GEOLOGY OF THE SOUTHERNMOST EXPOSURES OF THE BREVARD ZONE IN THE RED HILL QUADRANGLE, ALABAMA

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Date of Graduation

VITA

James Wesley Sterling, son of Ernest Ray and Adeline Orr Byford, was born August 21, 1978, in Decatur, Alabama. He graduated from Hartselle High School with an advanced diploma in Hartselle, Alabama, in 1997. He entered the Wallace State Community College in Hanceville, Alabama concentrating in pre-engineering. He enrolled in the College of Engineering at Auburn University in the fall of 1998 and transferred to the College of Science and Mathematics in 2000. He graduated in winter of 2001 with a Bachelor of Science degree in Geology/Earth Science and a minor in business. In the Spring of 2002, he entered the graduate program at Auburn University to pursue a Master of Science degree in geology.

THESIS ABSTRACT

GEOLOGY OF THE SOUTHERNMOST EXPOSURES OF THE BREVARD ZONE IN THE RED HILL QUADRANGLE, ALABAMA

James Wesley Sterling

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The southernmost exposures of the Brevard zone were mapped to characterize its lithologic makeup and structural character and to explore its significance to the tectonic evolution of the southernmost Appalachians. Two important findings were made. First, the Lake Martin duplex (LMD) was discovered. The LMD comprises repeated panels of lower-greenschist to lower-amphibolite-facies siliciclastics, cherts, carbonate-bearing pelites, and volcanics (?) of the Jackson's Gap Group (JGG) that are separated by earlier-formed Acadian or early-Alleghanian (?) oblique-right-slip, D_1, thrust zones. The structural top of the LMD is interleaved with units of the Inner Piedmont (hanging wall) along D_1 shear zones, whereas the base is in contact with units of the eastern Blue Ridge (EBR). Retrogressive D_2 semi-brittle shear zones locally shear and weakly stretch the duplexed panels and S_0/S_1 schistosity and gneissosity. S_2 shear bands and F_2 folds formed as a result of D_2 deformation. Rocks of the LMD, therefore, are principally

devoid of the D_2 retrogressive, semi-brittle, right-slip shear zones that elsewhere typify the Brevard zone. The present study area, thus, preserves the orogen's only location where JGG lithologies and their associated D_1 structures and fabrics are preserved in a relatively unaltered structural state. Relatively low metamorphic grade and low strains allow for the preservation of primary sedimentological structures and other features that help to clarify the depositional, structural, and tectonic settings of the JGG. The geology of the LMD is lithologically, geometrically, kinematically, and structurally comparable to that of the Hollins Line duplex of the Talladega Belt and the Pine Mountain imbricate zone that borders the Inner Piedmont and Pine Mountain window.

Second, previously undescribed igneous units were discovered within panels of the LMD. A bimodal suite of metatonalite and greenstone, the Lake Martin Dam metatonalite (LMDM) and Eagle Creek greenstone (ECG), respectively, were mapped and characterized using petrographic and whole-rock geochemical methods. Major oxide discrimination diagrams indicate that the LMDM and ECG are tholeiitic tonalite and calc-alkaline basalt, respectively, and exhibit a bimodal nature similar to that of the Hillabee Greenstone in the Talladega Belt. Chondrite-normalized REE patterns indicate the LMDM originated as a relatively shallow intrusion within a volcanic arc whereas the ECG formed in a continental rift setting similar to those of the Laurentian rift basalts of the western Blue Ridge.

The protolithic assemblage (i.e., orthoquartzite, quartz-pebble conglomerate, and carbonate-rich shale) and geochemical nature of the LMDM and ECG, clearly indicate that the JGG was deposited in a shallow-marine shelf setting off of the ancient, rifted margin of Laurentia.

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I would like to thank the faculty of the Department Geology and Geography at Auburn University for their patience and encouragement during the course of my graduate studies. I would especially like to express my gratitude to Dr. Steltenpohl, professor and friend, who challenged me to perform my best. I would also like to express my thanks to the many life-long friends I have made while at Auburn who provided endless escape and refuge.

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INTRODUCTION

Rocks of the southernmost exposures of the Brevard zone in east-central Alabama were investigated to further enhance our knowledge and understanding of southern Appalachian tectonic evolution within a relatively small part of the Alabama Piedmont. Work focused on the mapping of stream drainages, road-cuts, and shoreline exposures of crystalline rock in the vicinity of Martin Dam, Alabama that have never before been investigated in detail in order to better characterize one of the more classic and debated structures in Appalachian geology.

This thesis follows a manuscript format, as outlined by the Department of Geology and Geography at Auburn University, and comprises two papers written in the Geological Society of America's format. The first paper, "Geology of the southern exposures of the Brevard zone in the Red Hill Quadrangle near Martin Dam, Alabama," which is to be submitted to the *Journal of Structural Geology*, is a general geological synthesis of the lithologies and structures found in the study area. The second paper, "Petrology and geochemistry of igneous rocks in the southernmost Brevard zone of Alabama and their implications for southern Appalachian tectonic evolution," is to be submitted to *Southeastern Geology*. This paper compares the results of this study with the findings of other workers to place them into the regional geologic framework.

METHODS

Geologic mapping at a scale of 1:24,000 was conducted over an area of approximately 23 km^2. All primary and secondary roads with open access were mapped, including logging roads, hunting trails, and private roads where permission was obtained. Mapping was conducted in all major creek and stream drainages and their tributaries, powerline right-of-ways, and Alabama Power Company dam sites. Mapping of Lake Martin and the Tallapoosa River was accomplished by the use of a canoe and by foot. Approximately 60 miles were traversed during this study. Of these, 50 miles were mapped along roadway, trail, and ridge crests and 10 miles were mapped along shore.

In the northern half of the study area outcroppings of crystalline rock were abundant along the ridges on and adjacent to the east and west shores of the Tallapoosa River and in the area immediately adjacent to Martin Dam. In the southern half of the study area rock exposure was limited to access roads, major drainages, and creek beds and was partially covered by Cretaceous to Recent sediments. In low lying areas and along most ridge crests exposure was very poor due to the dense wooded cover. One hundred and eighty four stations were established at which lithologic, structural, and fabric observations were recorded. The southeast quadrant of the Red Hill 7½ minute USGS topographic quadrangle was used as the primary base map. Data collected at the various stations were plotted on this base map and a structural form-line map was constructed. The form-line map then was layered together with the lithologic and topographic information to generate the geologic map. Reconnaissance mapping with Dr. M. G. Steltenpohl was conducted outside the study area to establish and evaluate structural and lithostratigraphic trends.

During field mapping, a Garmin Rino120® handheld GPS unit was used to record the latitude, longitude, and elevation of station localities as well as for field orientation along previously imported preplanned traverses. The GPS unit was also used for tracking purposes to document a detailed record of areas traversed, planned and otherwise, during mapping. Data collected by GPS was imported into National Geographic TOPO! Alabama® state series software as waypoints (i.e., station localities) and tracks (i.e., traverses). This software was used to plan traverses to be carried out the following day as well as to create customized topographic base maps and profiles. Field notes and photographs taken at station localities were imported and then 'attached' to corresponding waypoints, allowing for comparison of lithologic distribution and structure to the topography of the study area.

Laboratory work included petrographic analysis of 80 thin sections and hand-sample analysis of 5 polished slabs. Thin sections were examined to determine lithologic characteristics, metamorphic mineral assemblages, rock fabrics, and textural and microstructural relationships. Thin sections and polished slabs were cut perpendicular to the dominant metamorphic or mylonitic foliation and parallel to the mineral or elongation lineation. Thin sections of oriented samples were used to compare microstructural features with established mesoscopic and macroscopic features. Staining of potassium feldspar and calcite was used in selected thin sections to aid in mineral identification.

Ten samples representing every igneous lithology found in the study area were selected for geochemical study. Small-boulder-sized (~15 cm diameter) samples were collected and submitted to ALS Chemex Labs, Ltd., for commercial analysis. Analytical methods used were ICPAES for whole-rock major-oxide analysis and ICPMS for trace- and REE-element analysis. Geochemical analyses of selected meta-igneous rocks of the Brevard zone, eastern Blue Ridge, and Inner Piedmont were compared to published geochemical studies of igneous bodies throughout the Alabama Piedmont to explore possible petrogenetic relationships. Materials resulting from this study, including computer diskettes, hand specimens, thin sections, and maps, are archived at the Department of Geology and Geography at Auburn University.

GEOLOGY OF THE SOUTHERN EXPOSURES OF THE BREVARD ZONE IN THE RED HILL QUADRANGLE NEAR MARTIN DAM, ALABAMA

Sterling, J.W., Steltenpohl, M.G., and Cook, R.B.

Abstract

The classically defined Brevard zone is a polyphase, up to 6 km wide, N55ºE trending ductile shear zone that separates the eastern Blue Ridge from the Inner Piedmont terrane. Northeast of Alabama, as far as the Virginia-North Carolina border, rocks of the Brevard zone have been pervasively deformed by late-stage, D_2, Alleghanian, right-slip brittle-plastic shears that have largely obliterated the earlier, D_1 movement history. At Jackson's Gap, Alabama, retrogressive greenschist-facies, D_2 right-slip shears splay out of the Brevard zone and continue straight along their S55ºW trend, some merging with the Alexander City fault zone to the west. Hence, south of Jackson's Gap the Brevard zone lithologies are mostly free of the late-stage D_2 overprint, leaving the earlier D_1 history isolated for structural and petrological analysis. In the vicinity of Martin Dam, the Brevard zone is defined by a major north-to-northeast-trending, right-slip duplex, herein called the Lake Martin duplex. This duplex contains stacked, ~0.5-1 km thick repeating panels of metamorphosed quartzite, conglomerate, chert (?), carbonate-bearing

pelite, and volcanic (?) rock assigned to the Jackson's Gap Group. The panels appear to have been emplaced along late, peak-metamorphic, contractional-right-slip, D_1 shear zones. These panels and the D_1 shears are only weakly stretched along semi-brittle, distributed, D_2 shear zones south of Jackson's Gap. The geometry and kinematics of the Lake Martin duplex is reminiscent of the Hollins Line duplex and the Pine Mountain imbricate zone, which also have comparable absolute timing relationships, similar relatively lower-grade metamorphic conditions of formation with respect to encapsulating terranes, and also contain similar siliciclastic stratigraphic sequences. Rocks of this area, therefore, are significant for gaining a better understanding of the earlier, pre-late-Alleghanian (i.e., early Alleghanian, Acadian , or Taconic (?)) tectonic history and lithostratigraphic framework of the Brevard zone.

Introduction

For over ~600 km, from the Gulf Coastal Plain onlap in Alabama to near the North Carolina-Virginia state line, the Brevard zone roughly represents the boundary between the southern Appalachian Blue Ridge and Piedmont provinces (King, 1955; Hatcher, 1978; Higgins et al., 1988). This boundary is one of the most controversial structures in the Appalachians with as many as 42 different interpretations (Bobyrachick, 1999). Keith (1905) first used the term "Brevard" for a graphitic schist unit near Brevard, North Carolina, which was interpreted to be within a syncline flanked by highly metamorphosed and deformed rocks. Jonas (1932) suggested that the Brevard was a regional thrust zone along which Inner Piedmont rocks were emplaced over rocks of the eastern Blue Ridge. Hatcher (1978) interpreted the Brevard zone to be a reactivated root thrust zone. Studies in the 1980's recognized the importance of late-stage Alleghanian right-slip movement along the Brevard zone that caused southwestward displacement of the Inner Piedmont relative to the Blue Ridge province (Vauchez, 1987).

Although the Brevard zone has been extensively studied and numerous models have been proposed, relatively little research has focused on its structure and lithologies in Alabama. Bentley (1964) regarded the Brevard zone in Alabama as a lithologic discontinuity between the Inner and 'northern' Piedmonts (the northern Piedmont being roughly equivalent to the eastern Blue Ridge) marked by a zone of deformation and shearing (Fig. 1). Bentley and Neathery (1970) described it as a deformational zone bounded by two brittle-plastic faults, the Abanda fault to the north and the Katy Creek fault to the south. The same authors proposed that the Brevard zone wraps around the hinge of the Tallassee synform as a continuation of the Towaliga fault, which marks the southern boundary of the Inner Piedmont. Crawford and Medlin (1974), Muangnoicharoen (1975), and Weilchowsky (1983) all noted that the Brevard in Alabama is a folded fault zone consisting of distinctive lithostratigraphic sequences that have been multiply deformed and cut by brittle-plastic shear zones and faults. Weilchowsky (1983) suggested that the units defining the Brevard zone are framed by a shear zone that flattens with depth. Interpretations of a Consortium of Continental Reflection Profiling (COCORP) seismic-reflection profile in Georgia (Cook et al., 1979) agreed with this model supporting the idea that the Brevard is a thrust soling beneath the Inner Piedmont. Subsequently, Vauchez (1987), Bittner et al. (1987), and Steltenpohl et al. (1990b) documented right-slip movement that is consistent with similar dextral

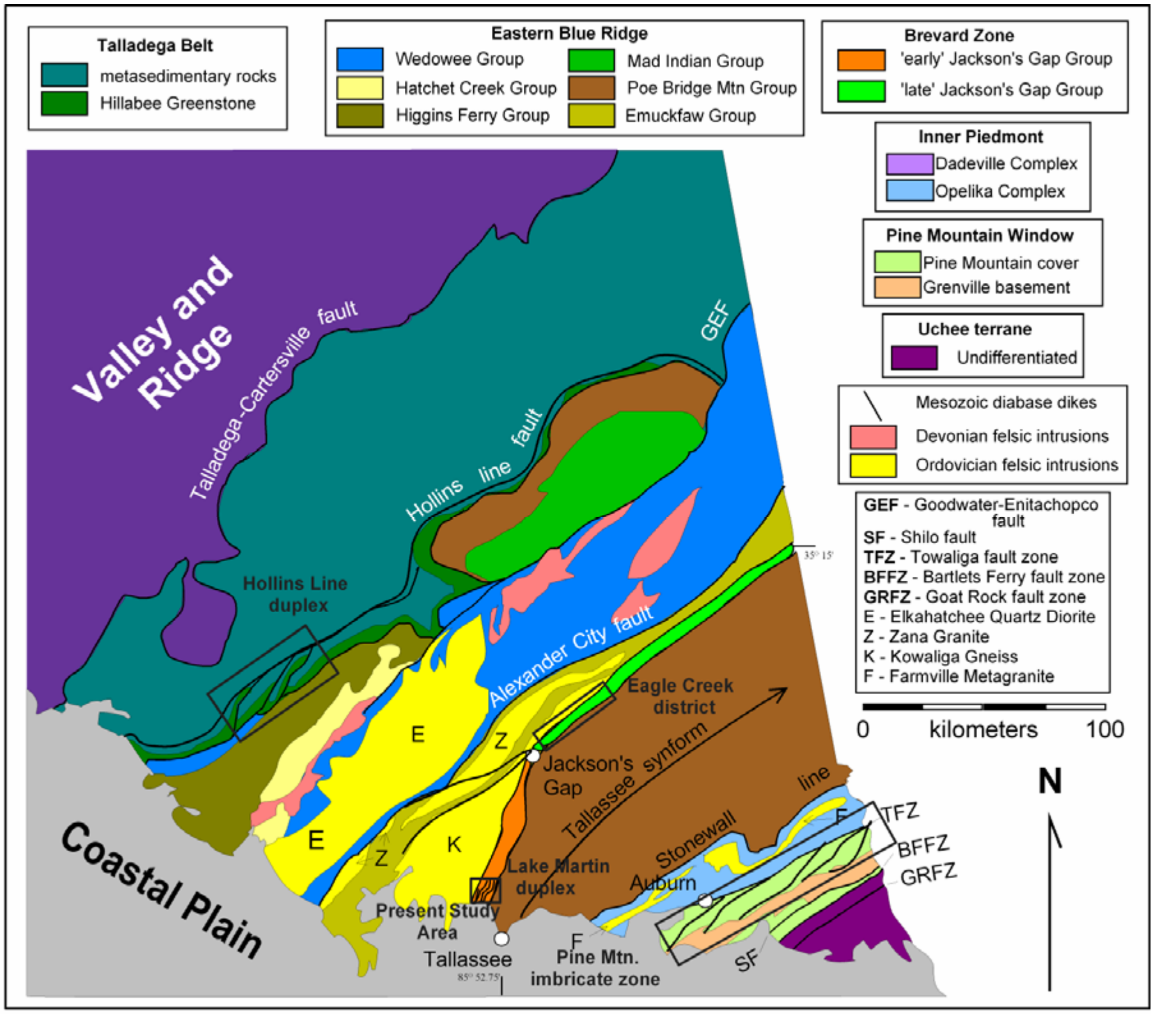

Figure 1. Generalized tectonic map of east-central Alabama. Areas pertinent to this study are outlined in black. Local cities are identified by white dots. Modified after Osborne et al. (1988).

displacement in northeast Georgia and North Carolina (Bobyrachick, 1983; Evans and Mosher, 1986; Vauchez, 1987; Bobyrachick et al., 1988).

We report the discovery of an oblique-right-slip contractional duplex, the Lake Martin duplex, within the southernmost exposures of the Brevard zone near Martin Dam (Figs. 2 and 3). The Lake Martin duplex is an Acadian (?) or Alleghanian (?) duplex formed under mid- to upper-crustal conditions, and is similar in geometry, kinematics, lithology, and relative timing to several other duplexes reported in the Alabama Piedmont. We explore the structure, metamorphic, and lithostratigraphic development of the Lake Martin duplex and speculate on its implications for Southern Appalachian tectonic evolution.

Lithostratigraphy

Dadeville Complex

The structurally highest terrane in the Red Hill quadrangle is a metaplutonic/metavolcanic and metasedimentary complex known as the Dadeville Complex (Fig. 4). The Dadeville Complex comprises various schists, gneisses, and mafic and ultramafic rocks that probably originated as volcanic arc basalt flows and related shallow marine sediments (Bentley and Neathery, 1970; Osborne et al., 1988; Steltenpohl et al., 1990a). Along the west limb of the Tallassee synform, the contact between rocks of the Dadeville Complex and those of the Brevard zone and/or Jackson’s Gap Group is a cataclastic zone known as the Katy Creek fault (Bentley and Neathery, 1970). Over much of its outcrop area, the Dadeville Complex forms the core of the Tallassee synform. The Dadeville Complex is bounded on the southeast by the Stonewall line shear zone,

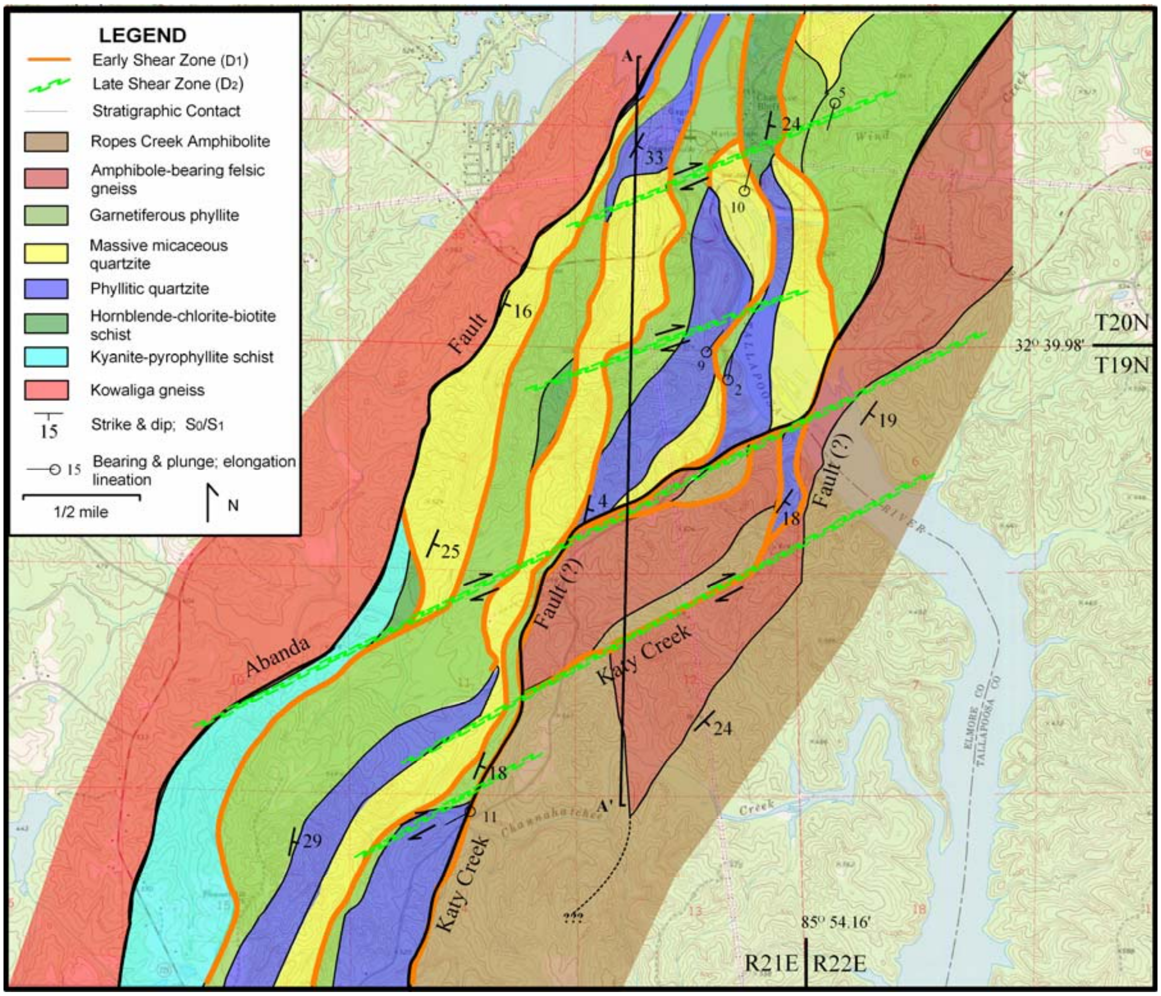

Figure 2. Geologic map of the Lake Martin duplex. Southeast quarter of USGS Red Hill $7^1/_2$' topographic quadrangle (as background). See figure 1 for location.

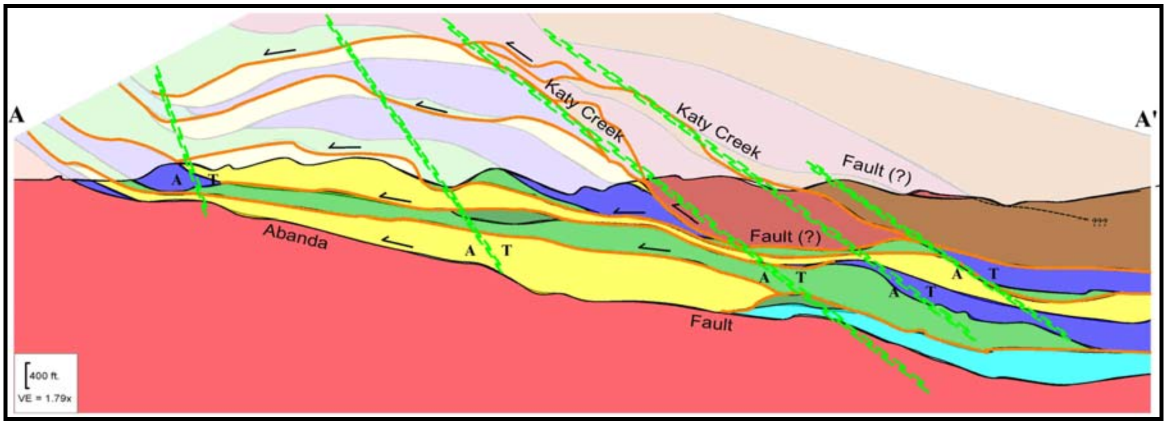

Figure 3. Geologic cross section A-A' of the Lake Martin duplex. See Figure 2 for location and legend.

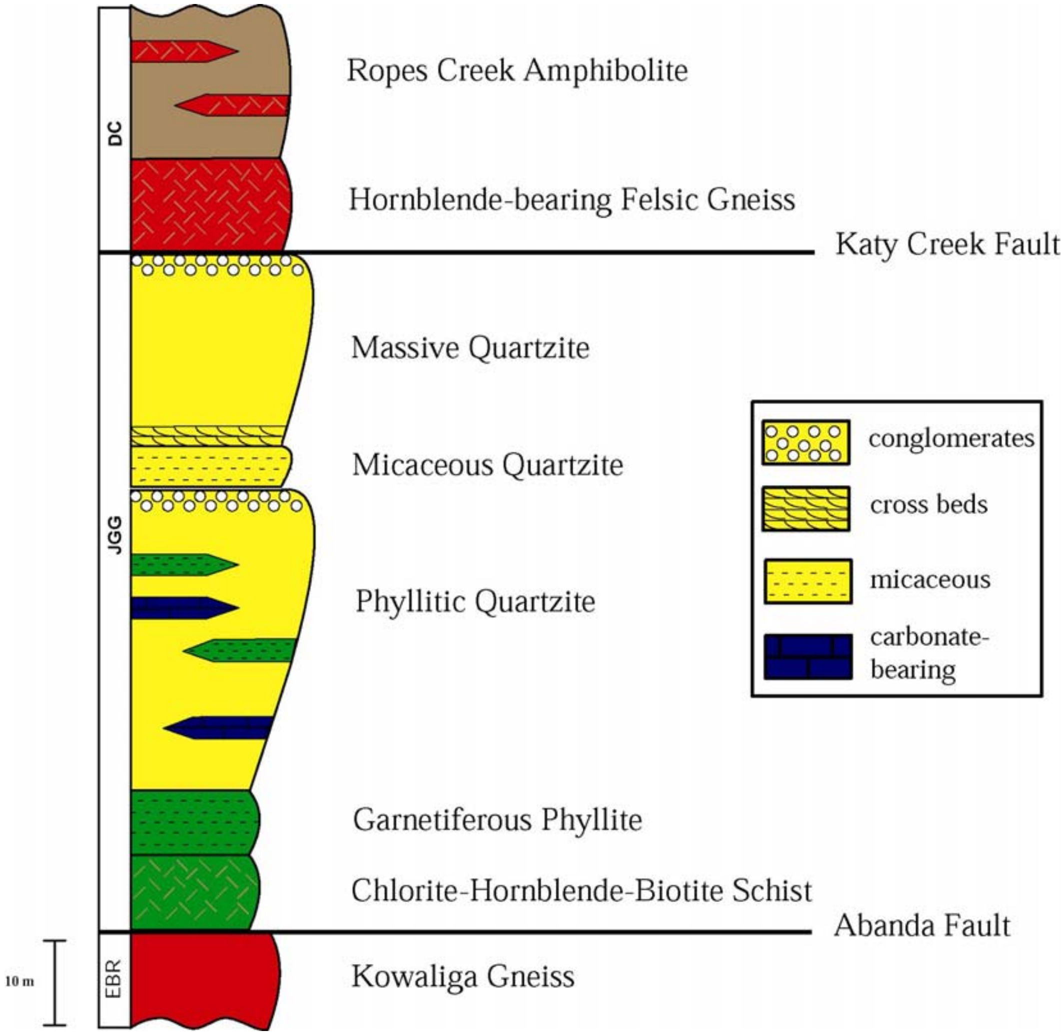

Figure 4. Idealized tectonostratigraphic sequence through the Brevard zone at Martin Dam. EBR = eastern Blue Ridge, JGG = Jackson's Gap Group, DC = Dadeville Complex.

which separates it from the Opelika Complex (Bentley and Neathery, 1970; Osborne et al., 1988, Steltenpohl et al., 1990a). Ropes Creek Amphibolite in the study area is equivalent to that extensively exposed at the type locality along Ropes Creek, Alabama (Bentley and Neathery, 1970). Locally thinly-banded felsic amphibolite and amphibole gneiss possibly correlate with units formerly ascribed to the Waresville Schist (Bentley and Neathery, 1970) but now are considered by most to be simply a phase of the Ropes Creek Amphibolite (Neilson, 1988; Steltenpohl et al., 1990a).

Ropes Creek Amphibolite

Near the base of the Dadeville Complex lies a distinctive metavolcanic sequence called the Ropes Creek Amphibolite (Bentley and Neathery, 1970). The Ropes Creek Amphibolite served as a reliable marker that clearly indicates passage across the Katy Creek fault from rocks of the Jackson’s Gap Group into those of the Inner Piedmont. Approximately 40% of the Dadeville Complex is composed of Ropes Creek Amphibolite (Bentley and Neathery, 1970) and it has been the subject of several petrologic and geochemical studies (Neilson and Stow, 1986; Higgins et al., 1988; Hall, 1991; Cook and Thomson, 1995). The Ropes Creek Amphibolite is a delicately layered to massive amphibolite consisting of 0.5-2 mm thick alternating hornblende- and plagioclase-rich layers, both having accessory apatite, augite, biotite, epidote, garnet, opaques, quartz, and sphene. Local ultramafic and gneissic pods are found within the amphibolite (Raymond et al., 1988), although some of these, particularly in areas dominated by ultramafic units, have been ascribed to an adjacent thrust slice (Higgins et al., 1988).

In the study area, the Ropes Creek Amphibolite is fine- to medium-grained, comprising green-brown pleochroic hornblende, plagioclase, biotite, quartz, and sphene. In outcrop, color ranges from greenish-black to dark-gray and in weathered exposures it is ochre to brown saprolite. Bands of mafic-rich interlaminated amphibolite and felsic-rich (tonalitic) layers occur on scales from less than a decimeter to several meters in thickness.

In thin section, the amphibolite is fine- to medium-grained, equigranular, and granoblastic with well-developed darker bands of hornblende and biotite and lighter bands of quartz and plagioclase forming the gneissic foliation. Primary minerals are quartz, hornblende, plagioclase, biotite, and unidentified opaque minerals. Accessory minerals include epidote, chlorite (having been retrograded from biotite), tremolite, and sphene. Hornblende occurs as medium-sized (1-3 mm) hypidiomorphic, prismatic grains with strong, light- to dark-green pleochroism and is locally altered to chlorite. Hornblende grains display a grain-shape preferred orientation parallel with one another forming the dominant foliation and lineation. Plagioclase ($An_{63,}$ determined by the Michel-Levy method) occurs as fine-grained hypidio- to xenomorphic crystals within a coarser hornblende-rich matrix; plagioclase is the dominant feldspar and locally accounts for over 45% of the volume of the rock. Quartz occurs as interstitial xenomorphic grains between plagioclase grains.

Amphibole-bearing felsic gneiss

Structurally beneath and locally interlayered with the Ropes Creek Amphibolite is amphibole-bearing felsic gneiss. This unit is locally sheared and brecciated and locally marks the position of the Katy Creek fault west of the Tallapoosa River in the study area. In outcrop, amphibole-bearing felsic gneiss is light-tan to light-gray and has sprays of hypidiomorphic medium-grained hornblende porphyroblasts that lie in the plane of the dominant foliation; locally a preferred orientation of these grains produces a distinctive lineation. Where sheared, the hornblende porphyroblasts have been strongly retrograded to biotite and chlorite, and the lithology becomes a chlorite-biotite gneiss. Weathered exposures are light-tan colored and show a distinctive papery parting between foliation planes, particularly where it is sheared.

In thin section, a matrix of very fine- to medium-grained quartz and porphyroblastic plagioclase alternates with medium-grained prismatic crystals of hornblende and platy biotite to form the gneissosity of the rock. The rock comprises plagioclase, quartz, hornblende, biotite, chlorite, epidote, and clinozoisite with minor amounts of muscovite, opaques, tourmaline, garnet, and apatite. Plagioclase (An_{61}) and quartz grains are xenomorphic, have interlobate grain boundaries, deformation twins, and locally are microbrecciated. Retrogression is indicated by biotite and hornblende grains that are altered to randomly-oriented aggregates of chlorite with subordinate quartz, clinozoisite, and epidote occurring as both inclusions and reaction rims.

Jackson's Gap Group

The Jackson's Gap Group is an assemblage of distinctly lower-metamorphic grade siliciclastics, cherts, carbonate-bearing pelites, carbonaceous sediments, and volcanics in the Alabama and Georgia Piedmont. In the study area the Jackson's Gap Group overlies, and is in fault contact with, Kowaliga Gneiss of the eastern Blue Ridge

(Bentley and Neathery, 1970). In the vicinity of Martin Dam, the Jackson's Gap Group occurs as repeating, ~0.5-1 km thick panels within the Lake Martin duplex. Although this sequence within individual panels is disrupted by shear zones, an idealized section appears to comprise, from structurally lowest to highest, chlorite-hornblende-biotite schist, garnetiferous and locally graphitic phyllite/schist, carbonate-bearing phyllitic quartzite, and micaceous to massive and locally pebbly quartzite (Fig. 4). Panels are divided by northeast trending right-slip ductile shear zones and cataclastic zones forming a previously unrecognized duplex structure that emplaces stratigraphically lower units upon higher ones. Truncation and shearing by later-formed, distributed shear zones has disrupted the sequence throughout the study area. The idealized section in figure 4 is inferred from observed contact relationships and localized preservation of direction of younging indicators (i.e., crossbedding). This geometry is constrained by southeast dipping oblique-right-slip thrust faults: the Katy Creek fault, the traditional boundary between the Brevard zone and Dadeville Complex, is the roof thrust and the Abanda fault, the traditional boundary between the Brevard zone and eastern Blue Ridge, is the floor thrust.

Chlorite-Hornblende-Biotite Schist

Chlorite-hornblende-biotite schist is the structurally lowest unit in the Jackson's Gap Group in the Red Hill Quadrangle. Exposure of this unit is limited to the lowest elevations in the study area along stream drainages and gulleys. In outcrop, chlorite-hornblende-biotite schist is grayish- to dark green with sparse, quartz and feldspar stringers (up to 2 cm thick) crossing the dominant foliation.

In thin-section, chlorite-hornblende-biotite schist is inequigranular with fine-grained quartz- and plagioclase-rich layers alternating with medium-grained hornblende-, chlorite-, and biotite-rich layers defining the foliation and hornblende porphyroblasts defining the mineral lineation. Essential minerals include garnet, plagioclase (An_{33}), hornblende, and quartz; accessory minerals include epidote, clinozoisite, opaques, chlorite, and biotite. Hornblende occurs as medium-grained crystals and 0.5 mm long prismatic crystals that show no cleavage. Reaction rims, composed of randomly-oriented chlorite, prismatic clinozoisite, and xenomorphic epidote replace hornblende throughout the rock.

Garnetiferous Phyllite

Contact between the garnetiferous phyllite/schist and chlorite-hornblende-biotite schist was not seen in the study area and is inferred by its location at the base of small ridges formed by the shallow-dipping garnetiferous phyllite. Garnetiferous phyllite is locally quartz-rich and grain-size differences in mica cause it to vary between a schist and phyllite. Narrow graphitic units like those that dominate Brevard zone lithologies north of this area are found throughout the garnetiferous phyllite and locally contain up to 10% garnet. Garnetiferous phyllite structurally and stratigraphically underlies and is interlayered with the phyllitic quartzite and the micaceous quartzite in the study area. Four distinct lithologies found throughout the study area belong to this unit as follows: 1) garnet phyllite that is locally schistose and contains distinctive graphitic layers; 2) chloritoid-sericite-chlorite phyllite/schist; 3) quartz-muscovite schist; and 4) kyanite-pyrophyllite schist. Due to dense vegetation, lack of access, and susceptibility to weathering, exposure of these units varies but generally is sparse and best seen on the shores of Lake Martin and the Tallapoosa River near Martin Dam or directly underlying prominent ridges formed by the phyllitic quartzite and massive micaceous quartzite.

Garnet phyllite ranges from dominantly a phyllite to subordinate schist and is distinguished by 1-3 mm (locally flattened and elongate up to 3 cm), idiomorphic, almandine garnet porphyroblasts that vary in abundance from ~5-15% of the rock. This unit is locally graphitic and its color ranges from dark-olive gray to light- grayish orange where quartz and sericite are relatively abundant. A “button” texture (Higgins, 1971), caused by intersecting S- and C-surfaces, is observed locally and reflects shear strain that progressively increases toward the footwall Abanda fault.

1 In thin section, garnet phyllite has a lepidoblastic texture with very fine-grained aggregates of quartz and micas forming the pervasive foliation. Minerals of the garnetiferous phyllite include biotite, garnet, muscovite, and quartz. Accessory minerals include local graphite, chlorite, unidentified opaque minerals, and epidote. Mica grains are locally kinked and show undulose extinction. Mica and quartz commonly form as pressure shadows around large 1-3 mm poikiloblastic garnet grains, many of which are locally flattened. Quartz occurs as fine-grained, straight-boundaried, equigranular to elongated grains with polygonal 120° triple-point boundaries suggesting annealing recrystallization. Biotite, which is locally retrograded to chlorite and muscovite, and intergrown with graphite occurs in bands that alternate with quartz-rich layers.

Chloritoid-sericite-chlorite phyllite structurally underlies the massive micaceous quartzite and is locally interlayered with garnet phyllite and graphitic phyllite units of the garnetiferous phyllite. Exposures of chloritoid-sericite-chlorite phyllite are sparse and restricted to outcrops along the Tallapoosa River at Martin Dam and along the rural road (Fig. 2) that traces the center of the study area. In outcrop, the chloritoid-sericite-chlorite phyllite is lustrous light-grey to dark-yellowish-green and weathers to light-gray to red saprolite and locally becomes schist where sericite is abundant.

In thin section the chloritoid-sericite-chlorite phyllite has a continuous foliation defined by distinctive, very-fine grained (< 0.10 mm) mica grains, referred hereto within as sericite (Fig. 5). Mineralogy is primarily biotite, muscovite, quartz, chlorite, and chloritoid with minor graphite, garnet, and staurolite. Phyllitic cleavage parallels the alternating sericite/chlorite-rich and quartz-rich layers that define the compositional banding within the rock. Chlorite is the dominant mineral and has grown at the expense of early biotite. Sericite forms the fine-grained matrix of the rock along with quartz. Quartz occurs as both very fine- to fine-grained xenoblastic crystals that have undulose extinction and medium-grained idioblastic crystals with straight polygonal boundaries and triple-point junctions. Medium-grained biotite is found within tabular chlorite grains, and poikiloblastic garnets occur between chlorite-rich and quartz-rich bands. Porphyroblasts of chloritoid (2-4 mm long) commonly display contact twins and are commonly randomly oriented within the rock, serving as a distinctive microscopic identifier for the unit. This unit has been shown to be spatially related to the gold deposits of the Brevard zone as far north as prospects at the north end of the Eagle Creek district (Fig. 1; Cook and Thomson, 1995).

Structurally overlying the massive micaceous quartzite is quartz-muscovite schist. This unit is the structurally highest unit of the various panels recognized in the study area and is separated from the amphibole-bearing felsic gneiss of the Dadeville Complex by

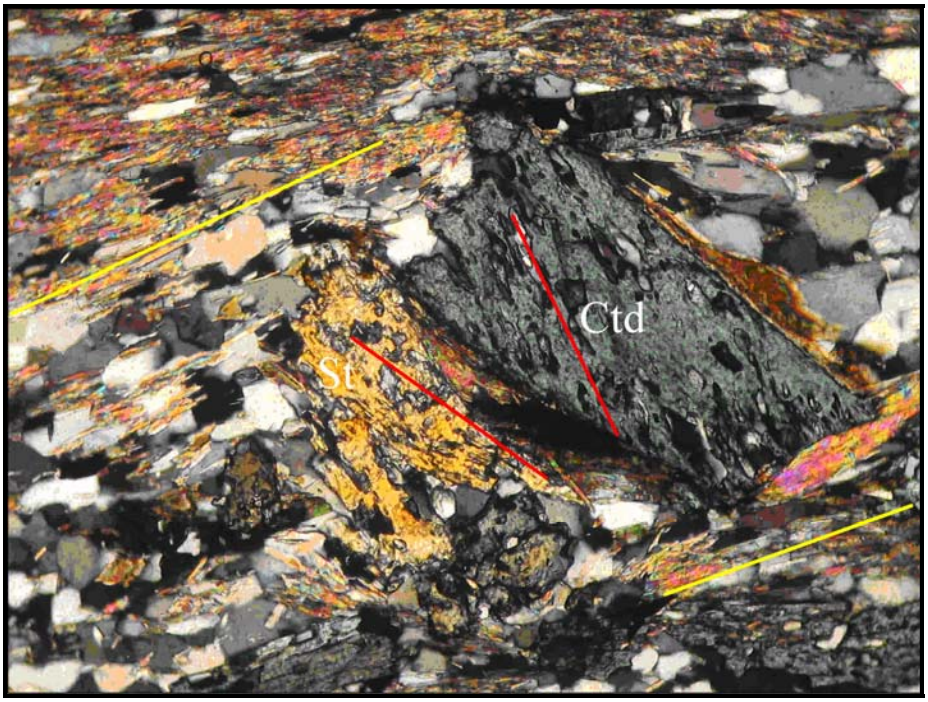

Figure 5. Photomicrograph of chloritoid-sericite-chlorite phyllite. Evidence of dextral-sense shearing include discordant S_e (yellow lines)/S_i (red lines) foliation surfaces within the rotated staurolite (St) poikiloblast as well as mica and quartz formation as pressure shadows. Also note chloritoid (Ctd) grain in contact with staurolite, indicating M_1 upper-greenschist to lower-amphibolite facies metamorphic conditions. Polarized light. Field of view = 2 mm wide.

the Katy Creek fault. Due to dense vegetation and susceptibility to weathering, exposure of this unit is poor and limited to the northeast section of the study area where it serves as a marker unit between the Jackson's Gap Group duplex and the Inner Piedmont. Where exposed, the unit is a light-gray to pale-orange, fine-grained, quartz-rich schist that weathers to a white to light-orange, papery saprolite rich in fine quartz grains. Quartz-muscovite schist has a well-developed foliation, contains varying amounts of quartz and white mica, and locally has abundant quartz lenses parallel with foliation.

In thin section, the quartz-muscovite schist has a granoblastic texture with well-developed alternating muscovite-rich and quartz-rich bands. Primary minerals include quartz, muscovite, and minor biotite. Accessory minerals include tourmaline, epidote, sericite, and garnet. Quartz occurs both as fine- to medium-grained, idioblastic grains with polygonal boundaries displaying triple point junctions suggestive of annealing recrystallization during the earlier amphibolite-facies metamorphic event, and hypidioblastic grains that have undulose extinction indicating greenschist-facies retrogression.

Kyanite-pyrophyllite schist is found in the southwestern part of the study area (Fig. 2) and serves as a distinctive local marker for the boundary between the Jackson's Gap Group and the eastern Blue Ridge in the southern half of the study area where it is separated from the underlying Kowaliga Gneiss by the Abanda fault. High susceptibility to weathering makes exposure of kyanite-pyrophyllite schist very limited; it is found only along fresh road cuts. In outcrop kyanite-pyrophyllite schist has a lustrous light-gray to light-orange color and has very distinctive sprays of idioblastic pyrophyllite. The kyanite-pyrophyllite schist weathers to a light-tan to light-orange saprolite that contains abundant crystals of kyanite, which we interpret to have occurred simultaneously with the pyrophyllite in the unit. Large (1-3 cm long) crystals of kyanite can be found within large (1-7 cm thick) quartz veins that locally cut across the unit. Due to its extreme susceptibility to weathering, no hand sample of kyanite-pyrophyllite schist coherent enough for thin section preparation could be collected.

Phyllitic Quartzite

Structurally overlying and locally interlayered with the garnetiferous phyllite is phyllitic quartzite. Contact with garnetiferous phyllite ranges from sharp to gradational over an interval of 1-5 m and is marked by the appearance of abundant garnet porphyroblasts. Massive micaceous quartzite structurally overlies this unit and contact is sharp, marked by a reduction in grain size, “button” texture, and an increase in schistosity. In outcrop, the phyllitic quartzite is best exposed, in the northern half of the Red Hill quadrangle, along the east and west shores of the Tallapoosa River and along the shores of Lake Martin immediately northwest of Martin Dam and, in the southern half of the Red Hill quadrangle along the shores of Channahatchee Creek (Fig. 2). The unit is fine- to coarse-grained, has phyllitic cleavage defined by sericite, and is locally mylonitic. Color varies from a light tan, where mica is abundant, to a dark gray, where quartz is predominant. The phyllitic quartzite is locally carbonate-bearing and has large (1-3 mm) kyanite and garnet porphyroblasts which were not observed to occur together. Due to the abundant, elongated, and isoclinally folded quartz ribbons, weathering produces a distinctive characteristic appearance (Fig. 6).

Figure 6. Photograph of the phyllitic quartzite unit in the Jackson's Gap Group at Martin Dam showing typical, sheared appearance. Note isolated isoclinal F_1 fold nose in quartz, lower-left center.

In thin section, the phyllitic quartzite displays an inequigranular porphyroblastic texture with a continuous foliation defined by sericitic muscovite. Primary minerals include local sillimanite, kyanite, staurolite, garnet, muscovite, and quartz. Accessory minerals include epidote, clinozoisite, calcite, tourmaline, biotite, and unidentified opaques. Staurolite and kyanite occur together in the phyllitic quartzite and were generally not observed to be present with garnet and biotite. Alternating quartz-rich and mica-rich bands produce a well-defined compositional banding and chlorite occurs as foliation-defining crystals with staurolite and kyanite. Quartz grains typically exhibit chararcteristics that range from interlobate grain boundaries and undulose extinction to triple-point junctions which indicate annealing recrystallization. Muscovite occurs as very-fine to fine grains that are wrapped around larger elongated quartz grains and around kyanite, staurolite, and garnet porphyroblasts as pressure shadows. It locally occurs in mica-rich bands as mica-fish and is locally kinked showing undulose extinction. Chlorite crystals show polysynthetic twinning and occur as very fine grains replacing biotite.

Massive Micaceous Quartzite

Structurally overlying and locally interlayered with both the garnetiferous phyllite and the phyllitic quartzite is a banded micaceous to thickly-bedded massive quartzite that corresponds to the Devil's Backbone Quartzite defined by Bentley and Neathery (1970). It is well developed further to the northeast near the Eagles Creek district (Fig. 1; Osborne et al., 1988; Weilchowsky, 1983; Johnson, 1988). Contact between the garnetiferous phyllite, phyllitic quartzite, and massive micaceous quartzite ranges from sharp to gradational over a narrow interval (5-10 m) and is marked by sheared, flaggy quartzite. Two distinctive lithotypes belong to this unit. One is mica-rich and located near the base of the unit. It grades into the other, a more massive quartzite located near the structural top of the unit, which locally contains pebbles (Fig. 7). The quartzite's occurrence above the garnetiferous phyllite and the coarsening upward of the unit likely reflects original changes in sedimentary facies. The massive micaceous quartzite is the predominant ridge former in the study area and thus is one of the best exposed units. In outcrop, the micaceous quartzite is fine-grained, grayish yellow to light-olive gray. The medium- to coarse-grained massive quartzite varies from white to red upon weathering. Local flattened garnet and magnetite porphyroblasts were observed in the unit. The micaceous quartzite correlates to the Tallassee Metaquartzite found in the hinge of the Tallassee synform (Keefer, 1992; Grimes et al., 1993). Relict cross-beds were observed in the micaceous quartzite along the eastern shore of the Tallapoosa River at Martin Dam and indicate that the unit is stratigraphically up-right (Fig. 8) at that location. Locally, coarsely crystalline quartz veins of varying thicknesses (1-15 cm) were observed cutting the unit.

In thin section, the dominant foliation is defined by parallel alignment of white mica. Primary minerals include quartz and muscovite with garnet, biotite, chlorite, magnetite, epidote, and graphite as accessory minerals. In the micaceous quartzite quartz occurs as very fine grains with irregular boundaries and undulose extinction. In the massive quartzite, quartz comprises over 90% of the rock and has straight, polygonal boundaries indicating annealing recrystallization (Passchier and Trouw, 1998).

Figure 7. Photograph of massive quartzite in the Jackson's Gap Group. Pebbles occur randomly within the quartz matrix though are weakly aligned. The largest pebble is ~3 cm in long dimension.

Figure 8. Photograph of crossbeds in the massive micaceous quartzite on the east shore of the Tallapoosa River at Martin Dam. Note that the crossbeds appear truncated from above (i.e., upright).

Muscovite occurs with minor biotite and graphite as very thin tabular grains that make up to approximately 30 percent of the rock.

Eastern Blue Ridge

The eastern Blue Ridge comprises sedimentary, volcanic, and plutonic rocks that have been regionally metamorphosed to various phyllites, schists, gneisses, and amphibolites (Bentley and Neathery, 1970). The eastern Blue Ridge is separated from the overlying Brevard zone to the southeast by the cataclastic Abanda fault and is bounded on the northwest by the Hollins Line fault (Bentley and Neathery, 1970; Tull, 1978). The single eastern Blue Ridge unit that is reported in this study is the Kowaliga Gneiss.

Kowaliga Gneiss

The Kowaliga Gneiss is a large northeast-trending pluton of coarse-grained quartz-monzonite gneiss (Russell, 1978) in the southeastern part of the eastern Blue Ridge. In the study area, the Kowaliga Gneiss is structurally overlain by the Jackson's Gap Group along a zone of dark, fine-grained cataclastic rock that marks the base of the Abanda fault. The Kowaliga Gneiss can be seen best on the shores of Lake Martin and is poorly exposed otherwise.

In outcrop, the Kowaliga Gneiss is a medium- to coarse-grained, well-foliated, banded gneiss with 2-3 cm potassium feldspar augen set in a finer-grained quartz-feldspar-biotite matrix. The Kowaliga Gneiss is a metamorphosed quartz monzonite, consisting of plagioclase, microcline, quartz, and biotite, with epidote, apatite, zircon, allanite, and sphene as accessory minerals. The gneiss weathers to a grayish-pink to medium-orange saprolite with medium- to coarse-grained fragments of quartz and feldspar. As one approaches the Abanda fault, the Kowaliga Gneiss becomes progressively finer-grained and the mica foliation becomes more intensely developed. The xenomorphic character of the feldspars, as opposed to the idiomorphic character of the feldspars in the main body of the pluton also corresponds to the contact (Bentley and Neathery, 1970).

In thin section, the Kowaliga Gneiss is a granoporphyroblastic rock that locally has a well-developed mylonitic foliation defined by biotite, muscovite, and quartz ribbons draping larger, resistant potassium feldspar and plagioclase porphyroblasts. The mineralogy comprises quartz, orthoclase, plagioclase (An_{25}-An_{40}), biotite, muscovite, epidote, and chlorite with minor amounts of sphene and opaque minerals. Quartz grains are hypidiomorphic, and show strong undulose extinction. Potassium feldspar augen are typically hypidiomorphic with lobate to embayed grain boundaries and have quartz, epidote, biotite, and plagioclase inclusions. Plagioclase porphyroblasts are xenomorphic, highly fractured, show deformation twins, and have been locally saussuritized. Subparallel biotite forms the dominant foliation between and around quartz bands and feldspar augen and have been locally retrograded to chlorite. Muscovite occurs in amounts subordinate to biotite.

Metamorphism

Field evidence and petrographic analysis of rocks in the Jackson’s Gap Group and Dadeville Complex indicate two periods of metamorphism. The earliest recognizable metamorphism (M_1) was a prograde dynamothermal Barrovian-type regional metamorphic event broadly synchronous with the first recognizable deformational event (D_1). M_1 mineral assemblages (orange region, Fig. 9) form the dominant schistosity in rocks throughout the study area. Evidence of syn-M_1 garnet growth, seen as rotated or flattened poikiloblasts, has been recognized in three pelitic rock units of the Jackson's Gap Group. The second metamorphic event (M_2) has retrograded the pre-existing higher grade M_1 assemblages and occurred simultaneously with the second deformational event (D_2). Although M_2 minerals (green region, Fig. 9) can be found throughout the rocks of this area, the intensity of M_2 metamorphism is variable but generally produced volumetrically little recrystallization and neomineralization.

Prograde, M_1, mineral assemblages observed in rocks of the study area are indicative of the lower-greenschist (M_{1a}) to amphibolite facies (M_{1b}) of Barrovian-type regional metamorphism. Pelitic lithologies contain the index minerals biotite, garnet, staurolite, kyanite, and sillimanite as well as local distinctive chloritoid porphyroblasts within prograde assemblages, indicating a "notable" wide range of peak metamorphic conditions ranging from lower staurolite zone to sillimanite zone (Hyndman, 1985; Fig. 9). Prograde assemblages include kyanite + pyrophyllite and chlorite + staurolite + kyanite which are found in rocks of the kyanite-pyrophyllite schist and phyllitic quartzite, respectively. Garnet and biotite were generally not observed to occur in the samples that contained staurolite and kyanite, though chlorite does occur as foliation-defining crystals with staurolite + kyanite. Pyrophyllite decomposes to make an aluminum silicate, quartz, and water at about 425°C for typical, regional metamorphic field gradients. The occurrence of kyanite + pyrophyllite suggests lower-greenschist conditions for the

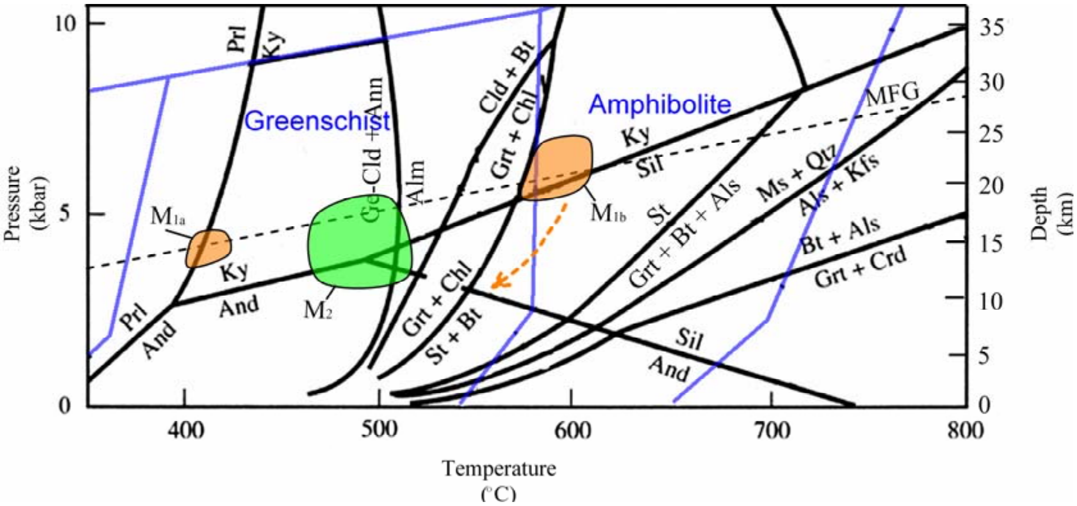

Figure 9. Petrogenetic grid with discontinuous reaction boundary curves and metamorphic conditions of temperature and pressure related to rocks of the study area. Area in orange reflects a lower (M_{1a}) and higher (M_{1b}) peak stable assemblages produced during M_1. Area in green reflects retrogressive stable assemblages produced during M_2. Dashed line indicates likely late-stage M_1 metamorphic pathway after peak conditions were reached. MFG = Moderate metamorphic field gradient. Modified after Blatt and Tracy (1996).

kyanite-pyrophyllite schist. Sillimanite replaces muscovite as fibrolitic needles in a late-generation foliation that clearly developed during the later stages of the deformation event that formed the kyanite and staurolite in the phyllitic quartzite. This occurrence of sillimanite is consistent with late metamorphic decompression and metamorphic pressures that passed from the kyanite to the sillimanite field while temperatures were at a minimum of about 500°C. The occurrence of staurolite + kyanite suggest minimum temperatures and pressures of ca. 575°C and 6 kb (Fig. 9). The assemblages noted are consistent with amphibolite facies peak, M_1, conditions that led to development of chlorite + staurolite + kyanite in very aluminous lithologies that were also rich in magnesium relative to iron. Prograde mineral assemblages found in non-pelitic rock units within the study area, mostly mafic and felsic units of the Dadeville Complex, indicate mostly middle-amphibolite facies pressure-temperature (P-T) conditions. The precise distribution of staurolite, kyanite, and sillimanite zones unfortunately has not yet been resolved.

Retrogressive, M_2, mineral assemblages observed in rocks from both the Dadeville Complex and the Jackson's Gap Group reflect lower- to middle-greenschist facies metamorphic conditions (Blatt and Tracy, 1996). Pelitic rocks, mafic rocks, and biotitic gneisses are pervasively to slightly retrograded with chlorite and/or white mica typically replacing biotite, plagioclase, and/or hornblende. Clinozoisite and epidote are found in some rocks and are related to this retrogression. M_1 minerals including biotite and chloritoid are replaced with chlorite in pelitic rocks and chlorite replaces calcite and quartz in carbonate bearing pelitic units and hornblende in felsic and mafic rocks. These mineral alterations are indicative of chlorite zone conditions and lie within the field of low-grade metamorphism (Winkler, 1979).

Structure

Structures in rocks of the study area reflect early amphibolite-facies and late retrogressive greenschist-facies crystal-plastic deformation and subsequent, local, brittle cataclasis related to formation of the Lake Martin duplex. Three deformational events are recognized on the basis of structural style, geometry, deformational fabrics, parageneses, and their mutual cross-cutting relationships. The area was divided into six subareas for structural analysis (Fig. 10). Subarea boundaries were chosen based on the spatial relationships of known lithologic and structural features. Structural nomenclature used herein is based on the convention that structural phases produced during a deformational event are numbered the same (e.g., F_1 and S_1 formed during D_1; F_2 and S_2 formed during D_2; and so on). Differences in structural development have not been recognized between any of the Jackson’s Gap Group units, implying pre- or synmetamorphic emplacement of the Lake Martin duplex.

D_1 Deformation

The earliest recognizable deformational event, D_1, was a lower- to middle-amphibolite facies ductile deformational event that affected all rocks in the study area. Primary bedding, S_0, rarely preserved in Alabama Piedmont rocks, is locally seen as coarsening upward sequences (over ~15 m intervals), cross beds, and pebbly layers in massive micaceous quartzite and phyllitic quartzite. The principle D_1 fabric, S_1, is a

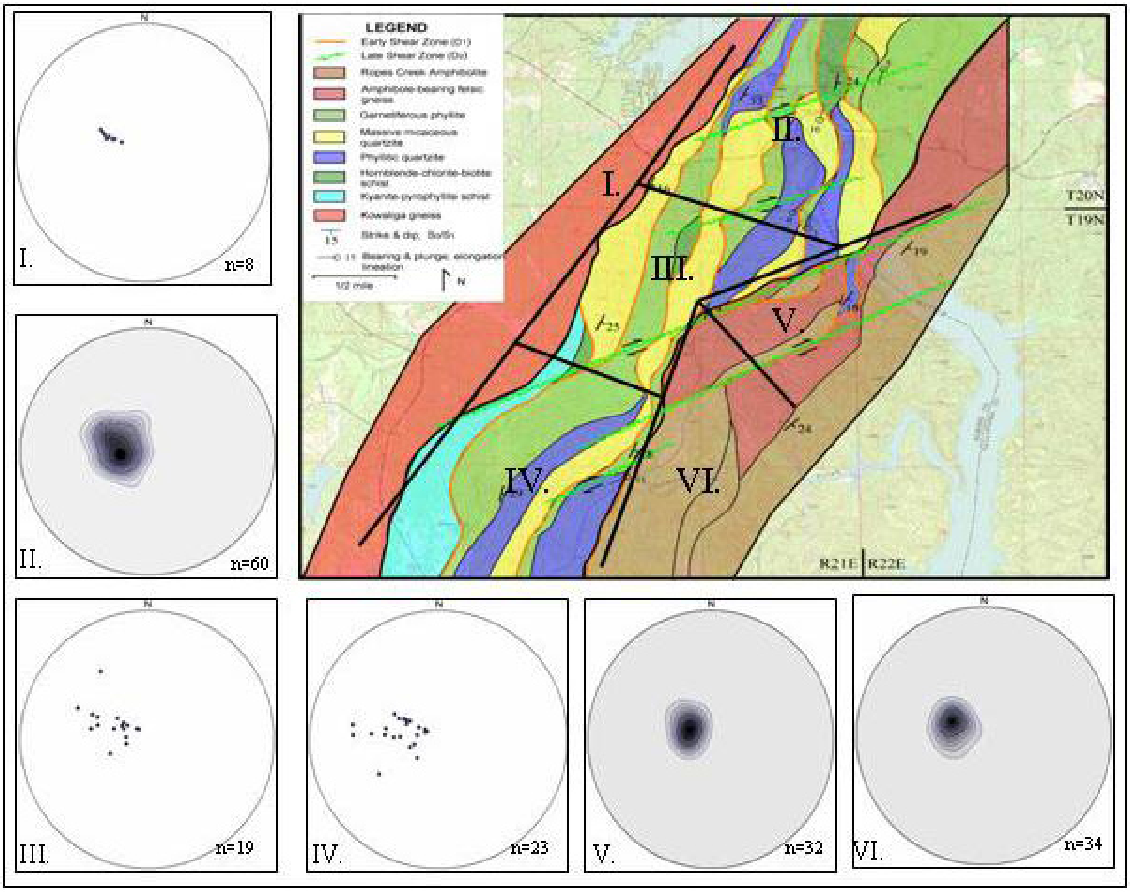

Figure 10. Map of the study area with lower hemisphere stereographic projection of contoured poles to S_1 for each subarea; data is contoured where the number of observations (i.e., n) is greater than 25.

composite S_0/S_1 feature. S_0 was mostly observed to parallel the S_1 foliation except in massive crossbedded rock and in the noses of F_1 folds. The earliest-formed deformational/metamorphic planar fabric recognized in rocks of the study area is defined by inclusion trails in M_1 garnet and staurolite poikiloblasts (Fig. 5), S_i, that are discordant to the external foliation, S_e. Minerals defining S_i are quartz and opaques. These discordant S_i/S_e relationships may indicate that some earlier deformation may have occurred prior to $D_{1.}$ These structures are rare, however, and are interpreted as an early part of D_1.

The dominant schistosity and gneissosity, S_1, and mineral lineation, L_1, are defined by the M_1 mineral assemblages. Macroscopically, S_1 is characterized by northeast striking and east-southeast, shallow-dipping foliation planes with an average orientation of N23ºE, 24ºSE for eastern Blue Ridge, N20ºE, 17ºSE for Jackson's Gap Group, and N25ºE, 14ºSE for Dadeville Complex rocks (Fig.10). The L_1 lineation, defined by hornblende, trends roughly S8ºE and plunges 14º within the plane of S_1. S_0/S_1 is coplanar throughout the eastern Blue Ridge, the Jackson's Gap Group, and the Dadeville Complex.

F_1 folds are tight to isoclinal, synmetamorphic folds of S_0 with S_1 paralleling the axial surfaces. F_1 folds are most commonly observed as ptygmatic folds in phyllitic quartzite. These ptygmatic F_1 folds are interpreted to have developed mainly by flattening strains during M_1/D_1. Idioblastic and flattened M_1 garnets also support predominantly flattening strains. Synkinematic, slightly rotated inclusion trails and continuous S_i/S_e relations also document syn-M_1 shearing.

The occurrence of greenschist-facies assemblages in the kyanite-pyrophyllite schist (kyanite + pyrophyllite) and amphibolite-facies assemblages in the phyllitic quartzite (staurolite + kyanite with overprinting sillimanite) can be interpreted to indicate that some post-metamorphic faulting and juxtaposition of these units occurred in the study area during the later stages of D_1 deformation.

D_2 Deformation

D_2 structures and fabrics are easily distinguished because they deform and retrograde D_1 structures, minerals, and fabrics. These structures and fabrics include a local weak schistosity and/or distinct shear bands (S_2), an elongation lineation (L_2), and a ductile, tight-to-isoclinal phase of folding (F_2). Prograde M_1 mineral assemblages are retrograded to lower-to-middle-greenschist-facies, $M_{2,}$ mineral assemblages along discrete S_2 shear bands and in the axial surfaces of F_2 folds. Garnet, chloritoid, staurolite, and kyanite porphyroblasts commonly are rimmed or completely pseudomorphed by concentrations of M_2 white mica, quartz, biotite, chlorite, epidote, and opaques; locally kyanite porphyroblasts were stretched and boudinaged during D_2.

In macroscopic D_2 shear zones, units of the Jackson's Gap Group and the Dadeville Complex were stretched and/or sheared (Fig. 2). Within D_2 shear zones, $S_{2,}$ extensional shear bands both parallel and crosscut S_1 fabrics at low angles. Units of the Jackson's Gap Group and the Dadeville Complex are thinned and/or truncated throughout the study area, demonstrating a style of distributed D_2 shearing that is recognizable at the scale of the geologic map (1:6,250; Fig. 2). Exposures containing S_2 extensional shear bands are rare, but where found they are relatively narrow (approximately 2-3 meters thick), weakly developed, semi-penetrative distributed ductile shear zones.

In thin section, mica-fish, quartz ribbons, and feldspar porphyroclasts imitate the style of deformation seen at outcrop scale (Figs. 11 and 12). Discontinuous fine- to medium-grained chlorite and white mica define the S_2 foliation and are parallel, or at a low angle to the dominant schistosity, S_1 (Fig. 13). Sense-of-shear and relative transport direction(s) were determined from only a few outcroppings where appropriate structures were exposed. Extensional shear bands, which define the C-surfaces, and the backs of associated phacoids defining the S-surfaces, were plotted on a stereographic projection and sliplines were graphically constrained (Fig. 14).

The slip vector between S- and C-surfaces was qualitatively determined by calculating the acute bisectrix along the great circle between the poles to paired S- and C-surface measurements; the approximate net-slip vector should lie 90 degrees along the great circle from this bisectrix, in the plane of the C-surface. A thin shear zone (~3 m thick) found between micaceous quartzite of the Jackson's Gap Group and units of the eastern Blue Ridge (NW$^1/_4$, NW$^1/_4$, Sec. 36, T20N, R21E) has chlorite growing along a normal-slip crenulation cleavage oriented N37ºE, 55ºSE (C-plane), and the schistosity oriented N14ºW, 07ºNE (S-plane). Sliplines, together with the well-developed S-C composite foliations, document oblique right-and-normal-slip motion along this narrow shear zone (Fig. 14). In thin section, mica is kinked, peeled, microfaulted, or stretched into the S_2 shear bands. L_2 elongation lineations for the entire area are sub-horizontal and clustered about point maxima oriented N10ºE, 8ºNE and S12ºW, 10ºSW.

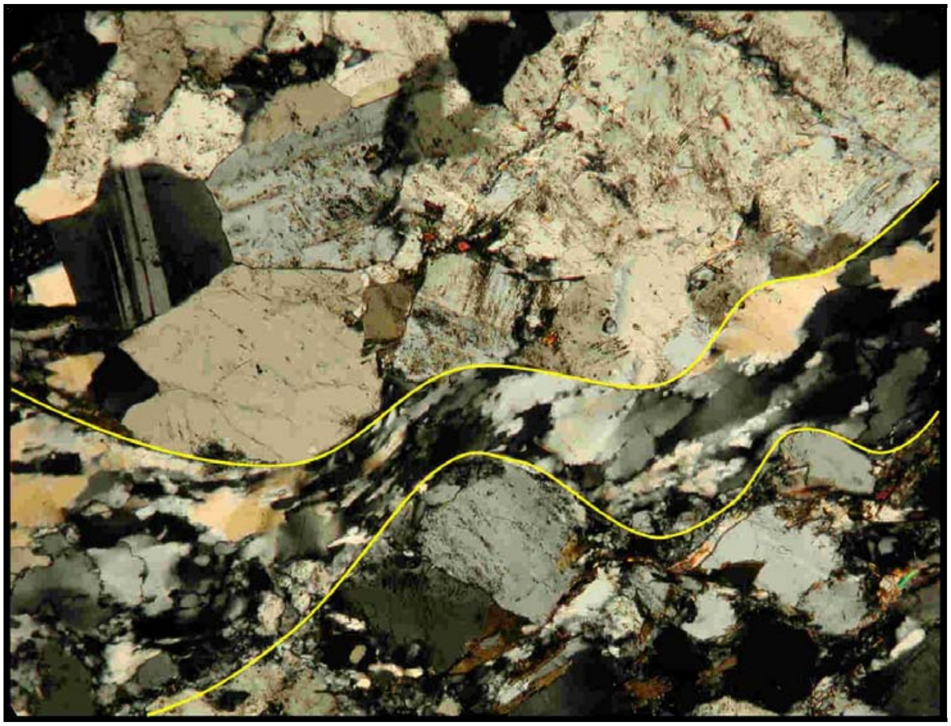

Figure 11. Photomicrograph of elongated quartz ribbon (outlined in yellow) typical of D_2 found in a granitoidal unit of the Brevard zone between Jackson's Gap and the study area (US 280, east of bridge over Tallapoosa River; 32º 52.883'N, 85º 50.938'W).

Figure 12. Photograph of D_2 shear zone in granitoidal unit of the Brevard zone between Jackson's Gap and the study area (US 280, east of bridge over Tallapoosa River; 32º 52.883'N, 85º 50.938'W). Note dextral sense of sigmoidal K-spar megacryst and S_2 shear bands. Note also pinching/thinning of the darker, finer-grained layer.

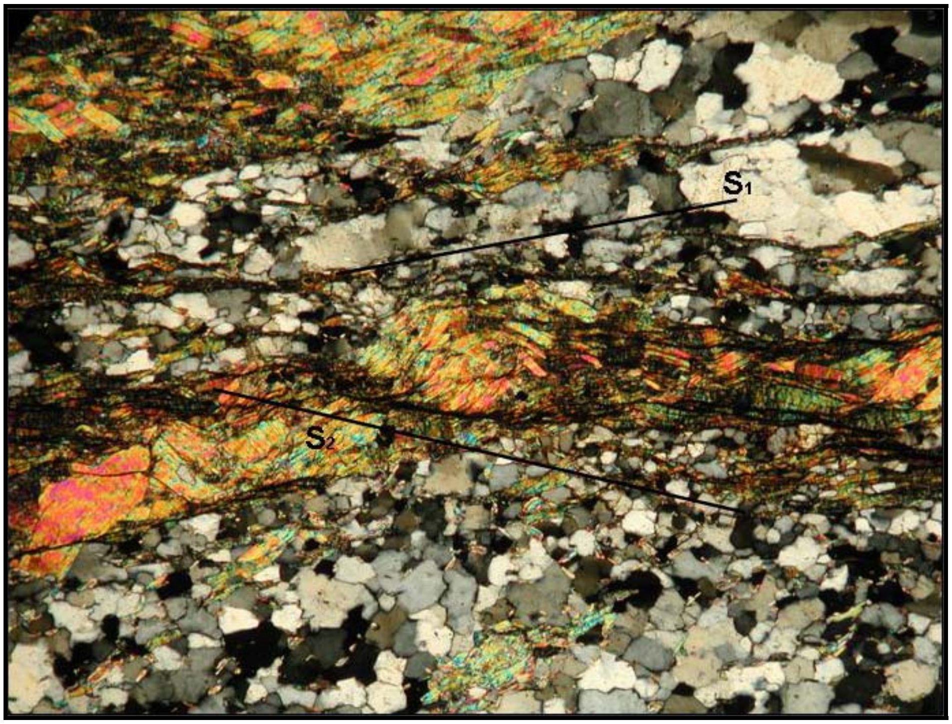

Figure 13. Photomicrograph of mica fish (center of photograph) developed at a low angle to S_1 foliation during D_2 shearing. Sample of phyllitic quartzite from the present study area (32º 40.86’N, 85º 55.05’W).

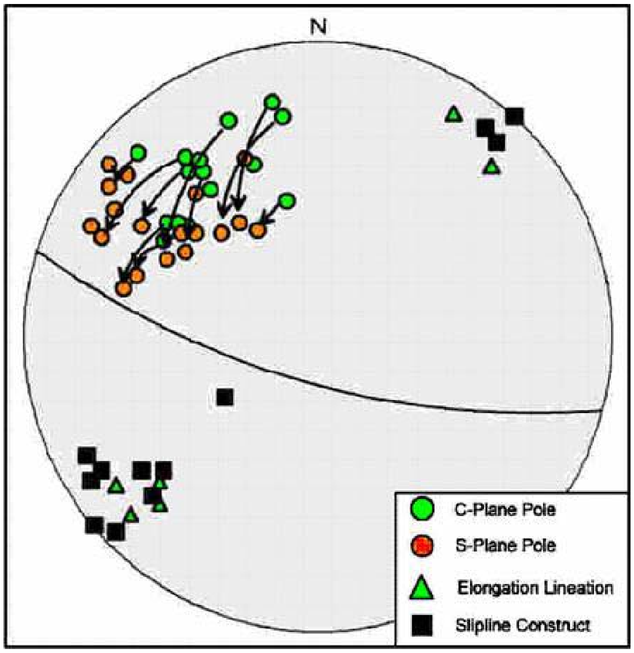

Figure 14. Lower hemisphere stereographic projection of net slip vectors as determined by a 90º rotation from the acute bisectrix of paired C-surfaces and S-surfaces in the direction of slip. Data plotted is for S_2 and L_2 measurements taken at Jackson's Gap and through the Brevard zone along US 280, Alabama.

D_3 Deformation

Late D_3 deformation resulted in brittle-fractures that cross-cut earlier-formed fabrics and structures. Exposures of cataclasite, as described for the Abanda and Katy Creek faults north of the study area (Bentley and Neathery, 1970; Johnson and Cook, 1989; Weilchowsky, 1983), were not seen in rocks south of Martin Dam. However, on the eastern flanks of the Jackson's Gap Group west of the Tallapoosa River (NE$^1/_4$, SW$^1/_4$, Sec. 1, T19N, R21E), several exposures of amphibole-bearing felsic gneiss wereobserved to be cross-cut by 3 cm wide tourmaline and quartz dikes indicating a late fracturing event. Porphyroclasts of plagioclase and quartz in the amphibole-bearing felsic gneiss are angular, shattered, and show a reduction of grain size. Similar structures were seen in thin-sections of Kowaliga Gneiss from west of the Jackson's Gap Group (SW$^1/_4$ SE$^1/_4$, Sec. 35, T20N, R21E).

Lake Martin Duplex

Detailed mapping in the Red Hill Quadrangle documents a previously unrecognized duplex, the Lake Martin duplex, within rocks in the Jackson's Gap Group and the Dadeville Complex (Inner Piedmont). Repeating panels of the north-striking Jackson's Gap Group lithologies are sheared and stretched along distributed northeast-trending right-slip semi-brittle D_2 shear zones. Metatonalite and amphibolite of the hanging wall Dadeville Complex are imbricated together with the Jackson's Gap Group units in the structurally higher levels of the duplex. The duplex is constrained between southeast dipping oblique-right-slip thrust faults; the Katy Creek fault, the traditional boundary between the Jackson's Gap Group and Dadeville Complex is the roof thrust and the Abanda fault is the floor thrust between the Jackson's Gap Group and eastern Blue Ridge. D_2 semibrittle shear zones, oriented N25ºE, 62ºSE (S-surface) and N43ºE, 48ºSE (C-surface), cut across the panels (average orientation of N20ºE, 17ºSE), stretching and locally truncating them (Fig. 2). L_2 elongation lineations in the vicinity of Jackson's Gap, Alabama, show an average orientation bearing N55ºE, and plunging 10º (Fig. 14; Steltenpohl et al., 1990b; Sterling and Steltenpohl, 2003), which is consistent with the average trend of late-shear zones throughout the Brevard zone (Fig. 15). In the present study area, however, L_2 elongation lineations change to an average orientation of N10ºE, 8ºNE and S12ºW, 10ºSW, indicating that subhorizontal shearing also occurred parallel or at a low angle to the panels of the Lake Martin duplex (Fig. 15).

Small scale-structures such as mica-fish, peeled micas, and stretched quartz grains (Fig. 11) mimic the larger-scale duplex geometry in their orientations, kinematics, and styles of pinch and swelled geometries (c.f., Fig. 2 with Figs. 11 and 12). Normal-slip crenulation cleavage (Dennis and Secor, 1987), S_2, are shear bands at low angles to and paralleling S_1 foliation (Fig. 13). S_2, generally associated with N55ºE trending mylonitic and cataclasitic D_2 shear zones that characterize the Brevard zone further north (Bentley and Neathery, 1970; Weilchowsky, 1983; Johnson and Cook, 1989), changes to a more northerly trend in the study area. The D_2 shears make a low angle to or parallel S_1 of the Lake Martin duplex panels, also reflecting the smaller-scale structures seen in thin section.

The map and cross sectional pattern of thick lenses of the massive quartzite suggests that this was the most competent unit controlling the style of duplexing, even though plastic deformation of quartz should be advanced under these greenschist-facies

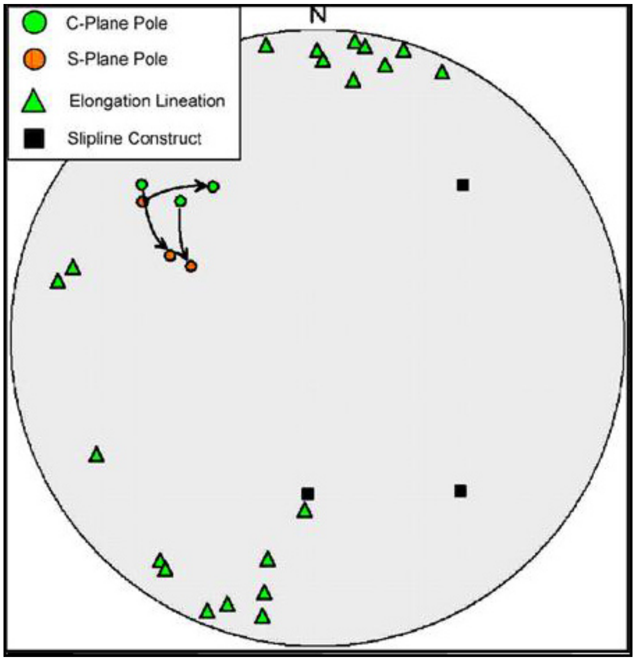

Figure 15. Lower hemisphere stereographic projection of net slip vectors as determined by a 90º rotation from the acute bisectrix of paired C-surfaces and S-surfaces in the direction of slip. Data plotted is for S_2 and L_2 measurements taken in the study area.

conditions (Simpson, 1986; Passchier and Trouw, 1998). The weakest units clearly are the phyllites, which envelope the massive quartzites and appear to have flowed around them. The massive quartzite rarely contains up to 10% mica; some phyllitic quartzite locally contains up to 80% quartz, and it too may form a butressing unit. Thus, there appears to be a direct correlation between plasticity and mica content. During deformation under metamorphic conditions, strain appears to have been concentrated in incompetent mica-rich units due to ductile behavior and fracturing of minerals caused by the release of water (Griggs, 1976; White and Knipe, 1978; Winkler, 1979). This hydrolytic weakening and ductility of quartz, feldspar, and micas controlled deformation through a series of distributed shears zones that aided in the preservation of original structures of the dryer, more competent units while at the same time facilitated production of the duplex geometry.

Discussion

Results of our investigation have important implications for the development of the Brevard zone and as a consequence, its significance for southern Appalachian tectonic evolution. Northeast of Jackson's Gap the Brevard is a polyphase structure with its trademark, linear N55^{o}E strike and moderate southeast dip. At Jackson's Gap, the lithologies defining the Brevard zone, that is, the Jackson's Gap Group, bend sharply south and dip progressively decreases toward the south. Also at Jackson's Gap, distinct, penetrative, right-slip, cataclastic shear zones splay off from the Jackson's Gap Group units, continuing along the Brevard zone structural trend toward S55^{o}W.

Though not yet described, the State geological map (Osborne et al., 1988) depicts these cataclastic splays to continue for more than 35 km to eventually merge with the Alexander City fault zone. Our mapping of the Jackson's Gap Group lithologies south of Jackson's Gap, however, demonstrates only a relatively weak retrograde overprint. Rather than pervasive, penetrative shears, we find only weakly penetrative, distributed right-slip D_2 shears with relatively minor displacements (only several hundreds of meters of estimated displacement) that tend mainly to stretch and thin units. These map-scale, semipenetrative D_2 shears, however, have roughly the same orientation as the penetrative structures to the north (c.f., striking ~N43ºE and dipping 48ºSE as estimated from the geologic map and cross sections) and have, apparently, identical kinematic and microstructural characteristics (right-slip and indicative of mid-to-upper-crustal level deformation, respectively). It, therefore, appears clear that in our study area the retrograde right-slip Alleghanian overprint that so characterizes the Brevard zone elsewhere, gradually diminishes, possibly to disappear before reaching the Coastal Plain onlap. We, for that reason, interpret structures and metamorphic relations preserved in rocks of the study area to reflect, wholly, the earlier tectonometamorphic history of the Brevard zone.

The Lake Martin duplex thus becomes significant in that it reflects the style of deformation and metamorphism that had occurred prior to D_2 right-slip overprinting during the Alleghanian. The Lake Martin duplex (footwall) is an oblique-right-slip-and-thrust duplex that imbricated units of the structurally higher Dadeville Complex (hanging wall) during thrusting of the Inner Piedmont terrane (Hatcher, 1987). Metamorphic grade in some units of the Lake Martin duplex is distinctly lower than that of typical mid-to upper amphibolite-facies rocks of the eastern Blue Ridge and Inner Piedmont terranes, as well as that of the Brevard zone north of Jackson's Gap. Some Jackson's Gap Group units are interpreted to have never experienced higher grade peak-metamorphic conditions than the lower-greenschist to lower-amphibolite facies for the following reasons: 1) no evidence was found to support that chloritoid and staurolite poikiloblasts formed from retrogression of higher-grade mineral assemblages; 2) there are no relict porphyroblasts of alumnosilicate minerals that would indicate a higher metamorphic grade; and 3) in some areas, chloritoid porphyroblasts have been retrograded to chlorite, indicating chloritoid's existence prior to retrogression. Other units do, however, contain higher-grade (middle amphibolite-facies) assemblages or relict porphyroblasts from earlier-formed assemblages. The rather wide range of metamorphic conditions determined for the Jackson's Gap Group rocks is unusual in that they appear compressed within a relatively narrow zone. The exact distribution of metamorphic isograds has not yet been established but we suspect that they parallel S_0/S_1 based on inferential evidence. First, schistosity, S_1, within the Jackson's Gap Group mainly parallels compositional layering, S_0/S_1, and these appear to be coplanar to that observed in the overlying Inner Piedmont and underlying eastern Blue Ridge units. Second, we have not identified any zones of post-metamorphic fabrics or structures between any of the panels. Third, we have noted an intensification of the metamorphic fabric between panels, and some units (e.g., the micaceous quartzite) do preserve evidence for annealed mylonitic microstructures that parallel S_0/S_1. Further studies are underway to evaluate the distribution of metamorphic zones in these rocks.

Exact timing of structural deformation in the Lake Martin duplex is not yet well constrained due to lack of definitive metamorphic mineral age data in rocks of the study area. The late-phase D_2 semi-brittle shears must have formed after ~305 Ma, because they transect the schistosity that contains muscovite that had cooled through closing temperature (~350ºC) at that time (Cook and Thomson, 1995). This time also is consistent with the relatively well established timing for Alleghanian right-slip shearing along the Brevard zone north of Jackson's Gap as well as for many other right-slip shear zones lacing the internal parts of the orogen (see: Vauchez, 1987; Gates, et al., 1988; and Steltenpohl et al., 1992). Timing of early-phase, D_1, right-slip/thrust stacking of the Jackson's Gap Group panels under syn-metamorphic (chloritoid-staurolite zone) conditions is even less constrained. Outside of the study area, early motion along the Brevard is interpreted to have occurred during either the Devonian (i.e., Acadian; Hatcher, 1987) or the Carboniferous (i.e., Alleghanian; Vauchez, 1987).

The Lake Martin duplex appears to be kinematically, geometrically, and temporally similar to two other major duplexes reported in the Alabama Piedmont. Two such contractional right-slip duplexes are the Hollins Line duplex, part of the boundary between the Talledga belt and the eastern Blue Ridge (Moore and Tull, 1989; Fig. 1), and the Pine Mountain imbricate zone, the boundary between the Pine Mountain window and the Inner Piedmont (Steltenpohl, 1988; Fig. 1). Comparison to the Hollins Line duplex is made difficult due to recent arguments about the proper tectonostratigraphic placement of the metavolcanic Hillabee Greenstone, specifically whether it stratigraphically and structurally overlies the Jemison Chert/Chulafinnee Schist of the Talladega Group (Tull, 1979) or if it was tectonically emplaced upon the Talladega Group along a major thrust

(Higgins et al., 1988; Mies, 1992; McClellan et al., 2005). Tull et al. (1993) and Tull (1995) interpreted the Hollins Line duplex as a major transpressional-right-slip duplex that imbricates the footwall units of the stratigraphically uppermost Talladega Group and the Hillabee Greenstone. This Alleghanian duplex has panels ~3 km thick and up to ~15 km along strike and post-dates formation of the metamorphic schistosity that formed sometime between Early Mississippian and ~320 Ma (McClellan et al., 2005). Higgins et al. (1988) and Mies (1992), on the other hand, interpreted the Hollins Line duplex to have imbricated units of the hanging wall (i.e., eastern Blue Ridge), similar to that seen in the Lake Martin duplex. Steltenpohl (1988) reported that the Pine Mountain imbricate zone is a contractional right-slip duplex that formed during the Alleghanian orogeny, circa 287 Ma (Steltenpohl et al., 1992). The Pine Mountain imbricate zone has horses ~3.5 km thick and ~10 km in strike length, and developed after the primary schistosity had formed within the basement-cover units. Northeast shallow-plunging elongation lineations, dextral, northwest-block to the northeast shear sense indicators are akin to that observed in the Lake Martin duplex.

Finally, recognition of the Lake Martin duplex allows for a better understanding of the stratigraphic sequence within the Jackson's Gap Group, hence, strengthening our ability to suggest potential correlations with other southern Appalachian terranes. Our reconstructed, idealized sequence in a Lake Martin duplex panel consists of, from structural bottom to top, chlorite-hornblende-biotite schist, garnetiferous and locally graphitic phyllite/schist, carbonate-bearing phyllitic quartzite, and micaceous to massive and locally pebbly quartzite. This sequence is lithologically similar to parts of the Sandy Springs Group further north in the Brevard zone (Higgins et al., 1988) and also along the southwestern border of the Inner Piedmont near the Georgia-Alabama state line (Higgins et al., 1988). The Sandy Springs Group comprises graphitic phyllite, various schists, and massive to micaceous quartzites (Medlin and Crawford, 1973; Weilchowsky, 1983; Cook and Thomson, 1995). Some have suggested that the Jackson's Gap Group is similar to that found in parts of both the eastern Blue Ridge and the Inner Piedmont. Keefer et al. (1993) and Grimes et al. (1993) noted that the only other packages of rocks in this region that contain similar orthoquartzite packages occur in the Pine Mountain Group and the Opelika Complex. Keefer et al. (1993) interpreted Brevard zone rocks in the hinge of the Tallassee synform (i.e., the Jackson's Gap Group/Tallassee Metaquartzite package) to be too dissimilar in lithology and tectonostratigraphic position to be correlated to the Pine Mountain Group. Keefer (1992) also noted, however, that the Hollis Quartzite is mineralogically similar to the Tallassee Metaquartzite. Grimes and Steltenpohl (1993) suggested correlation of the Jackson's Gap Group to the Loachapoka Formation of the Opelika Complex, a comparison based on overall appearance, mineralogy, and structure of the aluminous schists, orthoquartzites, and gneisses. Unlike the sequence found in the Opelika Complex, the Jackson's Gap Group in the present study area includes a carbonate-bearing unit; it is not uncommon, however, to find sequences in the Brevard zone lacking carbonate-bearing units. The Talladega belt also contains a similar siliciclastic sequence of phyllite, metagraywacke, and quartzite but also includes carbonaceous phyllite, marble, and metachert. The Lay Dam Formation, a sequence of metaturbidites and arkosic conglomerates, generally rests unconformably on top of the Sylacauga Marble group but northeastward along strike it lies above the predominantly clastic Heflin Phyllite that contains minor carbonate (Tull, 1982; 2002). Structurally overlying the Lay Dam Formation is a sequence of metasandstone/metaconglomerate, the Butting Ram Quartzite, and the Hillabee Greenstone. Although no unconformity was documented between the carbonate-bearing phyllitic quartzite and thinly-bedded-to-massive quartzite of the study area, the latter of which is locally interlayered with graphitic and sericitic phyllite, the occurrence of these units stratigraphically above the carbonate-bearing phyllitic quartzite is somewhat reminiscent of the metasedimentary sequence of the Talledega Group. Like the Lake Martin duplex, the Talladega belt also contains lower-grade metamorphic rocks than those in the hangingwall (i.e., chlorite-zone versus kyanite/sillimanite zone) and similarly preserves primary sedimentary structures (Muangnoicharoen, 1975; Tull, 1979; Guthrie and Lesher, 1989).

Conclusions

New discoveries brought about by detailed investigation of rocks and structures in the southernmost exposures of the Brevard zone in Alabama have potentially significant implications for southern Appalachian evolution. The Lake Martin duplex occurs just south of where units of the Brevard zone, the Jackson's Gap Group, diverge from their normal northeast strike to form the west limb of the Tallassee synform. The Lake Martin duplex comprises repeated panels of an unique assemblage of distinctly lower-metamorphic grade siliciclastics, cherts, carbonate-bearing pelites, and volcanics (?) that are separated by earlier-formed (Acadian or early-Alleghanian ?) oblique-right-slip, D_1, thrust zones. Although the timing of duplexing is not well understood, it is known that the duplex is transected by late-Alleghanian nonpenetrative semi-brittle shear zones and, thus, must have formed during earlier, deeper-crustal deformation. Portions of the

Jackson’s Gap Group in the Lake Martin duplex are interpreted to have never experienced higher grade peak-metamorphic conditions than the uppermost-greenschist-to-lower-amphibolite-facies, conditions. Lithologically, the Jackson’s Gap Group may correspond to either units of the Sandy Springs Group (Higgins et al., 1988) found near the Georgia-Alabama border, parts of the Talladega Group (Tull, 1979; Tull et al., 1993) further north in Alabama, or perhaps parts of the Pine Mountain Group (Steltenpohl, 1988;1992) south of the Inner Piedmont. These relationships, along with the geometry, kinematics, and timing of the Lake Martin duplex, are comparable to those reported for the Hollins Line duplex of the Talladega belt and the Pine Mountain imbricate zone.

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PETROLOGY AND GEOCHEMISTRY OF IGNEOUS ROCKS IN THE SOUTHERNMOST BREVARD ZONE OF ALABAMA AND THEIR IMPLICATIONS FOR SOUTHERN APPALACHIAN TECTONIC EVOLUTION

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Abstract

We have discovered a bimodal suite of metamorphosed basalt and tonalite, the Lake Martin Dam metatonalite and Eagle Creek greenstone, respectively, within the Lake Martin duplex of the Brevard fault zone in Alabama. Although meta-igneous rocks are known within the mostly metasedimentary Jackson's Gap Group (JGG) units within the Brevard zone, little is reported on their geochemistry or petrology. Because these igneous rocks are important indications of magmatic and tectonic settings, we investigated their geochemistry. We employ whole rock geochemical, trace-element, and rare-earth-element (REE) analyses to various discrimination plots to initiate characterization of the petrogenesis and tectonic settings of these rocks.

Our geochemical investigations indicate that the Lake Martin Dam metatonalite and Eagle Creek greenstone occur as a relatively unaltered bimodal suite of felsic and mafic volcanic intrusives. Analytical results for major oxide compositions plotted on various discrimination plots indicate that the Lake Martin Dam metatonalite is

subalkaline and is of tonalittic affinity. Chondrite-normalized REE patterns for the Lake Martin Dam metatonalite indicate that it was derived from low- to moderate-pressure partial melting of a basaltic source. Discrimination diagrams indicate that the Eagle Creek greenstone is calc-alkaline basalt that mainly lies within the mid-ocean ridge basalt (MORB) fields. Chondrite-normalized REE patterns for the Eagle Creek greenstone closely resemble those reported from continental rift settings and it overlaps data reported from Neoproterozic Laurentain rift basalts fo the western Blue Ridge of Georgia and North Carolina (Tull et al., 1998a).

Most of the igneous rocks along the floor and roof of the Lake Martin duplex are tectonic slivers from the eastern Blue Ridge (Kowaliga Gneiss) and Inner Piedmont (Ropes Creek Amphibolite and Camp Hill Gneiss, respectively). A comparison of our geochemical analyses to published data from igneous units within surrounding terranes indicates that the Eagle Creek greensone and Lake Martin Dam metatonalite are quite similar to the Hillabee metabasalt and metadacite, respectively, of the Talladega Slate Belt. The Lake Martin Dam metatonalite and Eagle Creek greenstone, however, are clearly part of the JGG and our analysis of their geochemistry implies that they formed, respectively, in a volcanic arc and continental rift tectonic setting. The JGG thus documents a shallow marine continental sequence, intruded by a bimodal suite of igneous rock, that is sandwiched between distal-slope rise Laurentian facies of the eastern Blue Ridge (beneath it) and suspect, oceanic realm (Dadeville Complex, above it).

Introduction

Although recognized in the early 1900's, the origin of the Brevard zone remains a classic problem in Appalachian geology. This major, polyphase, up to 6 km wide, ductile shear zone, which separates the eastern Blue Ridge from the Inner Piedmont terrane, is exposed from near the Virginia/North Carolina border southward to Tallassee, Alabama, where it is buried beneath Mesozoic and younger sedimentary rocks of the Gulf Coastal Plain (Fig. 1). As many as 42 different interpretations, ranging from the Gondwanan-Laurentian suture to a rather simple anticline/syncline fold pair, have been suggested to explain its development (Bobyarchick, 1999). Today, about all that workers agree on is that there has been an early, crystal-plastic, shearing history (D_1) that predated latest Carboniferous (Alleghanian), principally right-slip overprinting (D_2) that imparted its remarkably straight, ~N55ºE trend. Our ongoing mapping in the southernmost exposures of the Brevard zone show that near Jackson's Gap the traditional Jackson's Gap Group stratigraphic package bends sharply to the south, leaving the D_2 Brevard zone fabric domain to pass on uninterrupted into other rocks. Our observations suggest several unique occurrences with significant implications for interpretations of the Brevard zone's tectonic development (Fig. 2). First, as stated above, the D_2 brittle-plastic shears do not bend southward at Jackson's Gap but, rather, continue their straight trend along S55ºW ultimately to merge with the Alexander City fault zone. What is shown on earlier maps as bending due-South are lithologies and associated deeper-crustal-level (kyanite zone), D_1 plastic shears that we interpret to be the "early" D_1 Brevard zone, which here has escaped effects of the late-stage overprint. Second, in this area south of Jackson's Gap, the Brevard zone is defined by an unusual assemblage of relatively lower-metamorphic-grade

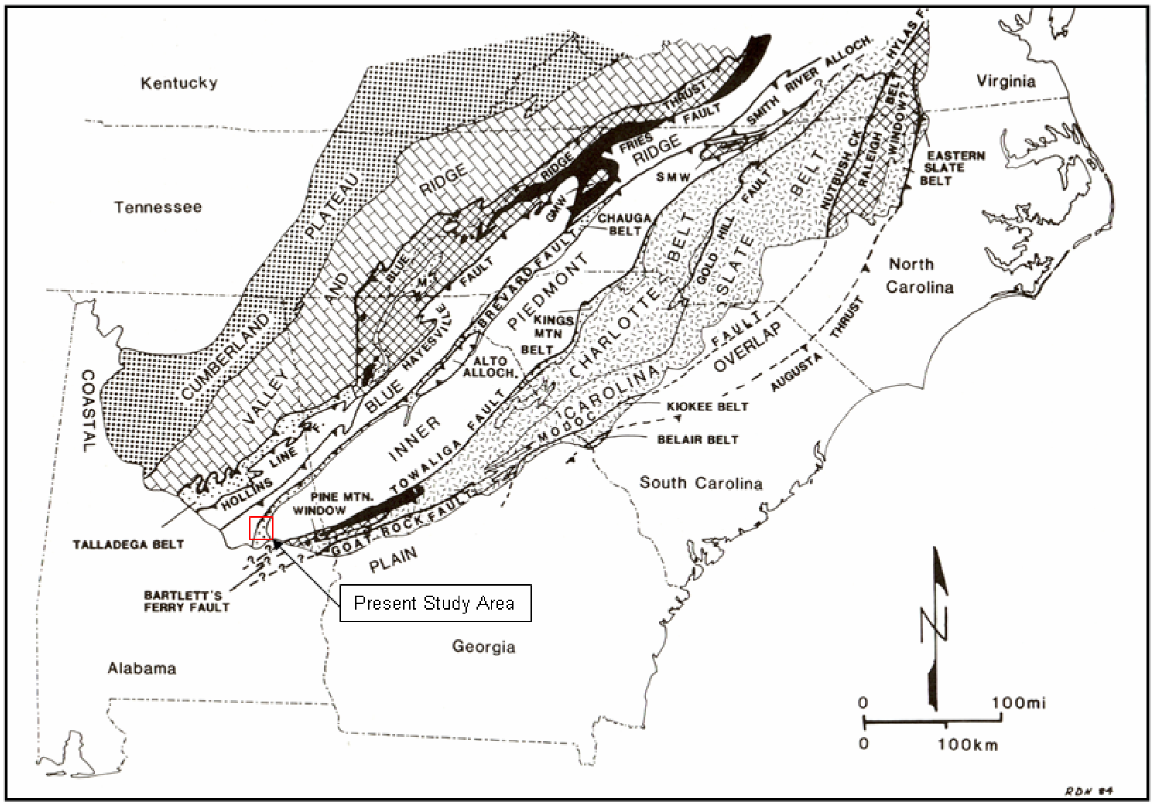

Figure 1. Generalized tectonic map of the southern Appalachians illustrating major tectonostratigraphic subdivisions and fault zones (from Hopson and Hatcher, 1988). Present study area outlined in red.

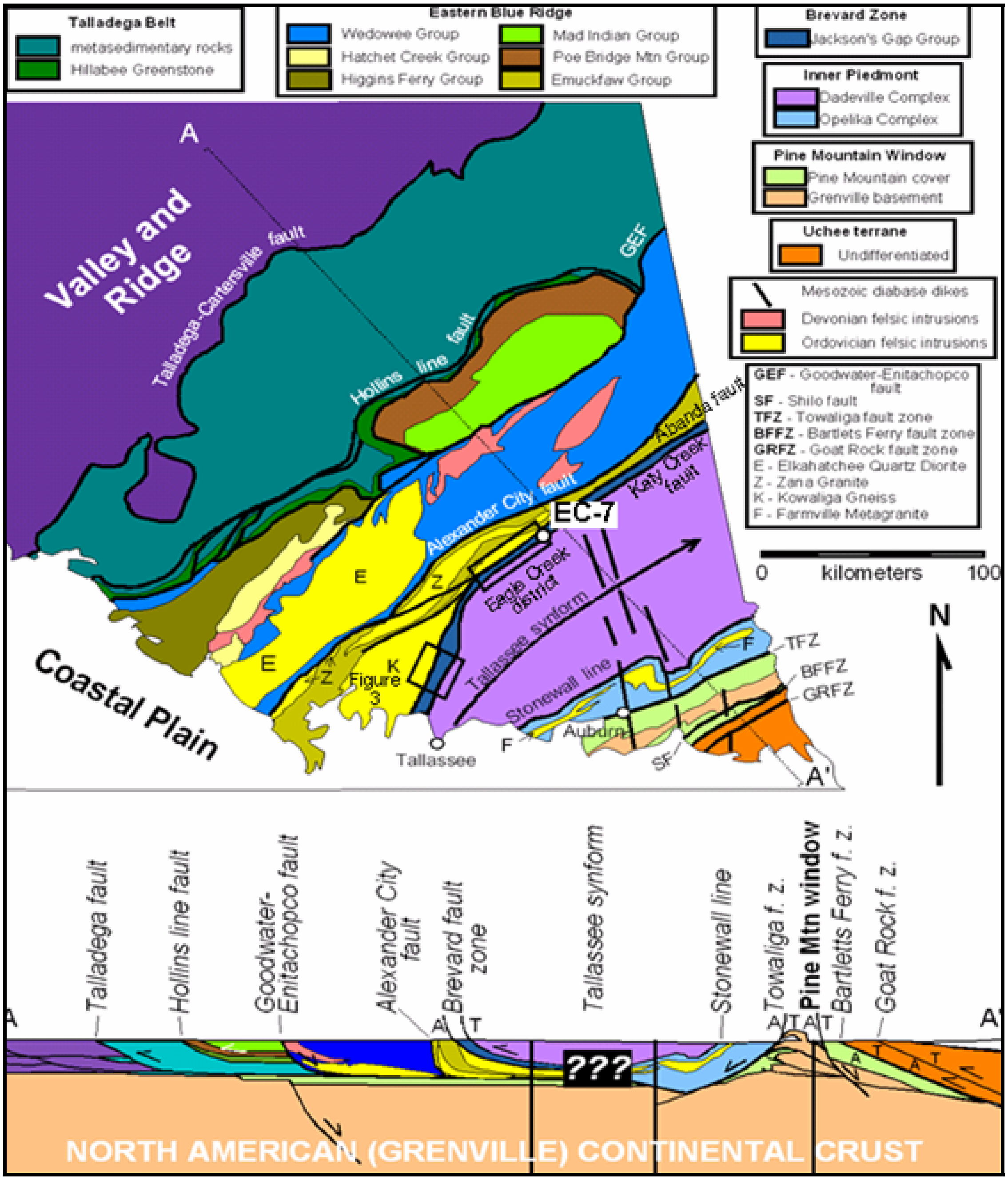

Figure 2. Geologic map of the southernmost Appalachian Piedmont, Alabama (modified after Osborne et al., 1988, and Steltenpohl, 2005). EC-7 is sample location of the Eagle Creek greenstone.

siliciclastics (lower-greenschist to lower-amphibolite facies vs mid- to upper-amphibolite facies; Fig. 2), called the Jackson's Gap Group, which in its northeastern-most extent is sandwiched between a clearly late-stage D_2 fault, the Abanda (west and beneath), and the Katy Creek fault (east and above). Given its structural isolation and our cursory understanding of the geological history, the tectonic affinity of the Jackson's Gap Group remains 'suspect.' Third, partitioning of D_1 and D_2 strains at Jackson's Gap resulted in the Abanda fault splaying westward from the Jackson's Gap Group and the Katy Creek fault dying out toward the south, preserving a major, D_1, right-slip contractional duplex, the Lake Martin duplex (Sterling et. al., 2005). Aside from some minor displacements along a few D_2 plastic shears, rocks within the duplex are devoid of the D_2 overprint and this area preserves the orogen's only location where unmolested Jackson's Gap Group lithologies and their associated D_1 structures and fabrics are available for surface study. Finally, the D_1 structures of the Brevard zone are folded by the regional, F_2, Tallassee synform but its hinge zone lies partially covered beneath Gulf Coastal Plain sediments rendering its trace and, consequently, its relations to adjacent terranes uncertain (Fig. 2).

In this paper we focus on the igneous rocks within the Lake Martin duplex. Although earlier workers certainly recognized metaplutonic and/or metavolcanic rocks associated within the Brevard zone outside of the duplex (Medlin and Crawford, 1973; Higgins et al., 1988; Reed, 1994; Cook and Thomson, 1995; McCullars, 2000) we are not aware of any published attempts to characterize their geochemistry and petrogenetic and tectonic significance. This probably is due to the specific objectives of these earlier works and the fact that primary igneous relations and chemistries have been largely modified by the intense D_1 and D_2 overprint. Our recognition and mapping of the Lake Martin duplex reveals, however, that metaplutonic and/or metavolcanic rocks along the floor and roof faults likely are tectonic slivers derived from the eastern Blue Ridge and Inner Piedmont, respectively. Some meta-igneous rock units, that is, the Lake Martin Dam metatonalite and Eagle Creek greenstone, however, are part and parcel to the Jackson's Gap Group. Other igneous rocks lie between these two styles of occurrence, being exposed in small isolated outcrops or so deeply saprolitized that they are difficult to confidently correlate to other units in the map area. Herein, we report field/structural relations and geochemical analyses of these igneous rocks. Our first objective is to classify them and characterize related petrogenetic 'groups' or 'suites.' Secondly, we explore what their chemistries tell us about the tectonic setting of the magmas/lavas and their Jackson's Gap Group hosts. Finally, we compare our findings with those described for other southern Appalachian terranes to infer where and how the Jackson's Gap Group fits into the tectonostratigraphic framework of the orogen.

Geologic Setting

Crystalline rocks of the southernmost exposed Appalachian Piedmont compose various lithotectonic entities that include, from northwest to southeast, the Talladega slate belt, eastern Blue Ridge, Brevard zone, Inner Piedmont, Pine Mountain, and Uchee terranes (Figs. 1 and 2). Each of these terranes is buried beneath sedimentary rocks of the Gulf Coastal Plain Physiographic Province in east-central Alabama. This report involves geological discussions and comparisons of rocks, particularly the igneous ones, from the first four of these terranes. Starting in the west and working eastward, the Talladega slate belt is the southwestern-most extension of the western Blue Ridge allochthon and extends northward to Cartersville, Georgia (Fig. 1; Hatcher, 1978; Tull, 1978). The Alleghanian-age Talladega-Cartersville thrust forms the northwest boarder juxtaposing these low-metamorphic grade (Chlorite zone) rocks upon sedimentary units of the Appalachian foreland fold and thrust belt (Tull, 1979). A regional footwall thrust system, the Hollins Line duplex, forms the southeast boundary of the Talladega belt, emplacing the amphibolite-facies eastern Blue Ridge allochthon during late Paleozoic (Alleghanian) Pangean collision.

The Talladega belt comprises a Lower Cambrian to Lower Ordovician siliciclastic/carbonate sequence that is unconformably separated from an overlying Silurian - lowest Mississippian siliciclastic/metavolcanic(?) sequence called the Talledega Group (Tull, 1982). The lower part of the Talladega Group contains metaturbidites and meta-olistostromes that are overlain by shallow-water metasandstone, metaconglomerate, metachert, black slate, and siliceous meta-argillite. The Talladega Group is interpreted to have been deposited in an extensional (transtensional?) setting above the foundered lower Paleozoic Laurentian outer shelf, deriving its sediments from both the underlying shelf siliciclastic/carbonate rocks as well as the underlying granitic Grenvillian basement (Tull and Telle, 1989).

Workers debate the proper tectonostratigraphic placement of the metavolcanic Hillabee Greenstone, specifically whether it has a stratigraphic or structural boundary above the youngest units, which contain Early Mississippian plant fossils (Gastaldo et al., 1993), of the Talladega Group (Tull, 1979; McClellan et al., 2005). Tull et al. (1998b) interpreted the basalts of the Hillabee Greenstone to have been deposited as lava flows directly upon the Talladega Group. The Hillabee volcanics are bimodal with 75-85%

metabasalt and 15-25% metadacite, which Tull and Stow (1980) interpreted to indicate a continental back-arc or pull-apart basin, implying west-directed (present-day geographic coordinates) subduction of oceanic crust beneath Laurentia sometime following deposition of the Talladega Group siliciclastics. U-Pb isotopic dates on zircon from the Hillabee dacite, however, yield Middle Ordovician dates for the Hillabee Greenstone (Russell, 1978; McClellan and Miller, 2000; McClellan et al., 2005), making it well older than the Talladega Group. The Hillabee, therefore, may be an exotic arc fragment, possibly part of the eastern Blue Ridge (?), which was accreted onto the Laurentian margin (McClellan et al., 2005).

The eastern Blue Ridge of Alabama is a composite terrane containing probable elements of the Laurentian distal margin (late Precambrian slope-rise sediments) interleaved or sutured with possible accretionary sequences (Hatcher, 1978; Higgins et al., 1988; Drummond et al., 1994). Bentley and Neathery (1970) assigned these rocks to the "Northern Alabama Piedmont" referring to them as the Ashland-Wedowee belt. The eastern Blue Ridge contains at least two significant internal faults. To the northwest, the Goodwater-Enitachopco fault separates the primarily metasedimentary Ashland Group from the overlying amphibolite-facies, phyllitic and schistose graphite-rich metapelites and minor amphibolites and quartzites of the Wedowee Group. The Emuckfaw Formation is separated from the underlying Wedowee Group by the Alexander City fault (Fig. 2), and is bound to the southeast by the Brevard zone (Osborne et al., 1988). The Emuckfaw Formation consists of a lower sequence of metagraywackes and associated schists, and an upper sequence of schists, calc-silicates, and quartzitic rocks that are host to two major granitoid units, the Kowaliga Gneiss and Zana Granite. The Kowaliga is an extensive body of feldspar augen gneiss ranging in composition from quartz monzonite to granodiorite (Russell, 1978). The name Zana Granite was applied to a group of gneisses of several lithologic types ranging from muscovite granite to biotite-bearing granodiorite (Bieler and Deininger, 1987). Muangnoicharoen (1975) and Stoddard (1983) interpreted the Zana Granite as being apophyses off the batholith-size Kowaliga Gneiss (Drummond et al., 1997). The present authors have observed migmatized zones in the Emuckfaw Formation that have ‘pooled’ into larger (meters thick) sill-like bodies that are lithologically identical to the Zana Granite; Bieler and Deininger (1987) described very similar relationships. Russell et al. (1987) report Rb-Sr whole-rock ‘errorchron’ ages for the Kowaliga and Zana within the Silurian and Devonian Periods, respectively, whereas U-Pb zircon (total population) dates for both plutonic phases are ~460 Ma.

The Brevard zone separates the eastern Blue Ridge from the Inner Piedmont (Fig. 1). Classically, the Brevard is mostly known as a polyphase structural ‘zone’ defined by mylonite and cataclasite (e.g., see Bobyarchick, 1999). Early-formed, D_1, mylonites generally have been pervasively overprinted by late-stage, D_2, right-slip brittle-plastic shears that have obscured the earlier, D_1 movement history (Vauchez, 1987; Bobyarchick, 1999). In the Jackson’s Gap, Alabama, area (Fig. 2), however, the Brevard zone also is recognized as a lithologic ‘zone,’ defined by a distinctive package of siliciclastics called the Jackson’s Gap Group. The Jackson’s Gap Group is traditionally considered to be bounded by late-stage, D_2, cataclastic faults, the Abanda fault to the northwest and the Katy Creek fault to the southeast (Bentley and Neathery, 1970; Raymond et al., 1988; Osborne et al., 1988). At Jackson’s Gap retrogressive D_2 shears splay westward out from the presumed structural base of the Jackson’s Gap Group rocks, suggesting that the Abanda fault continues straight along its S55ºW trend to merge with the right-slip Alexander City fault zone to the west (Fig. 2; Osborne et al., 1988; Grimes et al., 1993). In addition, the Katy Creek fault appears to die out directly south of Jackson's Gap (Sterling et al., 2005), leaving the Jackson's Gap Group and its associated D_1 shears free of the intense D_2 overprint. The favorable structural setting in this area has allowed for the discovery of a major right-slip contractional duplex called the Lake Martin duplex (Sterling et al., 2005). This duplex contains panels of relatively low-grade (lower-greenschist facies) siliciclastics that were emplaced along tops-west-right-slip, D_1 shear zones and both are only weakly stretched along semi-brittle, D_2 shears (Figs. 3, 4, and 5). Along the Katy Creek roof thrust, panels of Jackson's Gap Group are structurally interleaved with metavolcanic and metaplutonic units of the basal parts of the overlying Dadeville Complex (Sterling et al., 2005). The Abanda fault is the floor thrust and appears to interleave igneous and metamorphic rocks of the eastern Blue Ridge. We also have discovered two suites of meta-igneous rock that occur internally within units of the Jackson's Gap Group. Amphibolite (metabasalt) exposed in the Eagle Creek gold district (Johnson, 1988: and our Fig. 2), which we call the Eagle Creek greenstone, appears to be interlayered with schists and is interpreted as a flow. A multiphase, sill-like metatonalite at Martin Dam, herein called the Martin Dam metatonalite (sample RH-9 in Fig. 2), has clear intrusive relations with Jackson's Gap Group rocks. The geochemical studies presented below are aimed at characterizing these two igneous suites and to supply data that will aid in distinguishing them from other mafic and felsic rocks that are structurally interleaved with the duplex.

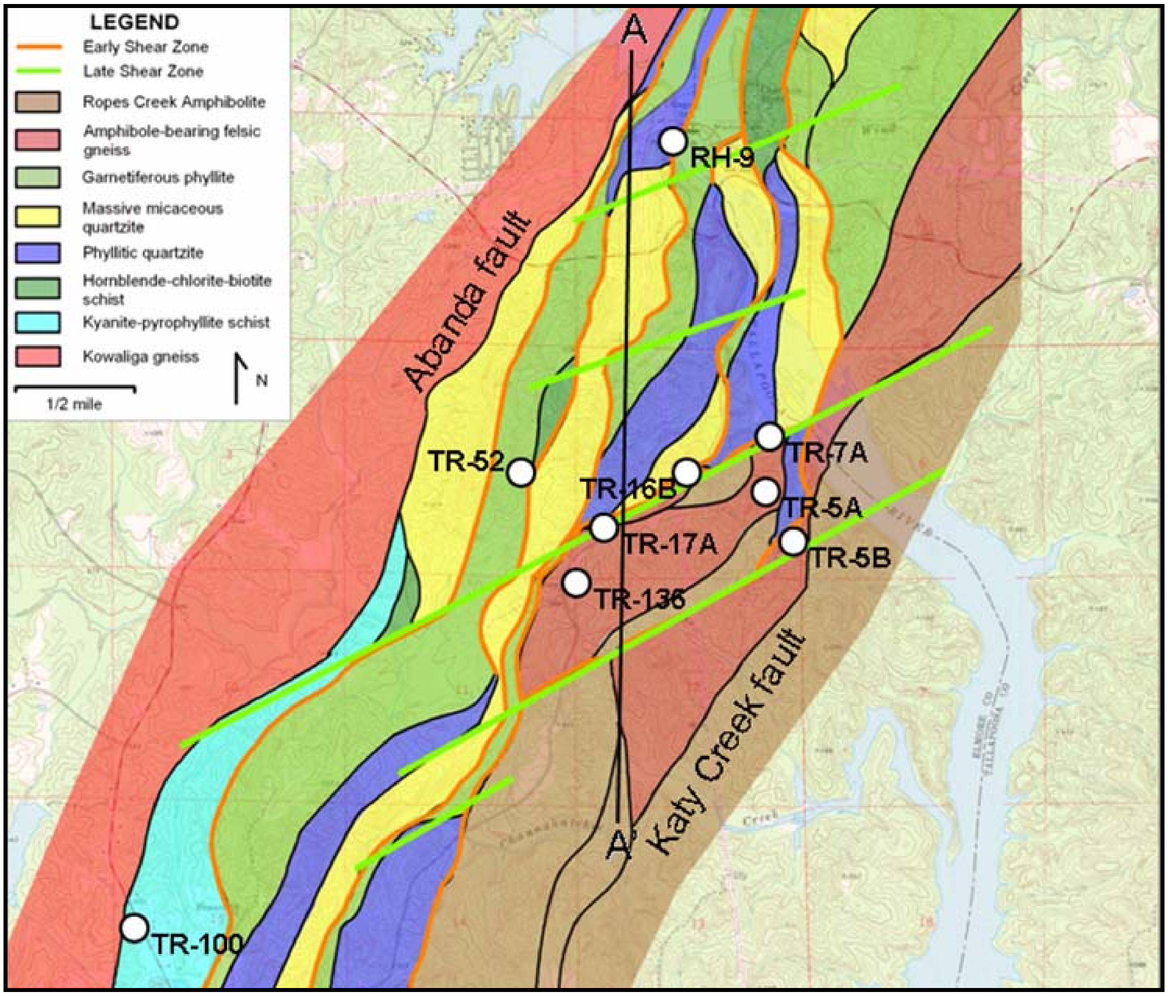

Figure 3. Geologic map of the Lake Martin duplex (Sterling et al., 2005). See Figure 2 for location. Orange lines are D_1 duplexing shear zones. Green lines are weakly developed D_2 shears that overprint the duplex. Locations of geochemical samples are shown.

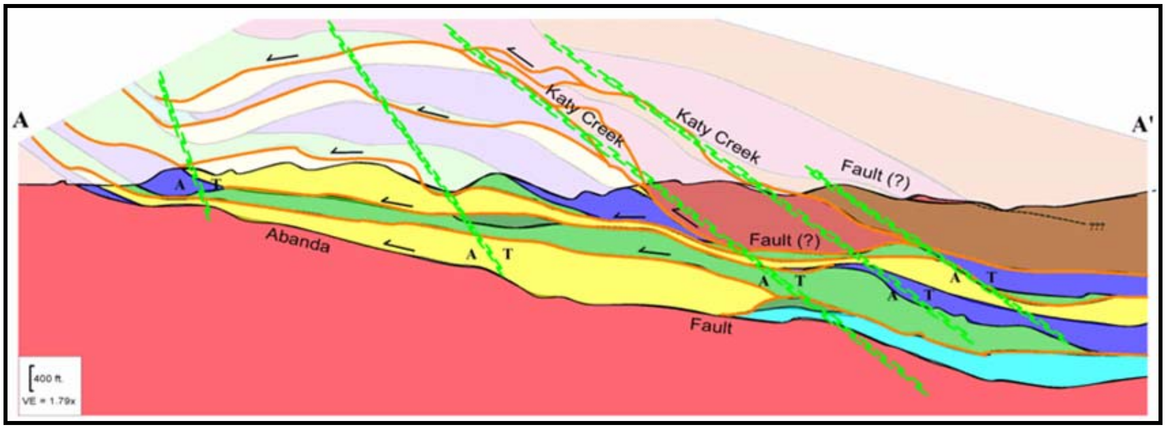

Figure 4. Geologic cross section of the Lake Martin duplex. See figure 3 for location of section line. Legend same as figure 3.

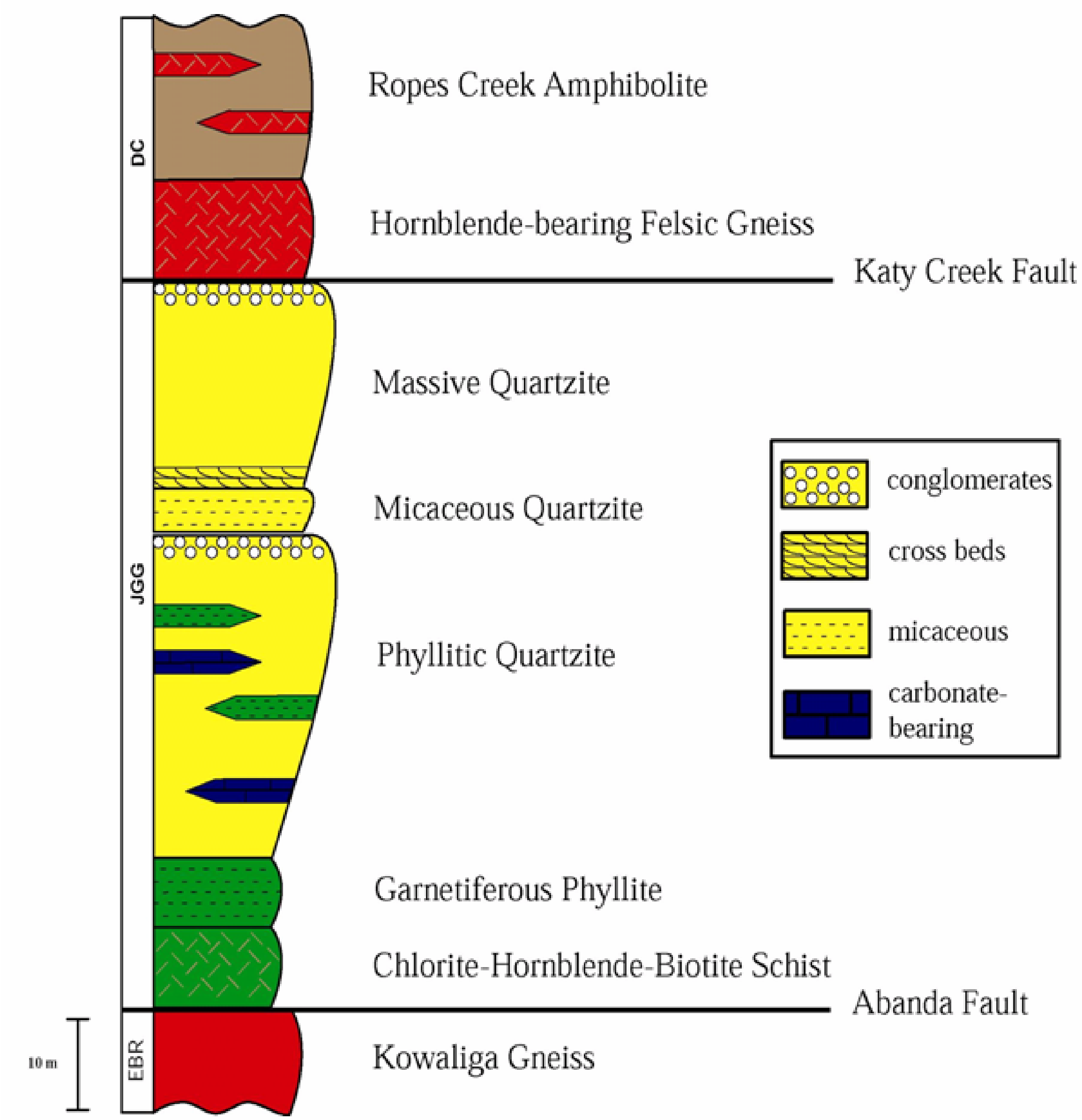

Figure 5. Idealized tectonostratigraphic sequence within a ‘panel’ of Jackson’s Gap Group within the Lake Martin duplex.

The Inner Piedmont is a metaplutonic/metavolcanic and metasedimentary composite terrane that has been variably interpreted as an allochthonous, early- to mid-Paleozoic arc or back-arc complex (Stow et al., 1984; Neilson and Stow, 1986; Steltenpohl et al., 1990), several amalgamated disrupted terranes (Horton et al., 1989), a sequence of stacked nappes (Higgins et al, 1988), and the reworked and thrust-emplaced remnants of the pre-Appalachian rifted margin of Laurentia (Hatcher, 1978). The Inner Piedmont of Alabama and Georgia comprises two lithologically distinct complexes, the Dadeville Complex and the Opelika Complex (Bentley and Neathery, 1970). Along the west limb of the Alleghanian-age Tallassee synform (Fig. 2), the contact between rocks of the Dadeville Complex and the Brevard zone and/or Jackson's Gap Group is marked by Katy Creek fault (Bentley and Neathery, 1970). Along the synform's southern limb, the Dadeville Complex is bounded by the Stonewall line shear zone, which separates it from the underlying Opelika Complex (Bentley and Neathery, 1970; Osborne et al., 1988; Steltenpohl et al., 1990). The Dadeville Complex comprises various schists, gneisses, and mafic and ultramafic rocks that probably originated as volcanic arc basalt flows and related shallow marine sediments and volcaniclastics (Bentley and Neathery, 1970; Stow et al., 1984; Neilson and Bittner, 1990; Steltenpohl et al., 1990). The pre-Middle Ordovician Ropes Creek Amphibolite is the most common unit and has tholeiitic basalt compositions that were probably generated by partial melting of an undepleted mantle beneath a back-arc basin (Stow et al., 1984; Hall and Salpas, 1990; Seal and Kish, 1990). Felsic interlayers within the amphibolite are dacitic to rhyolitic in composition, and are interpreted as either felsic volcanics emplaced in a back-arc basin or metamorphic differentiation of the amphibolite progenitors (Hall and Salpas, 1990).

Other mafic units in the Dadeville Complex include: the Waresville Schist, which occurs in contact with the Brevard zone and may be altered and retrograded Ropes Creek Amphibolite (Stow et al., 1984; Steltenpohl et al., 1990); the Zebulon Formation (Higgins et al., 1988); and the tholeiitic Doss Mountain metanorite/metaorthopyroxenite and calc-alkaline Slaughter's Suite metagabbro, both of which are interpreted to be arc-related intrusives by Stow et al. (1984) and Neilson and Stow (1986). The Dadeville Complex also contains the tonalitic/trondhjemitic Camp Hill Gneiss and the granitic Chattasofka Creek gneiss which are interpreted as late Precambrian to Middle Ordovician calc-alkaline intrusives with geochemical characteristics of volcanic arc "granite" and syn-collisional granite, respectively (Seal and Kish, 1990; Neilson et al., 1997). The timing of these intrusions is tentative; however, the Franklin Gneiss, which may be related to the Camp Hill and Chattasofka Creek gneisses and intrudes the Waresville Schist in the northwest corner of the Dadeville Complex (Seal and Kish, 1990), yields an ~462 Ma Rb-Sr whole rock date (Seal and Kish, 1990), placing a minimum age constraint on the Inner Piedmont rocks.

Bentley and Neathery (1970) first used the term Opelika Complex to describe rocks lying structurally beneath the Dadeville Complex and above (i.e., to the west of) the Towaliga fault, the southeastern boundary of the Inner Piedmont against the Laurentian, Pine Mountain basement (Grenville)-cover massif (Figs. 1 and 2). The Opelika Complex comprises a lower package of metagraywacke schist and gneiss called the Auburn Gneiss (Osborne et al., 1988; Raymond et al., 1988), and an upper package of kyanite-staurolite schist, graphitic schist, quartzite, called the Loachapoka Formation (Sears et al., 1981; i.e., Loachapoka Schist of Bentley and Neathery, 1970 and Osborne et al., 1988). Sears et al. (1981) interpreted these rocks as a transitional sequence from a continental slope into a volcanic apron of an island arc (?). These units are intruded by a predominantly granitic unit called the Farmville Metagranite (Goldberg and Burnell, 1987; Goldberg and Steltenpohl, 1990; Steltenpohl et al., 1990). Goldberg and Burnell (1987) reported a 369±5 Ma Rb-Sr whole-rock isochron age for the Farmville Metagranite to reflect timing of syntectonic emplacement and crystallization. Steltenpohl et al. (2005), however, report a U-Pb zircon date documenting a ~477 Ma igneous crystallization age for the Farmville.

Field Relationships and Petrographic Characteristics of Igneous Rocks within the Lake Martin Duplex

We have identified four different types of occurrences of igneous rocks within the Lake Martin duplex. 1) Tectonic slivers of metabasalt (samples TR-7A and TR-16B; see Figure 3 for locations) and metatonalite (TR-17A) occur along the roof thrust. 2) Tectonic slivers of granite (TR-100) occur along the floor thrust. 3) Distinct, massive metabasalt, the Eagle Creek greenstone (EC-7, Fig. 2), appears to be interlayered with Jackson's Gap Group units. And 4), the Lake Martin Dam metatonalite (RH-9), clearly is intrusive into the Jackson's Gap Group. Field relations of the remaining samples (TR-5A, TR-5b, TR-52, and TR-136) are unclear and part of our rationale for the geochemical study is to explore how they may or may not relate to 1) through 4), above.

We define the type exposure of the Lake Martin Dam metatonalite as that on the west shore of the Tallapoosa River directly beneath the spillway at Martin Dam (RH-9 locality in Fig. 3) where nearly 200 continuous feet of the metatonalite are exposed. The metatonalite is remarkably homogeneous, except for a few dikes of less and more mafic composition (Fig. 6a) and rare and scattered mafic xenoliths, and it is only weakly foliated. It is light-tan to light-gray in color and spotted with dark-green, hypidiomorphic hornblende grains (2 mm in length; see Figure 6b) that lie in the plane of the dominant foliation, S_1, commonly in 'sprays.' Locally, a preferred orientation of these hornblende grains produces a weak lineation. Very fine- to fine-grained quartz and plagioclase form the matrix. We do not observe any apophyses of tonalite within the overlying, sheared, metasedimentary rocks or any fining toward the margins to support an intrusive relationship. However, the presence of dikes (Fig. 6a) and xenoliths support a plutonic origin. Hard, thin layers of graphite-sulfide quartzite along the margins may suggest sheared contact metamorphic rocks. Where sheared, the hornblende porphyroblasts have been strongly retrograded to biotite and chlorite resulting in a chlorite-biotite gneiss. Weathered exposures are light-tan and have a distinctive papery parting between foliation planes, particularly where it is sheared. We interpret the metatonalite to have originated as shallow plutonic bodies that later were sheared into lenses during formation of the Lake Martin duplex.

In thin section, the matrix of the Lake Martin Dam metatonalite comprises very fine- to medium-grained quartz and porphyroclastic plagioclase that alternates with medium-grained prismatic crystals of hornblende and platy biotite to form the gneissosity of the rock. The rock comprises plagioclase, quartz, hornblende, biotite, chlorite, epidote, and clinozoisite with minor amounts of muscovite, opaques, tourmaline, garnet, and apatite. Plagioclase (An_{61}, defined petrographically) and quartz grains are xenomorphic, have interlobate grain boundaries and deformation twins, and locally are

Figure 6. Lake Martin Dam metatonalite. A. Field view of a darker, more mafic dike (trending vertically through center of photo) intruding the massive tonalite at the type locality below Lake Martin Dam. B. Polished slab of the metatonalite; dark mineral is hornblende.

microbrecciated. Retrogression is indicated by biotite and hornblende grains that are altered to randomly-oriented aggregates of chlorite with subordinate associated quartz, clinozoisite, and epidote occurring as both inclusions and reaction rims.

In other parts of the Lake Martin duplex, amphibole-bearing felsic gneiss that closely resembles the Lake Martin Dam metatonalite occurs both as isolated bodies within various metasedimentary rocks of the Jackson's Gap Group and as slivers structurally interleaved with the Ropes Creek Amphibolite along the roof of the Lake Martin duplex (Reed, 1994; McCullars, 2000). These gneisses locally are sheared and brecciated where they mark the position of the Katy Creek fault west of the Tallapoosa River (Fig. 2). In some areas, thick (several hundreds of meters) amphibole-bearing units commonly are strongly foliated, having a 'papery,' schistose appearance, which may indicate that the protolith was an ash flow/fall tuff. Porphyroclasts of amphibole and/or feldspar within these 'papery' schists rarely have idioblastic outlines, compatible with a phenocrystic origin. Cook and Thomson (1995) report similar observations for felsic igneous rocks in the Eagle Creek district (Fig. 2).

The type exposure of the Eagle Creek greenstone is in a ditch alongside a county road in the Eagle Creek gold district (Fig. 2). Here the Eagle Creek greenstone is a massive, equigranular, green-colored metabasalt that lies within schists and layered metaquartzite of the Jackson's Gap Group. This outcrop is very limited in extent but the contacts of the metabasalt clearly are concordant to lithologic layering in encapsulating Jackson's Gap Group units. The contacts are sharp and do not appear to be strongly modified by shearing. Johnson (1988) and Cook and Thomson (1995) report similar exposures of metabasalt in the same and nearby areas. In hand specimen, the Eagle

Creek greenstone is fine- to medium-grained, equigranular, nonfoliated, and olive-green in color. It contains local, small (<1-2 mm) light-colored feldspar and amphibole porphyroblasts and sparse, small (1-3 mm wide) quartz-filled fractures. We interpret the metabasalt as either a flow or a shallowly emplaced sill.

In thin section, the dominant texture is very fine- to fine-grained and equigranular with some alignment of small (<0.25 mm), tabular amphibole grains to produce a faint foliation that is generally not seen in hand sample. Chemical alteration of primary igneous grains has affected the sample so that identification of original texture is uncertain. Relict shapes of igneous pyroxene have been altered to fine-grained pale-green amphibole, olive-green epidote, and quartz and are rimmed with xenomorphic light-greenish-brown hornblende. Relatively large (up to 1mm) fibrous crystals of actinolite and hypidiomorphic hornblende can be found throughout the matrix of smaller aggregates of amphibole and epidote. Accessory minerals include zircon and opaques.

Geochemical Character, Petrogenesis, and Tectonic Setting of Igneous Rocks in the Brevard Zone

Ten samples representing every igneous lithology found in the study area were selected for geochemical study. Small-boulder-sized (~15 cm diameter) samples were collected and submitted to ALS Chemex for commercial analysis. Analytical methods used were ICPAES for whole-rock major-oxide analysis and ICPMS for trace- and REE-element analysis. Table 1 presents 100 major-element analyses for rocks within the study area. On plots involving major oxides, all analyses were recalculated to 100 percent on a volatile-free basis. Our rationale for the geochemical study begins by assuming that the

	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	LOI	Total
EC-7	50.00	1.35	9.24	8.32	14.50	11.25	1.29	0.77	0.13	0.24	1.77	99.10
TR-7A	49.40	0.44	15.75	11.25	9.72	8.60	2.03	0.26	0.21	0.02	1.87	99.60
TR-16B	52.90	1.82	14.30	12.90	7.08	5.61	3.49	0.14	0.29	0.14	1.04	99.80
TR-5A	66.30	0.46	13.95	5.48	3.43	2.02	4.41	0.86	0.11	0.11	2.72	99.90
TR-5B	76.10	0.23	11.75	2.91	0.82	1.04	4.93	0.26	0.02	0.03	1.30	99.40
TR-17A	76.60	0.25	12.90	1.74	0.38	1.08	4.65	0.66	0.01	0.01	1.83	100.0
RH-9	60.60	0.52	18.00	6.63	6.69	2.48	3.48	1.08	0.11	0.09	0.93	100.5
TR-52	57.90	0.67	15.95	8.10	7.71	3.93	3.72	0.46	0.17	0.11	0.76	99.60
TR-100	73.30	0.29	12.85	3.44	1.85	0.99	3.37	2.20	0.07	0.05	1.13	99.70
TR-136	71.30	0.33	13.00	4.36	0.80	1.42	5.04	0.63	0.03	0.02	2.21	99.20

Table 1. ICPAES major-element analyses of igneous rocks of the Lake Martin duplex. Sample locations are identified in Figure 3.

samples from the type localities of the Lake Martin Dam metatonalite (RH-9) and the Eagle Creek greenstone (EC-7) are an integral part of the Jackson's Gap Group and are not derived by structural interleaving, which is indicated by our field observations. These, therefore, provide starting points from which we can compare and contrast the chemistry and petrology of other mafic and felsic rocks that are either derived from outside of the Jackson's Gap Group or have other origins. Finally, a major objective is to compare the chemistry and petrology of the greenstone and metatonalite with various igneous rocks known in adjacent terranes. Our data, therefore, are plotted together with previously reported information.

The Lake Martin Dam metatonalite (RH-9) is subalkaline and plots within the basaltic andesite field in the total-alkali vs silica (TAS) felsic volcanic rock classification diagram (Fig. 7; Le Maitre et al., 1989). The CIPW normative mineral assemblage on an An-Ab-Or granite classification digram indicates Lake Martin Dam metatonalite is of tonalitic composition (Fig. 8; Barker, 1979). On a total-alkali vs total iron oxide vs magnesium oxide (AFM) ternary diagram (Fig. 9), the Lake Martin Dam metatonalite lies midway between the tholeiite and calc-alkaline trend lines with a closer inclination towards calc-alkaline, Cascades lavas compositions (Carmichael, 1964). In FeO/MgO vs SiO_2 space (not shown), however, it plots slightly into the tholeiite field; metamorphic alteration and fluid migration during the formation of the Lake Martin duplex likely account for this outlier. Chondrite-normalized REE patterns for the metatonalite (Fig. 10) have slight REE enrichment, high heavy REE concentrations, and a negative Eu anomaly. This is consistent with the interpretation that the tonalite was derived from low- to moderate-pressure partial melting of a basaltic source leaving behind a plagioclase-rich

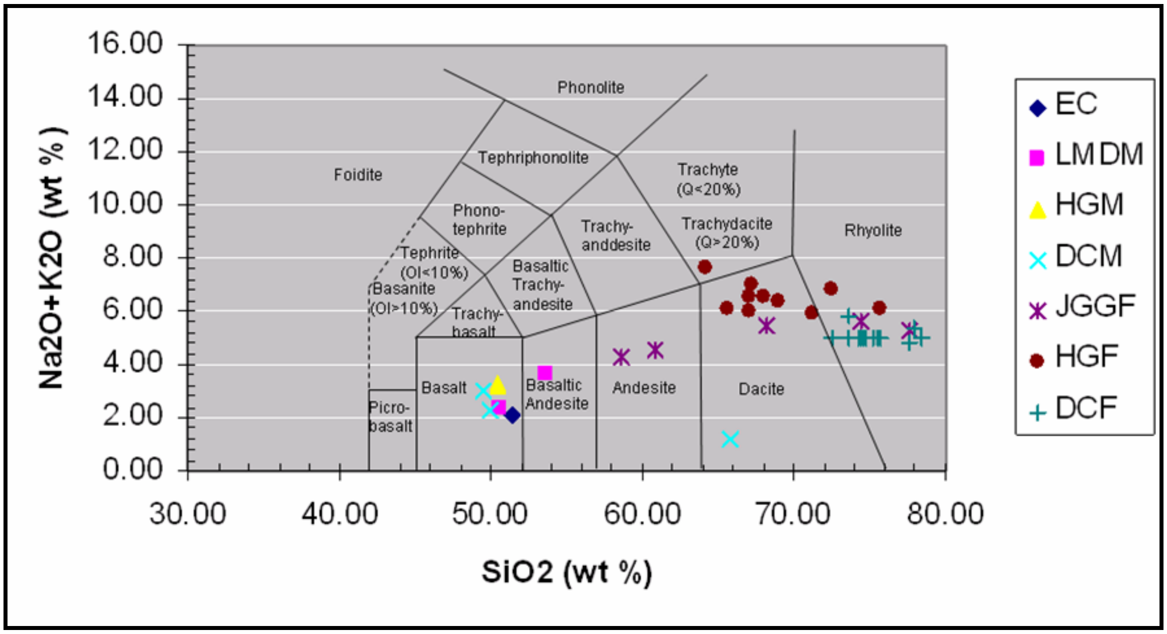

Figure 7. Total alkali versus silica plot (Le Maitre et al., 1989) comparing igneous rocks of the LMD to those of similar reported compositions in other southern Appalachian terranes. EC = Eagle Creek metabasalt, LMDM = LMD metatonalite, JGGF = JGG felsic rock (uncertain), DCM = Dadeville Complex mafic rock, DCF = Dadeville Complex felsic rock, HGM = Hillabee Greenstone mafic rock, HGF = Hillabee Greenstone felsic rock.

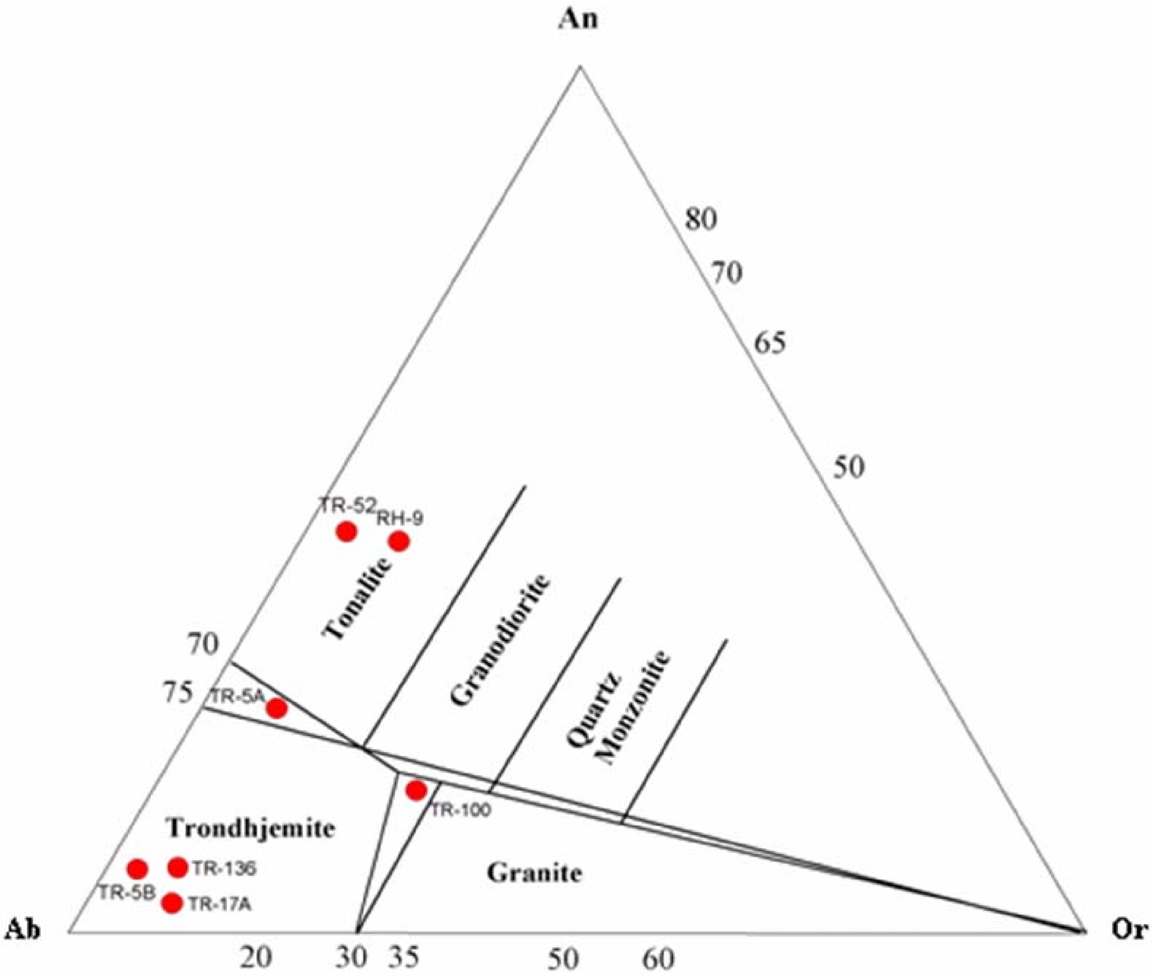

Figure 8. CIPW normative mineral compositions (Barker, 1979) of felsic rocks of the Lake Martin duplex.

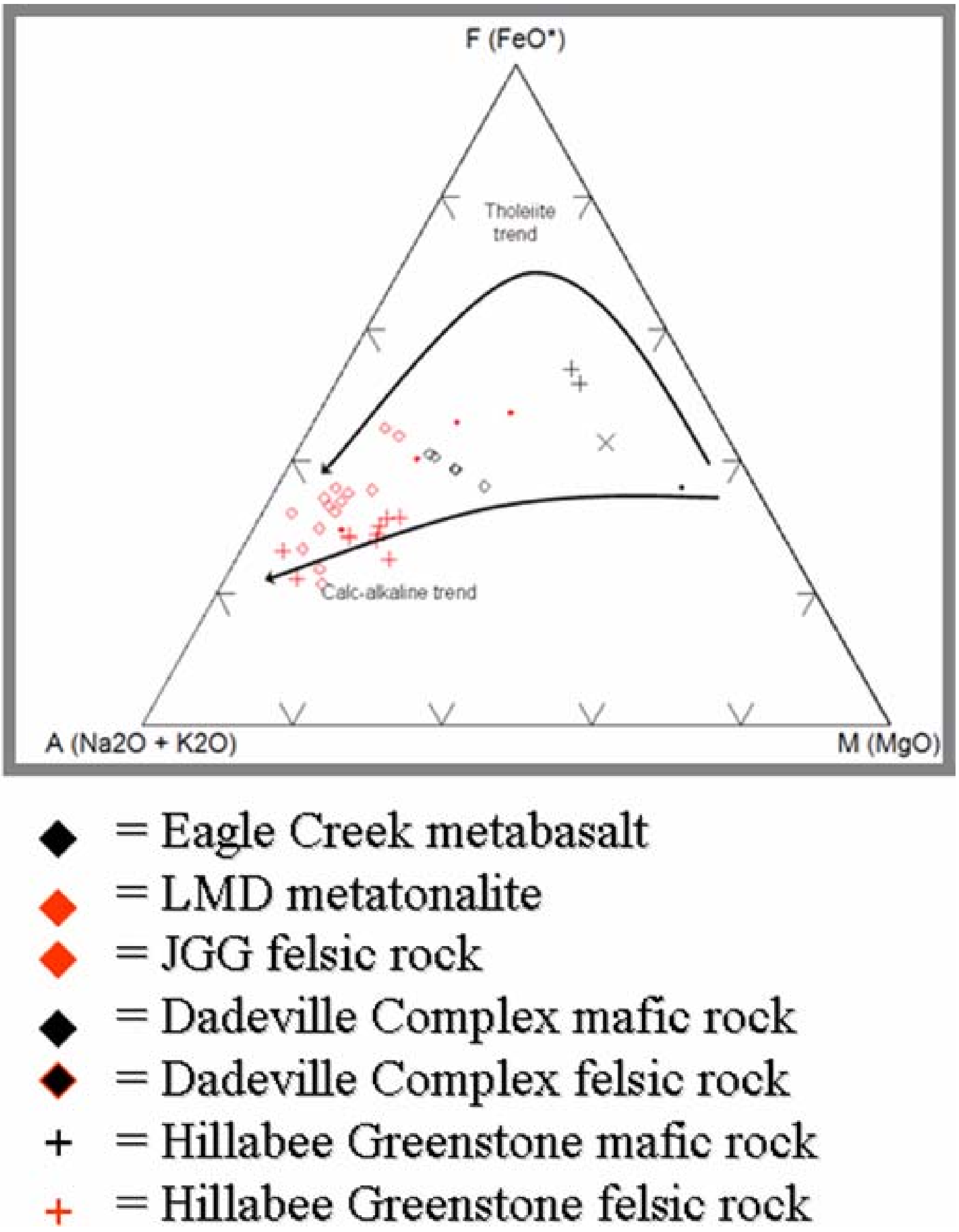

Figure 9. A-F-M plot of felsic rocks of the Lake Martin duplex. Tholeiitic and calc-alkaline trends from Kuno (1968, upper) and Carmicheal (1964, lower), respectively.

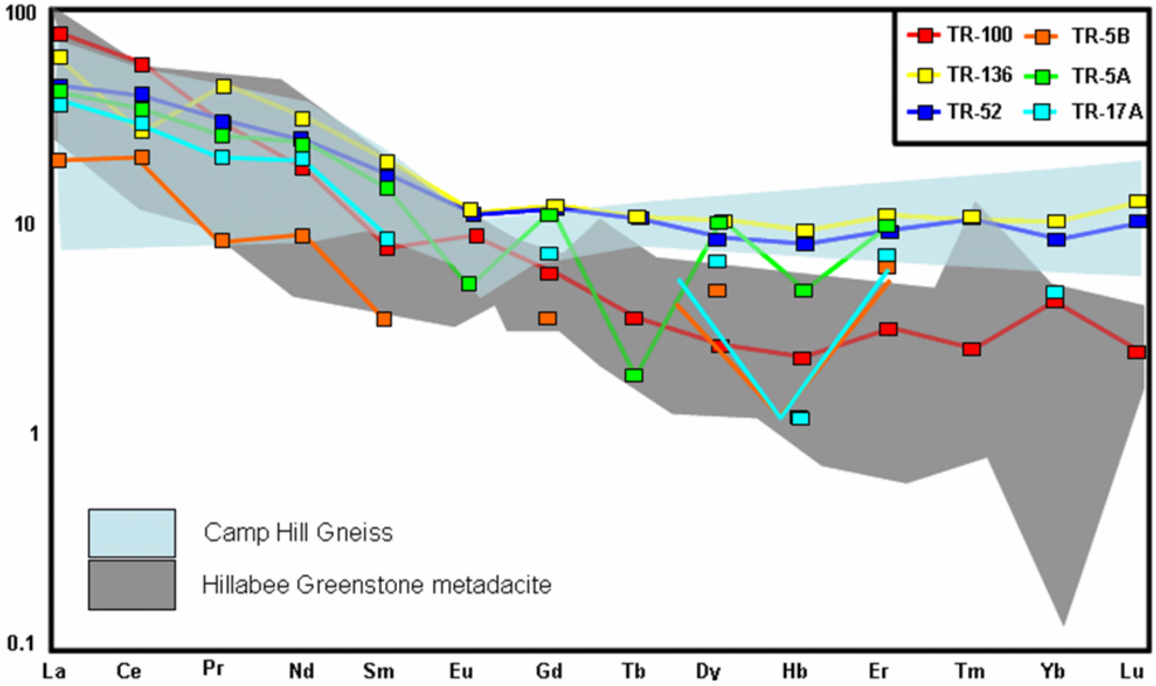

Figure 10. Chondrite-normalized REE patterns (Masuda, 1962; Coryell et al., 1963) for igneous rocks of the Lake Martin Dam duplex. Metatonalite samples with one Kowaliga Gneiss (TR-100); comparative fields are those reported by Drummond et al. (1997) for Camp Hill Gneiss, and Tull et al. (1998a) for Hillabee Greenstone metadacite.

residuum (Beard and Lofgren, 1991; Rapp et al., 1991; Rushmer et al., 1994; Drummond et al., 1997). The field relations, chemistry, and mineralogy of the Lake Martin Dam metatonalite, thus, imply that it originated as a relatively shallow intrusion within a volcanic arc.

The Eagle Creek greenstone plots as basalt on the TAS diagram (Fig. 7). Perhaps due to its rather high MgO content, the greenstone is closer to the calc-alkaline trend on an AFM plot (Fig. 9). On various discrimination plots the Eagle Creek greenstone is plotted mainly as MORB (e.g.: MgO-FeO-Al_2O_3; Al_2O_3/TiO_2 vs TiO_2; CaO/TiO_2 vs TiO_2), falling along the MORB/ocean-island alkali basalt field boundary on MnO*10-TiO_2-P_2O_5*10. It is plotted as a continental basalt on a TiO_2-K2O-P_2O_5 diagram. The high MgO content resembles boninite but it lacks other boninitic signatures (e.g., high Ni, Cr, Co, low TiO_2, and intermediate [andesitic] SiO_2 contents [>53wt%]; Piercey et al., 2001; Fig. 11). The high MgO content makes it plot both as BABB and "island arc" basalts when MgO is compared to TiO_2 and Na_2O, respectively. Chondrite-normalized REE patterns for the greenstone (Fig. 12) have strong LREE enrichments that gradually decrease toward slight and flattening HREE enrichment, with no Eu anomaly. This REE pattern is remarkably similar to those reported from continental rift settings and it overlaps data reported from Neoproterozoic Laurentian rift basalts of the western Blue Ridge of Georgia and North Carolina (Tull et al., 1998a).

When plotted on various discriminant diagrams (not shown) together with other felsic igneous rocks of the Lake Martin duplex, the Lake Martin metatonalite either falls within the same clusters or along trend lines, suggesting that they probably relate to the same types of petrogenesis and tectonic settings, consistent with field observations

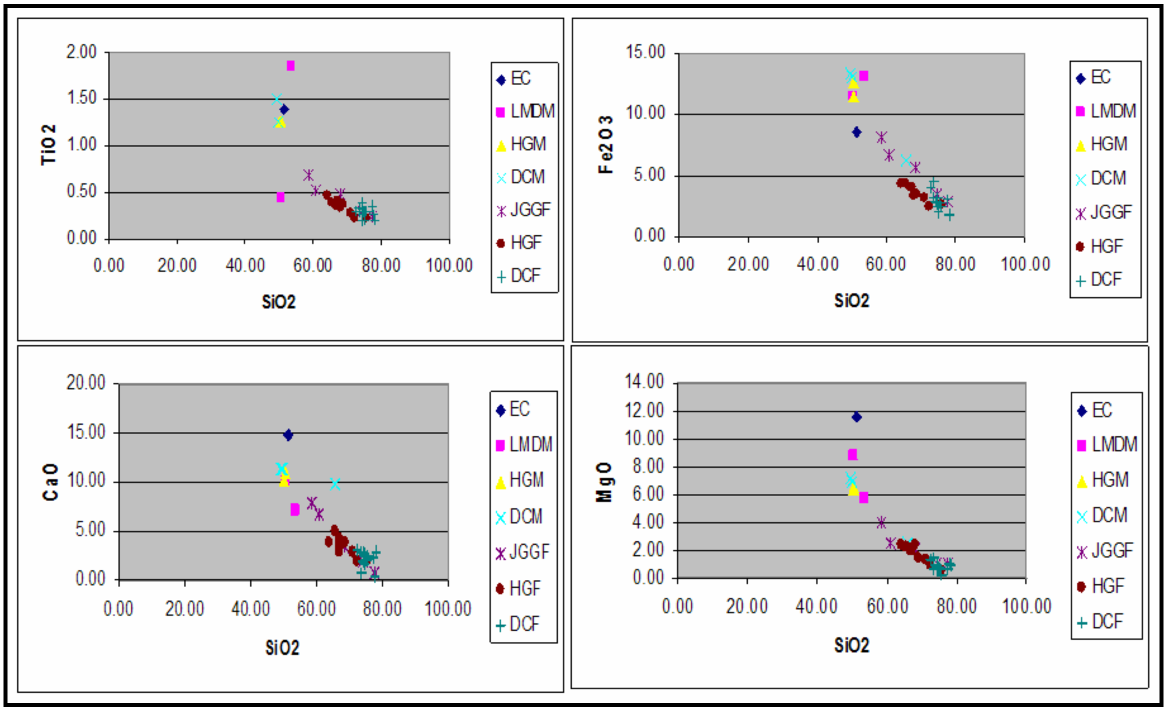

Figure 11. Selected Harker plots that illustrate relations between the various igneous rocks of the Lake Martin duplex and also rocks in other Piedmont terranes. EC = Eagle Creek greenstone, LMDM = Lake Martin duplex mafic, HGM = Hillabee Greenstone mafic (i.e., greenstone), JGGF = Jackson's Gap Group felsic (= Lake Martin Dam metatonalite), HGF = Hillabee Greenstone metadacite, DCF = Dadeville Complex felsic.

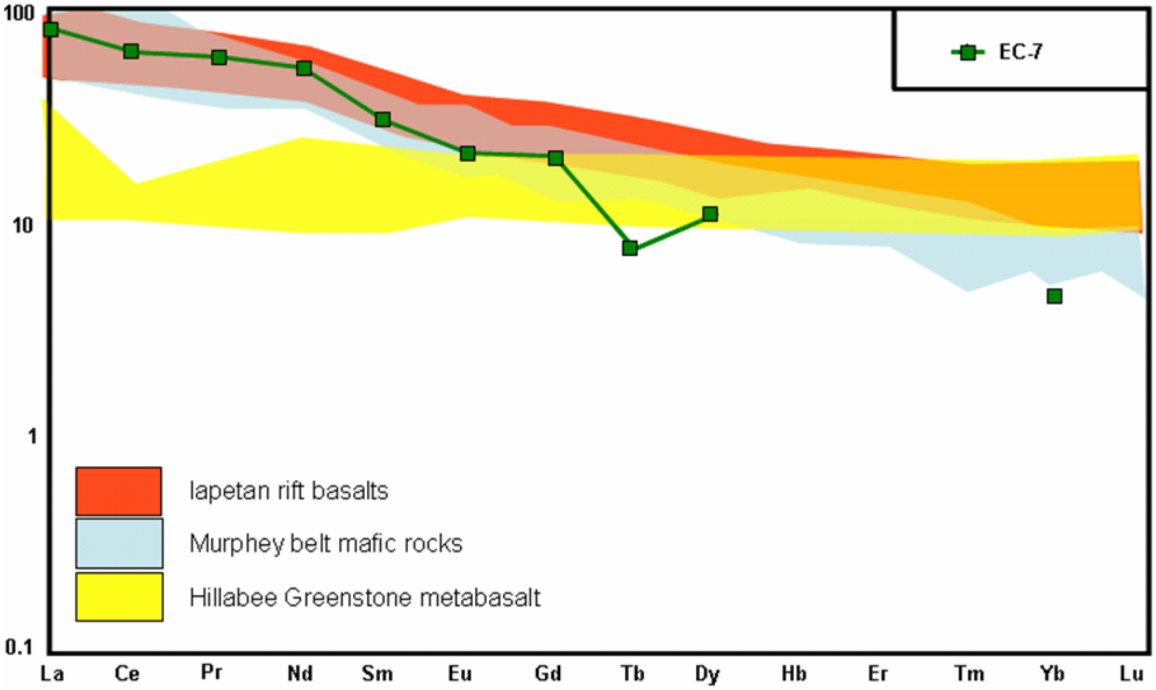

Figure 12. Chondrite-normalized REE pattern for the Eagle Creek greenstone of the Lake Martin Dam duplex; comparative fields are those reported by Tull et al. (1998a).

suggesting that they may link along shear zones (for example TR-52). Similarly, Harker plots exhibit both non-linear and strong linear and polynomial trends that appear to extend to the mafic rocks (Fig. 11). The r values for all oxides, with the exception of K_2O with a value of -0.22, are quite significant for all samples within the Jackson's Gap Group and range from -0.85 for Al_2O_3 to -0.97 for CaO. Some major oxides exhibit a spatial gap, most notably TiO_2 and P_2O_5 (Fig. 11) between the mafic and felsic rocks. All oxides, with the exception of Na_2O, are negatively correlated with silica. Chondrite-normalized REE patterns for several felsic samples from within the duplex (e.g., TR-5A, TR-5b, TR-52, and TR-136) show slight REE enrichment, high HREE concentrations, and negative or nonexistent Eu anomalies that largely overlap those for the Lake Martin Dam metatonalite sample RH-9 (Fig. 10). Felsic units of the Dadeville Complex that are structurally interleaved with the Jackson's Gap Group of the duplex are assigned to the Camp Hill and/or Waverly Gneiss (Sterling et al., 2005). Unfortunately, we are not aware of any geochemistry reported for the Waverly Gneiss, which is known to be a highly saprolitized unit (Bentley and Neathery, 1970; Steltenpohl et al., 1990), so it is not presently possible to make comparisons to the Waverly. For the Camp Hill Gneiss, however, Drummond et al. (1997) report chondrite-normalized REE patterns with slight REE enrichment, high HREE concentrations (e.g., $Yb_N \geq 10$), and a negative Eu anomaly, that tightly overlap those for the felsic rocks of the Lake Martin duplex. Like the Lake Martin Dam metatonalites, Drummond et al. (1997) interpret the Camp Hill gneisses to be highly differentiated trondhjemite-tonalites derived from low- to moderate-pressure partial melting (≤ 8 kb) of a basalt that left behind a plagioclase-rich residuum. Thus, the field relations, chemistry, and mineralogy support the conclusion that the Lake

Martin Dam metatonalite is petrogenetically identical to the Camp Hill Gneiss and may be a related intrusion.

Petrogenetically, sample TR-100, a true granite (Fig. 8), is unrelated to the tonalites because field studies clearly show that it is a sliver of Kowaliga Gneiss interleaved along the floor thrust to the duplex. Although no REE data are reported for the Kowaliga Gneiss, the pattern displayed in Figure 10 for sample TR-100 mimics the shape and abundancies of REE's reported for the Elkahatchee Quartz Diorite (Drummond et al., 1997), an Early Ordovician batholith within the Alabama eastern Blue Ridge (Fig. 2). Relative to the tonalitic rocks of the Lake Martin duplex, the REE pattern for sample TR-100 has higher LREE and lower HREE enrichments, cutting across all of the tonalite patterns.

Our analysis indicates that the Eagle Creek greenstone is not petrogenetically related to any of the other mafic rocks we investigated from the Lake Martin duplex (TR-7A and TR-16B). Field observations from the structurally upper parts of the duplex are that the Ropes Creek Amphibolite of the Dadeville Complex is strongly sheared and interleaved with Jackson's Gap Group units along D_1 shear zones. Groupings and trends displayed in various discriminant diagrams (not shown) and Harker plots (Fig. 11) support a MORB origin for these metabasalts, which is well established for the Ropes Creek Amphibolite (Stow et al., 1984). The chondrite-normalized REE pattern for sample TR-16B (Fig. 12) most resembles MORB (Basaltic Volcanism Study Project, 1981), having a relatively flat REE pattern that is slightly depleted in LREE's. This pattern is similar to that reported by Hall (1991), whose detailed geochemical studies of the Ropes Creek Amphibolite helped to demonstrate a MORB protolith. Polynomial trends for all of the Jackson's Gap Group felsic igneous rocks (not all shown), suggest that they may be petrogenetically related to the Ropes Creek amphibolites, which Hall and Salpas (1990) suggested may indicate either alternating mafic and felsic volcanism in a back-arc environment of an island arc or metamorphic differentiation of a MORB.

The Eagle Creek greenstone, on the other hand, does not resemble the Ropes Creek Amphibolite (for example, c.f. Figs. 12 and 13). In the field, the Eagle Creek greenstone has the appearance of a true greenstone, with a massive, granular texture and an olive-green color due to a large percentage of epidote; the Ropes Creek is a highly sheared and foliated gneiss. On discriminant diagrams (not shown) and Harker plots (Fig. 11) the Eagle Creek greenstone lies separate from the Ropes Creek Amphibolite. Finally, as described above, LREE plots (Fig. 11) the Eagle Creek greenstone lies separate from the Ropes Creek Amphibolite; as described above, LREE enrichment in the Eagle Creek greenstone implies a continental rift basalt, which contrasts sharply to the Ropes Creek mid-ocean ridge basalt.

Comparisons with the Hillabee metabasalt/metadacite

Given the similarities in host siliciclastics, anomalously lower metamorphic grade, and bimodal igneous rocks, a comparison of the Jackson's Gap Group greenstone/metatonalite with the bimodal Hillabee greenstone/metadacite suite of the Talladega slate belt is a potential correlation (Sterling et al., 2005). The Eagle Creek greenstone, like the Hillabee Greenstone, are plotted as basalt. Mafic rocks other than Eagle Creek greenstone found within the Lake Martin duplex are interleaved Ropes Creek Amphibolite of the Dadeville Complex (Sterling et al., 2005) and likewise are

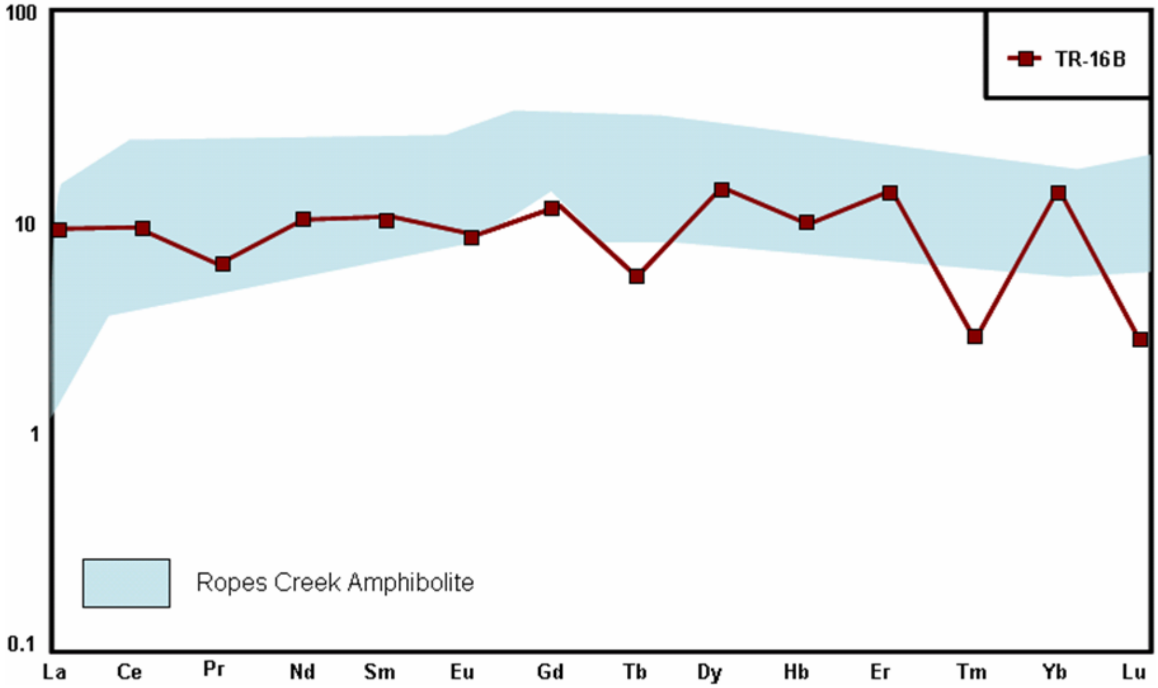

Figure 13. Chondrite-normalized REE pattern for Mafic rock TR-16B rocks of the Lake Martin Dam duplex; comparative field is that reported by Hall (1991).

plotted as basalt and basaltic andesite. Other mafic units of the Dadeville Complex outside the Lake Martin duplex, such as the Waresville Schist, Slaughters Suite metagabbro, and the Zebulon Formation, are plotted as basalt, gabbro (Waresville and Slaughters, respectively) and dacite (Figs. 7, 8, and 9). Felsic units within the Dadeville Complex used for analysis in this study consist of felsic layers within the Ropes Creek Amphibolite and Camp Hill Gneiss and lie wholly within the rhyolite field (Fig. 7).

Tull and Stow (1980) concluded that the Hillabee metabasalt is tholeiitic and the Hillabee dacites are calc-alkaline. Due to its higher proportion of MgO, the Eagle Creek greenstone plots near the calc-alkaline trend line although it contains no more alkalis than the average Hillabee metabasalt or Dadeville Complex mafic rocks (Fig. 9). Lake Martin Dam metatonalites lie midway between the tholeiite and calc-alkaline trend lines, with a closer inclination towards the calc-alkaline trend and thus are similar to that of the Hillabee dacites (Fig. 9). Stow et al. (1984) found mafics of the Dadeville Complex to be tholeiitic. Neilson et al. (1997) interpreted that the Dadeville Complex felsic rocks (Camp Hill Gneiss) are calc-alkaline. Neilson and Stow (1986) found that the Slaughters Suite fell along the calc-alkaline trend on an AFM plot, which is very similar to the Eagle Creek greenstone (Fig. 9). Distinct from both the Hillabee metabasalt and most Dadeville Complex mafic rocks, except the Slaughters Suite, the Eagle Creek greenstone is plotted within the calc-alkaline field (Fig. 9). Unlike the findings of Neilson et al. (1997), the majority of Dadeville Complex felsic rocks (Camp Hill Gneiss in particular) are of a thoeliitic affinity. Similarly, most of the Lake Martin Dam metatonalite, albeit one sample, lie within the tholeiite field. Metamorphic alteration and fluid migration during the formation of the Lake Martin duplex and the retrogressive brittle-plastic shear zones that crosscut it may be one explanation for this outlier.

The bimodal nature of the Hillabee suite becomes apparent with a compositional gap of ~9 % SiO_2 and a lack of rocks with intermediate composition. It becomes more difficult to suggest a similar bimodal distribution for the meta-igneous rocks of the Jackson's Gap Group in that there are rocks of intermediate composition; however, the end-member rocks, namely the dacites, rhyolites, and basalt, plot compositionally very similar to the Hillabee metavolcanics (Fig. 7) and they also show comparable fractionation trends as described below.

Harker diagrams for analyses of the Hillabee, Jackson's Gap Group, and Dadeville Complex suites, including both mafic and felsic rocks, are given in Figure 11. The bimodal nature of the Hillabee suite again becomes apparent; other oxides in addition to silica exhibit compositional gaps between the mafic and felsic end members (e.g., TiO_2, MgO, CaO). Some oxides in the Jackson's Gap Group rocks exhibit a spatial gap, most notably TiO_2 and P_2O_5, which may represent to some degree a bimodal distribution similar to that of the Hillabee metavolcanics. It would seem there may be a bimodal distribution to the Dadeville Complex suites; however, the intrusive nature between the Camp Hill Gneiss and its host Dadeville mafics precludes such an interpretation.

Although no apparent trends exist between silica and other oxides for the Hillabee metabasalt, Eagle Creek greenstone, or Dadeville Complex mafic rocks (not shown), plots for the felsics from the Hillabee and Jackson's Gap Group exhibit similar strong linear and non-linear trends (Fig. 11) while felsics from the Dadeville Complex are typically enriched in silica and show poorer correlation coefficients (r values). All oxides, with the exception of Na_2O, are negatively correlated with silica for all suites. The r values for all oxides, with the exception of K_2O with a value of -0.22, are quite significant for all samples within the Jackson's Gap Group and range from -0.85 for Al_2O_3 to -0.97 for CaO. Samples from the Hillabee are slightly less significant with r values ranging from -0.59 for K_2O to -0.92 for Al_2O_3. Trends for the Dadeville Complex are markedly less significant than either of the previous suites with a range -0.01 for P_2O_5 to -0.56 for Al_2O_3.

For the Hillabee suite, the possibility of magma mixing between end-member basalts and rhyolites might explain the range of dacite compositions. The patterns of the Harker plots preclude such an explanation, however, in that a best-fit line through the trend for the felsic rocks (not shown) would not pass through the metabasalt field, especially those for Al_2O_3, K_2O, TiO_2, and MgO. For rocks of the Jackson's Gap Group suite, such an explanation for the occurrence of dacite and andesite compositions may be refuted for the same reasons, especially those for Al_2O_3, K_2O, TiO_2, Fe_2O_3. These trends for the Jackson's Gap Group rocks are based on linear analyses. Polynomial trends for the felsics (not shown), however, show a closer approximation to the Jackson's Gap Group mafics, which may indicate magma mixing or the possibility of contamination of a basaltic magma from a lower crustal source to explain the dacites and andesites.

Significance for tectonic evolution

Tull et al. (1998b) present detailed descriptions and geochemical analyses of the bimodal metabasalts and metadacites within the Hillabee Greenstone of the Talladega slate belt. The Hillabee units are concordant to lithologic layering and are interpreted as a series of flows and tuffs. The Eagle Creek metabasalt resembles the Hillabee in that it is a true greenstone and is concordant with encapsulating lithologies. That, however, is where the similarities appear to end. The Eagle Creek is a continental rift basalt with REE spider patterns overlapping those of classic rift Iapetan basalts of the western Blue Ridge (Fig. 12); Tull et al. (1998a) argue that the Hillabee is related to contractional tectonics. Based on their MORB geochemistries and overlapping REE patterns (Fig. 13), the sheared Ropes Creek amphibolites of the Lake Martin Dam duplex may correlate to the Hillabee metabasalts as suggested by Higgins et al. (1988). Tull et al. (1998b) present stratigraphic arguments for a middle Paleozoic age (Devonian) for the Hillabee, which conflicts with U-Pb dating of zircons that indicate a Middle Ordovician date for igneous crystallization (Russell, 1978; Russell et al., 1984; McClellan and Miller, 2000; McClellan et al., 2005). The age of igneous crystallization of the Ropes Creek metabasalt is only loosely constrained as older than 462±4 Ma, which is the age of the Franklin Gneiss (part of the Camp Hill Gneiss) that intrudes it (Seal and Kish, 1990). Until future dating of the Ropes Creek proves otherwise, a pre-462 Ma age is at least compatible with its hypothetical correlation with the Hillabee.

There are numerous field and geochemical similarities between the metatonalites of the Lake Martin duplex and the metadacites of the Hillabee Greenstone. With one exception, analyses of the Hillabee felsic metavolcanic rocks are subalkaline and plot in the dacite and rhyolite fields, whereas the mafic rocks plot as basalt (Fig. 7). Although felsic rocks within the Jackson’s Gap Group have experienced varying degrees of alkali metasomatism during metamorphism, as can be seen in the lack of correlation between

Na_2O/K_2O and any other major oxide (not shown), the total alkalis may be useful in describing the igneous protolith. The Lake Martin Dam metatonalites are subalkaline and plot within the andesite, dacite, and rhyolite fields (Fig. 7). CIPW normative mineral assemblages for the Hillabee dacites (Tull et al., 1998b) plot in all compositional domains of the An-Ab-Or granite classification diagram except tonalite, but primarily in the granodiorite field (Fig. 8). The Lake Martin Dam metatonalite has tonalite/trondhjemite normative compositions (Fig. 8) and thus are more similar to those reported for the Camp Hill Gneiss (not shown; Drummond et al., 1997). REE patterns are practically identical between the metatonalite and metadacite (Fig. 10). If the Lake Martin Dam metatonalite is correlative with the Camp Hill Gneiss, then it too would be pre-462 Ma, opening up the possibility that it correlates with the Hillabee metadacite. Alternatively, the metatonalites of the duplex may be comagmatic with respect to the Camp Hill magmas, thus reflecting middle- to upper-crustal intrusion that may have fed volcanism at ca. 462 Ma. This timing overlaps, within analytical uncertainty, the age of Middle Ordovician bentonites that are well known throughout the eastern (present day geography) Laurentian platform (e.g., Tucker and McKerrow, 1995). The correlation would also constrain a minimum age for deposition of the Jackson's Gap Group.

Perhaps the most exciting implication of our study is the recognition of continental-rift basaltic magmatism within the Jackson's Gap Group. Rift basalts in the southern Appalachians are only documented in Laurentian margin rocks of the western and eastern Blue Ridge (see Tull et al., 1998a, and references therein) and in the internal Pine Mountain window (Steltenpohl et al., 2002). The shallow-marine shelf depositional setting of the Jackson's Gap Group (e.g., orthoquartzite, quartz-pebble conglomerate, and carbonate-rich shale), and what is known about the pre-Middle-Ordovician depositional age (see also Steltenpohl et al., 2005), is compatible with an origin along the ancient, rifted margin of Laurentia. This interpretation is somewhat surprising because the Jackson's Gap Group is tectonically sandwiched between what is thought to be the most distally preserved parts of the Laurentian slope/rise facies (i.e., eastern Blue Ridge) and the 'suspect' Inner Piedmont terrane. Hatcher (1971) interpreted carbonate slices in the Brevard zone of South Carolina as chunks of Shady Dolomite brought up from the underlying Laurentian platform along thrust faults; later, COCORP seismic reflection profiling (Cook et al., 1979) appears to have validated his hypothesis. Later, however, it became well documented that late motion (Alleghanian) along the Brevard zone was principally right-lateral strike slip (Vauchez, 1987; see also Bobyarchick, 1999, and references therein), a fact that must be incorporated into any explanation for the relationships we have documented at Jackson's Gap, Alabama. Our study suggests that, oblique, right-slip and thrust motion along the Lake Martin duplex, combined with the northeast plunge of the Tallassee synform, has somehow elevated Laurentian margin rocks from beneath the Piedmont allochthon to the present day erosional surface. It further throws into question the tectonic affinity of rocks lying between the Alexander City fault and the traditional Jackson's Gap Group between Dadeville and the Coastal Plain onlap some 30 km to the southwest. Ongoing mapping in this and the area around Tallassee, Alabama, is focusing on these problems. Conceptually, however, all of our observations lead us to suspect a shallow depth for the southern Appalachian decollement in the area.

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SUMMARY

Published geologic maps of Alabama equate rocks of the Jackson's Gap Group to those lithologies that define the Brevard zone (e.g., Bentley and Neathery, 1970, and Osborne et al., 1988). These units and this structure are shown to be covered by Coastal Plain sedimentary rocks south of Tallassee, Alabama (Bentley and Neathery, 1970; Osborne et al., 1988). Subsequent studies (Keefer, 1992; Grimes et. al, 1993) indicate the structures that typically define the Brevard zone, that is overprinting, late-stage Alleghanian right-slip brittle-plastic shears, do not coincide with the Jackson's Gap Group units south of Jackson's Gap, Alabama. What is shown on earlier maps as bending due-South are lithologies and associated deeper-crustal-level (kyanite zone), D_1 plastic shears that are interpreted to be the 'early' D_1 structural imprint to the Brevard zone. In the study area, the Jackson's Gap Group is defined by an unusual assemblage of lower-greenschist-to-lower-amphibolite-facies siliciclastics and is found to occur within a major, D_1, oblique right-slip contractional duplex, the Lake Martin duplex. Although the timing of duplexing is not well understood, it is known that the duplex is transected by late-Alleghanian nonpenetrative semi-brittle shear zones and, thus, must have formed during Acadian or early-Alleghanian (?) deeper-crustal deformation. Key findings of this project include: 1) recognition of the Lake Martin duplex; 2) establishment of a comparable analogy between the Lake Martin duplex and both the Hollins Line duplex and Pine Mountain imbricate zone; 3) recognition of bi-modal volcanism within the

Jackson's Gap Group; and 4) recognition of a Laurentian shallow-marine shelf setting for the Jackson's Gap Group.

The present study documents that the Jackson's Gap Group rocks occur as relatively lower-metamorphic grade (some rocks experienced lower-greenschist-facies conditions at most) quartzite, conglomerate, chert, carbonate-bearing pelites, and plutonic and volcanic rocks which were stacked during D_1 deformation. Lithologically, the Jackson's Gap Group may correspond to either units of the Sandy Springs Group (Higgins et al., 1988) found near the Georgia-Alabama border, parts of the Talladega Group (Tull, 1979; Tull et al., 1993) further north in Alabama, or perhaps parts of the Pine Mountain Group (Steltenpohl, 1988, 1992) southeast of the Inner Piedmont. These relationships, along with the north-trending, top-to-the-west geometry, right-slip kinematics, and the Acadian to pre-Alleghanian (?) timing of the Lake Martin duplex, make the geology of the southernmost Brevard zone quite comparable to that reported for the Hollins Line duplex of the Talladega belt (Moore and Tull, 1989) and the Pine Mountain imbricate zone (Steltenpohl, 1988).

Not only are the Jackson's Gap Group siliciclastics lithologically similar to rocks of the Talladega belt, but a previously unidentified bimodal suite of metamorphosed basalt and tonalite within the Jackson's Gap Group, the Eagle Creek greenstone and the Lake Martin Dam metatonalite, respectively, were found to be remarkably similar to the Hillabee metabasalt and metadacite of the Talladega belt. Tull and Stow (1980) concluded that the Hillabee metabasalt and dacites are tholeiitic and calc-alkaline, respectively, and are flows and tuffs deposited in a subduction/back-arc setting. Major oxide discriminate diagrams indicate that the Lake Martin Dam metatonalite and Eagle

Creek greenstone are tholeiitic tonalite and calc-alkaline basalt, respectively, and exhibit a bimodal nature strongly similar to that of the Hillabee Greenstone. Chondrite normalized REE patterns indicate that the Lake Martin Dam metatonalite originated as a relatively shallow intrusion within a volcanic arc and that it is petrogenetically very similar to the Camp Hill Gneiss of the Dadeville Complex and may be a related intrusion. REE patterns show that the Eagle Creek greenstone formed in a continental rift setting similar to those of the Laurentian rift basalts of the western Blue Ridge. Based on their MORB geochemistries and overlapping REE patterns, the sheared Ropes Creek amphibolite of the Lake Martin Dam duplex might correlate to the Hillabee metabasalt. The age of igneous crystallization of the Ropes Creek metabasalt is only loosely constrained to before 462 Ma, which is the age for the Franklin Gneiss (part of the Camp Hill Gneiss; Seal and Kish, 1990) that intrudes it. The Lake Martin Dam metatonalite, though petrogenetically similar to the Camp Hill Gneiss, is also geochemically very similar to the Hillabee metadacite. Thus, an Ordovician age for the deposition of the Jackson's Gap Group and the Hillabee Greenstone (McClellan et al., 2005) is hypothetically compatible. The depositional setting of the Jackson's Gap Group and geochemical nature of the Lake Martin Dam metatonalite and Eagle Creek greenstone, clearly indicate that the Jackson's Gap Group was deposited in a shallow-marine shelf setting off of the ancient, rifted margin of Laurentia, similar to that interpreted for the Talladega and Pine Mountain terranes.

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