2009, Fig. 6).

Although the RGM and SMis gabbros are heterogeneously altered, immobile elements can shed light on the original character of the rocks. Zr, Ti, Nb and Y are all relatively immobile under normal metamorphic conditions (Pollock and Hibbard, 2010); Zr/TiO_2 can be used as a proxy for igneous affinity and Nb/Y is a proxy for alkalinity. The SMis gabbros show basaltic affinities ($Zr/TiO_2 < 0.1$) and low alkalinities (Nb/Y < 0.8). RGM gabbro samples plot directly in the center of the SMis cluster (Figure 14).
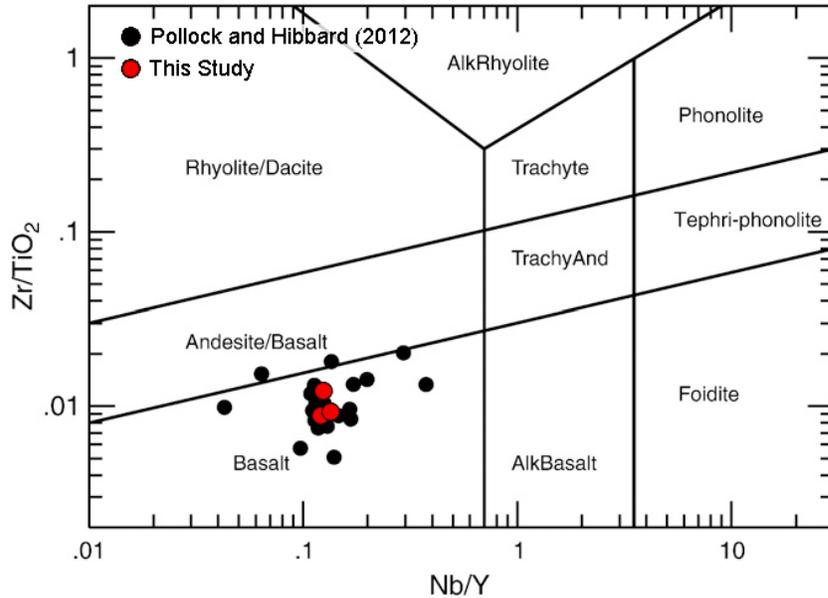
Figure 14: Immobile element proxies for basaltic affinity (Zr/TiO2) and alkalinity (Nb/Y) plotted against one another. SMis gabbros cluster strongly in the basalt field (Pollock and Hibbard, 2010, Fig. 7). RGM gabbro plots at the center of this cluster as well.

In order to best compare the chemical fingerprints of the SMis and RGM gabbro, selected immobile elements are plotted on an extended rare-earth element diagram (Figure 15). The trends seen in the SMis and the RGM gabbros are essentially identical, indicating that they likely share a common magma source.

In summary, immobile elements within the RGM gabbro are geochemically indistinguishable from SMis. In conjunction with the similarities in mode of occurrence and lithic attributes, these data provide strong evidence that the RGM gabbro is a member of the SMis.
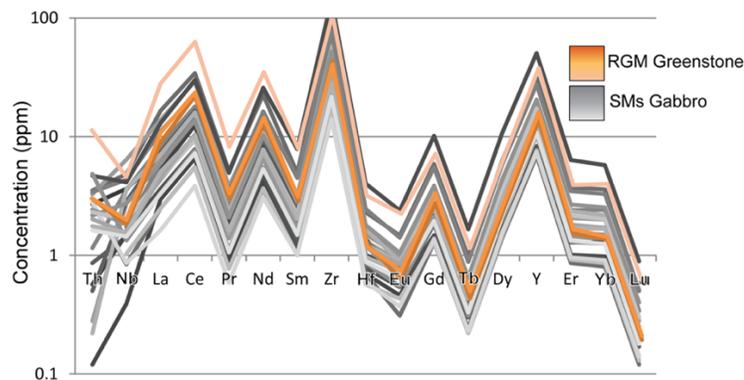

Figure 15: Trends in immobile elements across the SMis (data from Pollock and Hibbard, 2010) and the samples of RGM gabbro. The trends are essentially identical across all of them, offering robust support for the inclusion of the RGM gabbro in the SMis.

Structural Analysis

Perhaps more than any other approach, an analysis of structural data is the best method to understand the localization of gold at the RGM. The precipitation of auriferous veins at a particular site is largely influenced by local structures, for they provide the space for ponding and precipitation of mineralizing fluids.

Structural analysis in this study focuses on two main points. First, the form of the RGM gabbro body and the character of the RGM fold are clarified by use of local and regional structural context and magnetometry. Second, the geometry of RGM quartz veins is described and a mechanism for the localization of mineralization is modeled from all of these data.

Form of the RGM gabbro body

The RGM gabbro has been interpreted to be either a steep to vertical dike (e.g. Nitze and Hanna, 1896; El Samani, 1978), or a sill (Pardee and Park, 1946), within Albemarle Group strata. Our new mapping of the gabbro shows that it has an elliptical outcrop pattern centered on the RGM fold axis, which is inconsistent with the dike interpretation; instead it suggests a domal structure. In order to further address the form of the gabbro body, we utilize field observations of the contact of the gabbro with surrounding strata, mapping and structural observations of the RGM fold, and magnetometry.

If the primary contact between the gabbro and the surrounding Albemarle Group strata is preserved, it should reveal if the RGM body was intruded either concordantly or discordantly with respect to surrounding strata. The contact is not exposed at the surface, although our mapping strongly suggests that it is, for the most part, concordant with bedding in surrounding Albemarle Group strata. The contact is exposed at only one limited exposure on the RGM property, underground, along the wall of Linker adit. At this location, the gabbro is in contact with the bedded tuffaceous argillite for approximately 2 meters (Figure 16). Despite having an exposure of the contact, definitive interpretation of its nature is complicated by a several 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, to the point that it can be readily removed and crumbled by hand (Figure 16b), and extra wood supports were needed to shore up the immediately adjacent wall of the adit.

Tuffaceous argillite near the contact is well bedded, although bedding is indistinct in the saprolite marking the contact. Away from the contact, bedding in the argillite is at a high angle to the contact saprolite zone, and it is likely on this basis that some earlier geologists have described the gabbro as a dike (Nitze and Hanna, 1896; El Samani, 1978). However, bedding in the tuffaceous argillite deflects upwards in the immediate vicinity of the contact saprolite (Figure 16a), suggesting drag along the contact. These factors, in addition to the extreme saprolitization, which is common in faulted rocks in the Carolina terrane, lead us to interpret the contact at this locale is structural rather than a primary intrusive contact. This interpretation is consistent with the expectation of slippage along a strong rheological discontinuity such as this contact during folding and tectonism. We conclude that it is not possible to determine the original nature of the contact between the gabbro and the argillite on the basis of this exposure.
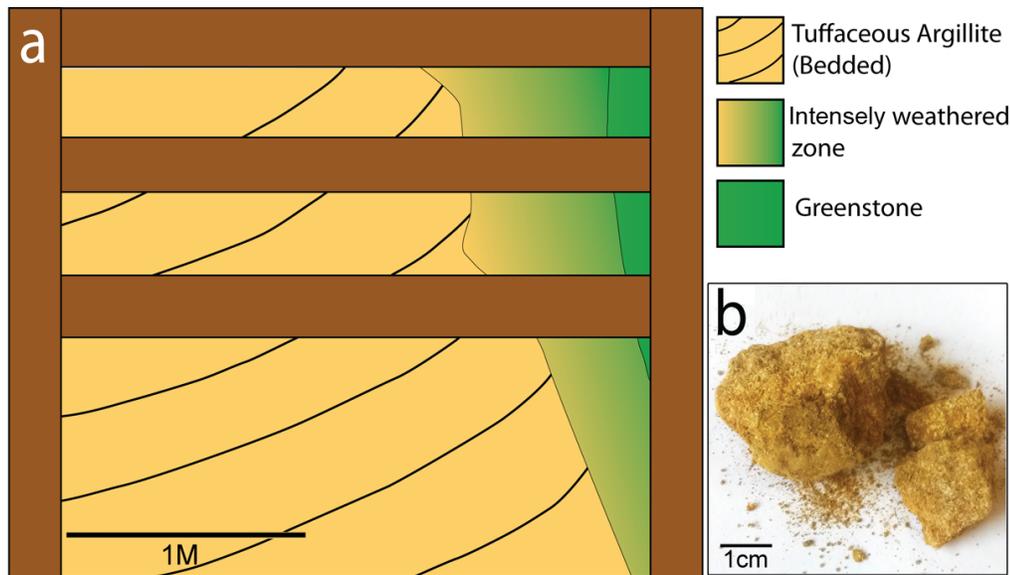

Figure 16: (a) Schematic view of the contact between tuffaceous argillite and the RGM gabbro in the wall of Linker adit, with the rock visible between wooden slats (in brown). The image is constructed from photos taken during the course of underground mapping. Bedding in the argillite deflects upward 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 gabbro adjacent to the contact (b) is saprolitic and can easily be crumbled into silt- and clay-sized particles.

Turning now to the form of the RGM fold, the apparent domal form of the RGM gabbro at the core of the 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 (Figure 4) and from the northeast-plunging line of intersection between bedding and cleavage measurements in the same area (Figure 17A).
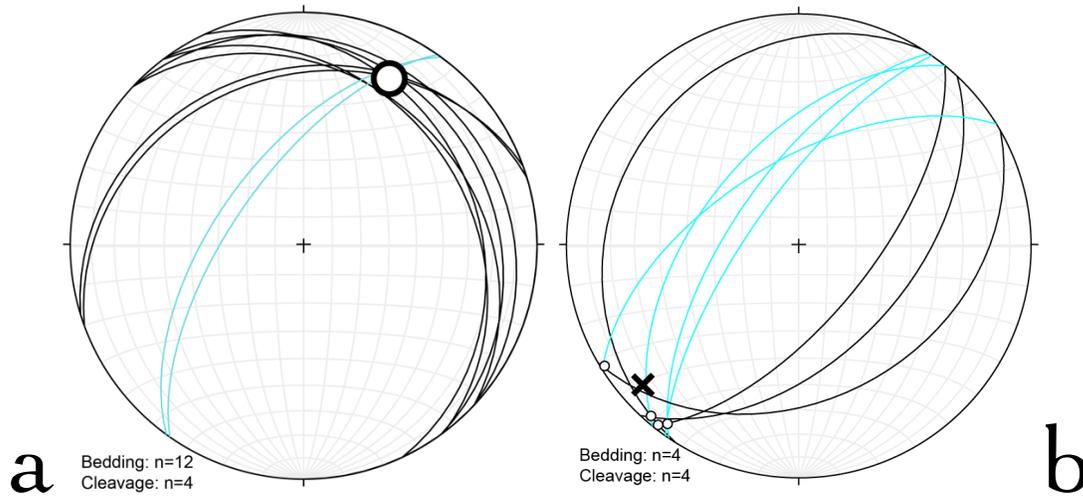

Figure 17: a. The line of intersection of bedding and cleavage orientations from stratified rocks in the northeastern area of the RGM property plunges to the northeast, indicating a northeast plunge to the fold in that area. b. Four pairs of bedding orientations (in black) and cleavage orientations (in 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 intersections.

The outcrop pattern of the gabbro 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 (Figure 17b).

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 (Figure 18) that also plunges to the southwest (Figure 17b). 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.
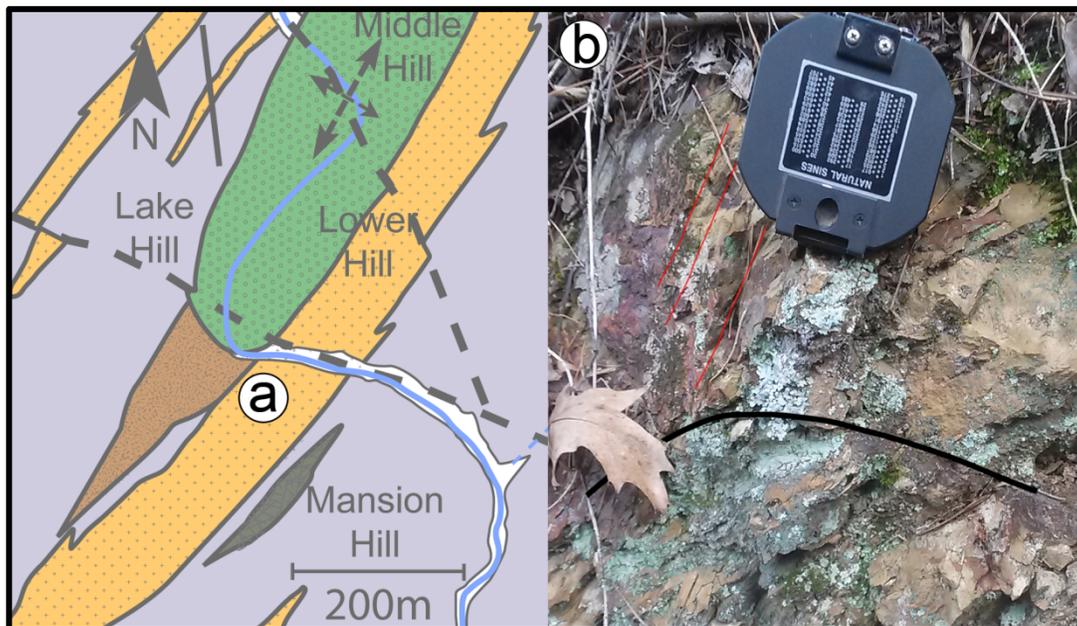

Figure 18: At site (a) on the map, a small southwest-plunging fold was observed in an outcrop (b). Cleavage traces marked in red on (b) are axial planar to the fold, showing that it is parasitic to the main RGM fold.

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; Sundelius and Stromquist, 1978; Stromquist and Henderson, 1985; Goldsmith et al., 1988). Lithostratigraphic units in their cores produce northeast-trending ovoid outcrop patterns similar to that of the RGM gabbro (Figure 2). Smaller folds also attributed to Cherokee deformation in the adjacent Charlotte terrane to the west are also typically doubly plunging (Allen, 2005).

Taken in conjunction, both the RGM gabbro outcrop pattern and structural data from the surrounding Albemarle Group strata indicate that the RGM fold defines a domal structure. The spatial coincidence of the two lines of evidence for a domal feature strongly suggests that there is a concordant relationship between the gabbro and Albemarle Group strata at the site.

In order to better understand the subsurface geometry of the RGM gabbro magnetometric measurements were collected at the RGM site. The gabbro is iron-rich 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 gabbro with a sharp dropoff on either side above the various RGM argillites. In contrast, a folded sill would be expected to have a more broadly distributed signal, with the strongest response at the center of the gabbro exposure gradually dropping off on either side, down the dip of the limbs.

Measurements were collected with a Geometrics G-859 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 (Figure 19).
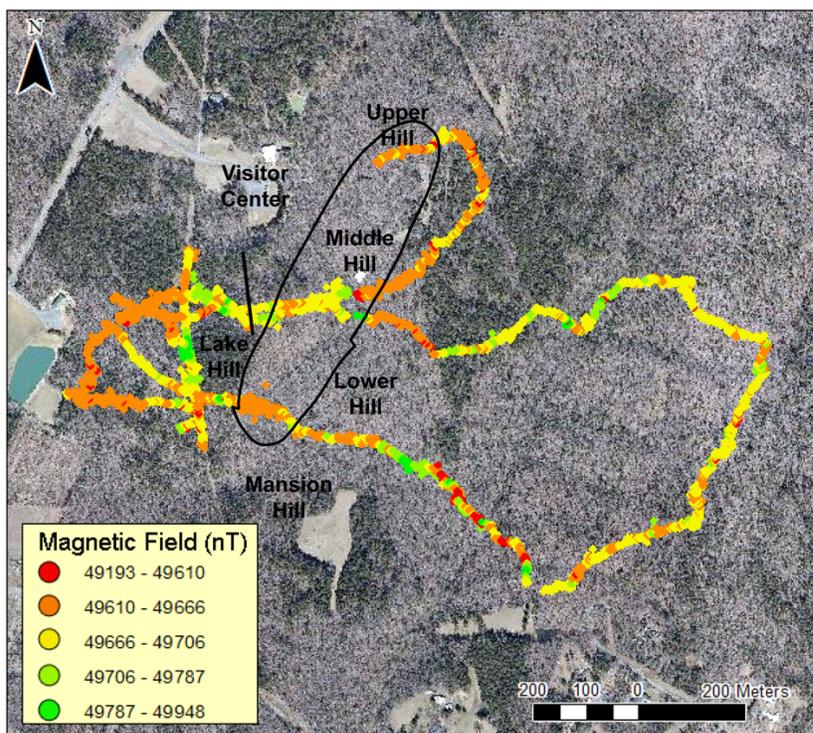

Figure 19: Geomagnetometric data collected at the RGM, plotted over a 2015 orthophoto of the area (NC Onemap, 2015) with the outcrop pattern of the RGM gabbro superimposed over it. After processing and despiking, numerous small anomalies are visible with a broad trend towards lower values in the eastern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

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 that might be expected from a sill. There is, however, a slight trend towards lower 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.

In summary, multiple observations provide strong indirect evidence for the form of the RGM gabbro body. The limited exposure of the contact of the gabbro and surrounding strata appears to show a discordant relationship; however, this contact appears to be structurally modified and not primary. The newly mapped outcrop pattern of the RGM gabbro combined with structural observations from the surrounding Albemarle Group strata suggests concordance of the gabbro body with strata defining the doubly plunging RGM anticline. This local scenario is consistent with the periclinal geometry of regional folds in the Carolina terrane. Finally, magnetometric data appear to be more consistent with a gabbro body concordant with surrounding strata than with a steeply to vertically dipping dike. Therefore, we conclude that the RGM gabbro body is most likely a sill within Albemarle Group strata.

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, we examined the orientation of the Au-bearing quartz veins. We visually estimate that the gabbro hosts at least 90 vol% of the vein quartz at the RGM. Economic workings were restricted to the gabbro near the crest of the RGM fold, particularly on Middle and Upper Hill. The relatively more competent volcaniclastic units also locally host quartz veins to a much lesser degree, particularly near the hinge of the fold. At least four test shafts were sunk into volcaniclastic material northeast of the gabbro, but quantities of gold were apparently uneconomic as the shafts were terminated at shallow levels.

Since subsurface portions of the mine are accessible, orientations of quartz veins were measured directly in the tunnel walls. The opening to the subsurface workings is at Linker adit (Figure 4) 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 hinge. All quartz veins have an approximately planar geometry at outcrop scale. The poles to quartz veins plot along a great circle, with a pole that plunges to the southeast (Figure 20). 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 approximately perpendicular to the gabbro sill.
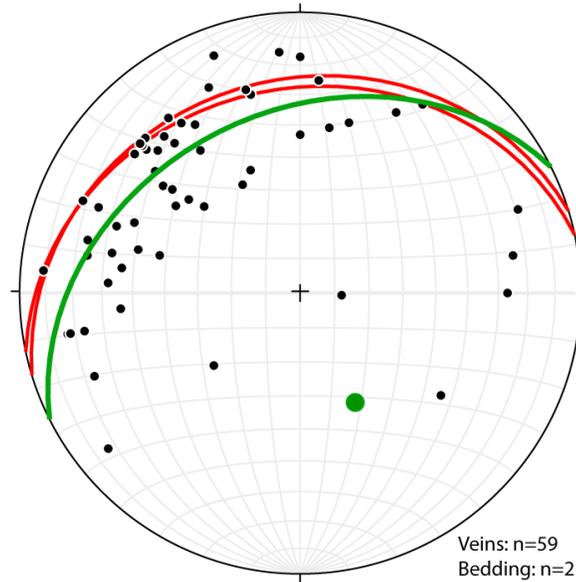
Figure 20: Poles to quartz veins measured in the underground workings define a great circle (marked in green). The great circle defined by poles to veins is subparallel to bedding measurements taken in immediately adjacent sediments (marked in red, based on data from El-Samani (1978)).

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 unknown. Such a folded surface is consistent with broad warping of the veins during the formation of the pericline, the axis of warping is suborthogonal to that of the main trend of the RGM anticline (Figure 20).

The orientation of the veins 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 gabbro 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 shows a resultant 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. 21a).
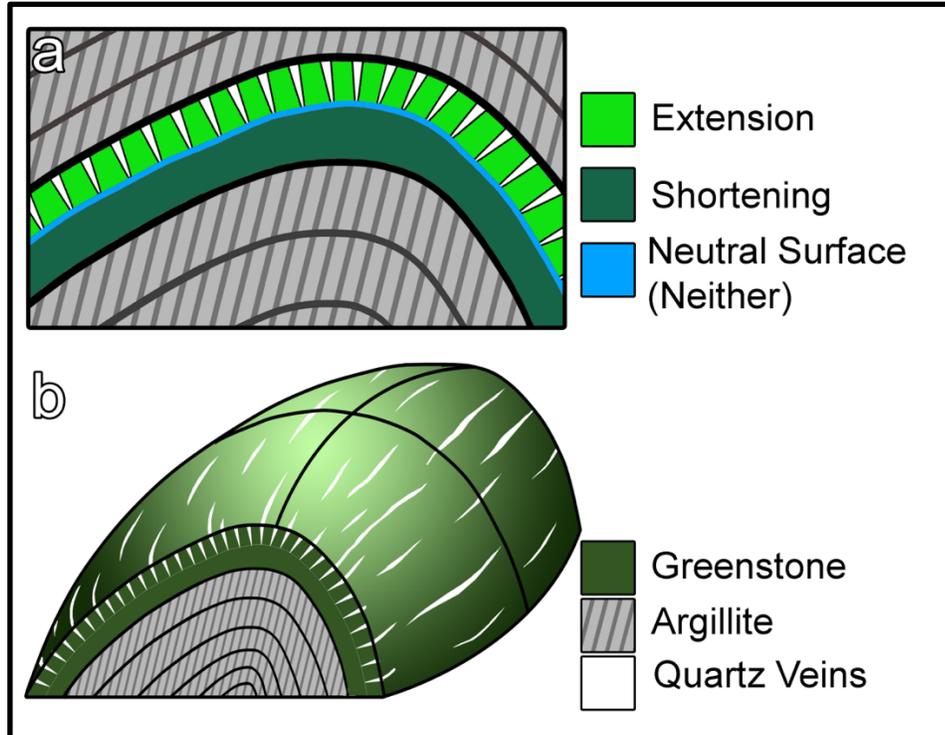
Figure 21: Visualization of the folded sill model for the RGM gabbro, shown in shades of green. In (a) zones of extension and shortening, and the neutral surface that experiences neither, are marked. Extension is accomodated by fractures that host auriferous quartz veins. In (b) a three-dimensional rendering shows the two fold axes in black that define 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.

Considering the high concentration of quartz veins in the RGM gabbro, its apparent concordancy with the stratified Albemarle Group rocks, and the orientation of the quartz veins in the gabbro, the RGM gabbro is most consistent with a simplified folded sill model as depicted in Figure 21b.

This model has important implications for the timing of mineralization at the RGM. The extension fractures that allowed vein formation in the gabbro are geometrically linked to the RGM fold; it is also unlikely that extensional cracks would remain open at depth (e.g. Yardley, 1986), so precipitation of vein material must have occurred as the fractures formed. The RGM fold, along with other folds within the GHsz, is attributed to the Late Orodvician-Silurian Cherokee orogeny c. 460-430 Ma (Hibbard et al., 2010, 2012). As such, mineralization must be syorogenic with the Cherokee event.

Comparison of the RGM with Similar Deposits

Although 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).

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., 2017). 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., 2017). However, in the scarce available information no other gold mine in the GHsz is recorded as having auriferous veins primarily hosted in a gabbro 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), Newfoundland (Ramezani et al., 2000) 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).

One of these deposits, the Stog'er Tight gold prospect in Newfoundland (Ramezani et al., 2000) is hosted in a massive gabbro sill within mainly volcaniclastic strata that form the cover sequence above ophiolitic components of the Pt. Rousse Complex. The entire complex is

deformed in a syncline and metamorphosed to greenschist facies. The gold is closely associated with quartz veins and a hydrothermal alteration envelope that occur in, and immediately adjacent to, shear zones in the gabbro sill. The mineralized shear zones are confined to the gabbro sill, likely due to its mechanical rigidity (Ramezani et al., 2000); thus, as at RGM, the gabbro exerted a structural control on ore localization, albeit in the form of shear zones rather than extension fractures as present at RGM. In addition, gabbro at the Stog'er Tight prospect served as a chemical sink for gold mineralization, wherein ilmenite-magnetite in the gabbro reacted with hydrothermal fluids to induce precipitation of pyrite and gold within altered gabbro (Ramezani et al., 2000). The chemical role of the gabbro sill at RGM is unknown at this time and beyond the scope of the present study, but could be a fruitful subject for future research.

SUMMARY AND DEDUCTIONS

This study has yielded multiple new findings. In this section, the findings of the study are summarized and 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.

Summary of New Findings

• On the basis of similarities in petrography, geochemistry, and mode of occurrence, the RGM gabbro is shown to be a member of the SMis.

• New mapping establishes the outcrop pattern of the RGM gabbro is an elongated ellipse.

• Structural analysis shows that the RGM fold is doubly plunging.

• Based on mapping, structural and magnetometric data, the the RGM gabbro is most likely a folded sill.

• Auriferous quartz veins within the RGM gabbro 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 gabbro indicate that the Au mineralization is syntectonic with respect to the Cherokee Orogeny.

• The RGM deposit represents an unusual style of gold localization, with auriferous quartz veins forming in extensional cracks on the outside of a folded gabbro sill. This form of a mechanical sink for mineralized fluids 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 gabbro was intruded mainly in the Early Cambrian as a bedding concordant sill. Although it could not be directly dated, the RGM greenstone is a member of the SMis. The intrusion of the SMis was likely 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 with respect to this event. 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. These fluids are likely the result of metamorphic dewatering and pressure solution in the Albemarle arc pile. The competent RGM gabbro sill was folded amongst surrounding sedimentary rocks of the Albemarle Group, 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 auriferous veins may be expected at the core of anticlines that fold intrusive sills of the Stony Mountain suite gabbro. 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 nearby 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 globally.

• A systematic study of vein localization styles in the various GHsz orogenic deposits would provide more context for 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.

• The role of the RMG gabbro as chemical sink for gold mineralization, similar to that of the gabbro at the Stog'er Tight gold prospect, could provide a fruitful avenue of future research.

• 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 to identify the source of mineralizing fluids and help identify linkages 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 North Carolina (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.

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