CHARACTERISTICS, EXTENT, AND TECTONIC SIGNIFICANCE OF A MIDDLE ORDOVICIAN BACK-ARC BASIN IN THE SOUTHERN APPALACHIAN BLUE RIDGE

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ABSTRACT

A growing body of evidence suggests that a number of Ordovician-aged stratigraphic units in separate lithotectonic belts of the southern Appalachian orogen are genetically related, having formed in a back-arc setting on the Laurentian plate. Research on the Hillabee Greenstone in the Talladega belt and Pumpkinvinve Creek Formation and related bimodal metavolcanic rocks in the Dahlonega Gold belt suggest a similar temporal, spatial, and tectonic origin. Additionally, recent Ordovician isotopic ages for detrital zircons from the Wedowee and Emuckfaw Groups in the Ashland-Wedowee-Emuckfaw belt of Alabama (eastern Blue Ridge), as well as stratigraphic correlations of these units with metasedimentary and metavolcanic rocks of the southwestern Dahlonega Gold belt (New Georgia Group) support the idea that the Ashland-Wedowee-Emuckfaw belt and Dahlonega Gold belt should be considered a single lithotectonic terrane. Correlation of the Emuckfaw Group and overlying units (Jackson's Gap Group) with similar rocks around the southwestern terminus of the Brevard Zone in the Opelika Complex, and farther northeast within the western Inner Piedmont of Georgia and North Carolina (Poor Mountain Formation) indicate that these rocks may also have formed in the same extensive Laurentian plate back-arc basin. Correlations of these units have a significant bearing on interpretations of the tectonic setting for the Taconic orogeny in the southernmost Appalachians, suggesting that it formed as a result of extensional accretionary orogenesis on the overriding (Laurentian) plate, unlike the collisional-style orogenic setting for initial phases of the Taconic in the northern Appalachians.

INTRODUCTION

Researchers over the last few decades have detailed the geology of different segments of what now appears to be an extensive and tectonically significant eastern Blue Ridge basin(s), composed of thick sequences of immature deep-water metasedimentary rocks, intercalated with significant amounts of mafic metavolcanic rocks and their associated base metal deposits, and to a lesser degree intermediate and felsic metavolcanic rocks. An important addition to these observations is that recent geochronological work on both sedimentary detrital components and igneous rocks has documented that the age of much of this sequence is Early to Middle Ordovician, spanning a time interval of ~20 million years (~480 to 460 Ma). Multiple stages of subsequent Alleghanian faulting have dismembered and fragmented what we believe to have once been a much more extensive basin, but the preserved contiguous parts indicate that it exceeded 10 km in thickness, extended along strike for >500 km, and across strike for >115 km, making it at least one third the size of the Sea of Japan. The southwestern extent of the basin is now covered by the Gulf Coastal Plain, and to the northeast near Waynesville, North Carolina, it is covered by overlying, more outboard thrust sheets carrying the Cowrock and Cartoogechaye terranes (Hatcher et al., 2005; 2007). Because of Alleghanian fragmentation and previous uncertainties in age, units included within this basin have commonly been studied and described in the past as separate and not necessarily related entities. Thus, little discussion has focused upon their linkage from a genetic and tectonic standpoint. These sequences include, from southwest to northeast, the Hillabee Greenstone and the Emuckfaw, Wedowee, Opelika, and Jackson's Gap Groups in Alabama; the New Georgia Group and at least part of the 'western Sandy Springs' Group in Georgia; and the Otto, Chauga River, and Poor Mountain Formations in North and South Carolina (Appendix A).

The fundamental premise of this report is that the metavolcanic assemblages and enclosing thick metasedimentary sequences constituting this extensive basin(s) formed in a back-arc setting along the outer margin of Laurentia. This indicates that southernmost Appalachian Ordovician orogenesis began in an extensional accretionary tectonic setting, in which extension, probably within previously weakened and thinned continental crust amalgamated with transitional and/or oceanic crust, created a sedimentary basin(s) floored by and/or intercalated with back-arc volcanic sequences. The most probable palinspastic reconstructions of the southernmost Appalachian orogen place these sequences southeast of the Pine Mountain belt, outboard of the rifted-margin hinge zone on thinned Laurentian continental or transitional Iapetus oceanic crust (Thomas and Bayona, 2005; Tull et al., 2010).

Because of the earlier lack of protolith age constraints, most of these sequences were previously correlated with the Neoproterozoic Ocoee Supergroup (or equivalents), or early Paleozoic Laurentian margin slope-rise sequences (Hadley, 1970; McConnell and Abrams, 1984; Hatcher, 1988; Drummond et al., 1994; Thomas et al., 1980; Tull et al., 2007). Our goal here is to describe the collective characteristics of this basin and to discuss its tectonic implications.

METASEDIMENTARY ROCKS (LITHOSTRATIGRAPHY)

With the exception of the Hillabee Greenstone in the Talladega belt, metamorphism over most of the area occurred under mid-crustal conditions (middle amphibolite facies), ranging from staurolite to kyanite grade. As a result, the metasedimentary rocks contain a general lack of primary depositional features other than bedding (compositional layering). Sediments in each of these units, which generally make up 80% to 90% of the total section, appear to have formed on the continental slope/rise as immature rhythmically bedded flysh-like (turbidite) deposits (Muangnoicharoen, 1975; McConnell and Abrams, 1984; Beiler and Deininger, 1987; German, 1987). Aluminous metapelites (meta-argillites) make up ≥ 85% of the metasedimentary rocks, and intercalated psammites, commonly characterized as "metagreywacke" or "biotite gneiss," and rare muscovite quartzites and calcsilicate layers constitute the bulk of the remaining rocks. The metapelites consist of coarse- to medium-grained, garnitiferous and non-garnetiferous, locally carbonaceous, quartz-muscovite schists with variable amounts of biotite, garnet, feldspar and graphite. The relatively thin (<0.5 m thick) gneissic layers contain quartz, two-micas (muscovite and lesser biotite), two-feldspars (plagioclase and lesser K-feldspar), and garnet, and based on whole rock chemistry, are graywackes (Crawford and Medlin, 1974). Contacts between these lithologies are commonly sharp. Overall, there is little to no evidence for shallow-water depositional conditions throughout the stratigraphy. In those parts of the sequence containing metavolcanic rocks, chemical sediments that include highly siliceous units (e.g., Cedar Lake Quartzite in Georgia), banded iron formation, and manganiferous and ferruginous alteration products occur, and are likely of volcanogenic origin (McConnell and Abrams, 1984; German, 1989; Holm-Denoma, 2006). Thickness estimates (from a few km to ~10 km) for the sequences discussed here, considered to have formed over an age range of ~20 m.y. (~460-480 Ma), suggest overall depositional rates from a few 100 m/m.y. to ~1,000 m/m.y., i.e., within the range of depositional rates calculated for active back-arc spreading and tectonic subsidence in the Sea of Japan (100-500 m/m.y.; Ingle, 1992).

Emuckfaw Group

The Emuckfaw Group was originally named the Heard Group by Bentley and Neathery (1970). They described a sequence of thin bedded schists and gneisses ("metagreywacke") exposed in Heard County, Georgia and subdivided the unit into three formations: the Roopville, Glenloch, and Centralhatchee. However, in Alabama, Neathery and Reynolds (1975) were unable to subdivide this sequence, and formally renamed it the Emuckfaw Formation for exposures along

Emuckfaw Creek in Tallapoosa County. The upper contact of the Emuckfaw in Alabama is the Abanda fault, the kinematically-late (Alleghanian) frontal fault of the Brevard zone. The base of the Emuckfaw at its contact with the underlying Wedowee Group has been a subject of debate for decades (Bentley and Neathery, 1970; Neathery and Reynolds, 1975; Muangnoicharoen, 1975; Guthrie and Dean, 1989; Tull, 2011). In northern Tallapoosa, Clay, and Randolph Counties, we interpret it to be a polydeformed stratigraphic boundary (See Tull and Campbell, this guidebook).

Although the Emuckfaw is difficult to subdivide in Alabama, Muangnoicharoen (1975) informally divided it in Clay and Tallapoosa Counties into a northwestern, more garnetiferous and less graphitic unit, and a southeastern, less garnitiferous, more graphitic unit. Beiler and Deininger (1987), working in the northwestern part of the Jackson's Gap quadrangle in Tallapoosa County, also established an informal two-part subdivision of the Emuckfaw, defining a lower "Josie Leg member" composed of interlayered coarse-grained, non-graphitic, garnet two-mica schist, and ~10%-15%, 0.1 to 0.5 m thick layers of garnitiferous metagreywacke, and an upper "Timbergut member" composed of interlayered mica schists, more quartzitic metagreywacke, and minor calcsilicate. Kyanite has been recognized at several localities in the Timbergut, but has not been found in the Josie Leg, probably because of compositional variations. The two units are separated by a zone of megacrystic gneiss along Hillabee Creek that extends northeastward along strike into a lens (sill?) of Zana Granite (age discussed below). Although Beiler and Deininger (1987) used independent criteria, they positioned the internal Emuckfaw boundary at a very similar stratigraphic level to that established earlier by Muangnoicharoen (1975). Guthrie and Dean (1989) extended the Wedowee/Emuckfaw contact defined by Beiler and Deininger (1987) into the adjacent quadrangle to the northeast (New Site), and upgraded the Emuckfaw to group status using Beiler and Deininger's subdivision. Although Beiler and Deininger (1987) did not map amphibolites within the Josie Leg, the trace of the contact with the Timbergut trends northeastward through Tallapoosa and into Randolph County, where amphibolites make up 14 to 40% of the Josie Leg. In Randolph County, the Josie Leg is part of the stratigraphic section that contains the Beaver Dam Amphibolite, which was originally defined by Bentley and Neathery (1970) as part of the lower Emuckfaw (their Heard Group) (Appendix A). Above the contact with the Timbergut, amphibolites have not been recognized and must, therefore, be rare or absent in the Timbergut. It thus appears that the Josie Leg/Timbergut subdivision, with amphibolites confined to the Josie Leg, is a mappable subdivision for the Emuckfaw over its areal extent (4.8 to 16 km-wide belt) in eastern Alabama and western Georgia. Of the total section, ~7% to 19% of the total Emuckfaw in Alabama is metabasalt. Thus far, no felsic volcanics have been recognized in the Emuckfaw Group in Alabama, but it is possible that some of the "metagreywacke" beds could be volcanic in origin. Granitic sill-like bodies mapped as Kowaliga Gneiss are confined to the Timbergut Formation, but rocks mapped as Zana Granite intrude the Timbergut and structurally underlying Josie Leg, as well as apparently stitching the contact between the Emuckfaw and the Wedowee Groups in Coosa and Elmore Counties (Osborne et al., 1988; Pazel, 2012). Ignoring mesoscopic folding, the thickness of the Emuckfaw in Alabama is ~4 to 5 km, with the Josie Leg making up the lower 1.5 km.

Historical and New (preliminary) Geochrology of the Zana (meta-) Granite and Kowaliga Gneiss

Rocks of the Zana (meta-) Granite and Kowaliga Gneiss are petrologically diverse bodies consisting of tonalites, granodiorites, and granites that may or may not be genetically and temporally related (Beiler and Deininger, 1987; Drummond et al., 1997). Both plutonic bodies, which intrude the Emuckfaw Group, and have geochemical signatures indicative of mixed mantle-crustal sources with elevated initial Sr isotopic compositions (0.705-0.706; Russell et al., 1982; Drummond et al., 1997; Holm-Denoma, 2006) have been dated using whole rock (Rb-Sr) and multi-grain (zircon U-Pb) analytical techniques. Russell et al., (1987) assigned an age of 461±12 to both plutons based on an upper intercept age and a single concordant point, arguing that similarities between the 207Pb/206Pb, 207Pb/235U, and 206Pb/238U ages for the concordant sample (459±18 Ma, 462±4 Ma, and 463±3 Ma, respectively) closely constrained the age. Attempts by Russell et al. (1987) to date the Zana and Kowaliga via whole-rock Rb-Sr analysis did not yield precise results, but were consistent with the zircon results within a large analytical uncertainty (± 100 m.y.).

Samples of Zana and Kowaliga analyzed by SHRIMP for zircon U-Pb ages showed evidence of systematic Pb-loss and yield what appear to be "young" ages, similar to results obtained from granitic rocks in Georgia that have similar stratigraphic (in the New Georgia Group) and tectonic settings (e.g. Mulberry Rock, Sand Hill, and Austell Gneisses). Data from these Georgia and Alabama Gneisses show evidence for formation between 480 and 430 Ma (C. Holm-Denoma, 2010 unpub. data). Statistical analyses of the Kowaliga show a coherent age grouping at 430 Ma. The Zana has no coherent age group and contains single analyses that range between 480 and 410 Ma. However, using the "zircon age extractor" function in Isoplot v.3.75 (Ludwig, 2012) an age of 439 Ma can be tentatively assigned to the Zana. Previous studies of the Austell Gneiss yielded similarly ambiguous results where a whole-rock Rb-Sr isotope isochron age of 430 Ma and highly ambiguous U-Pb zircon TIMS ages between 485 and 400 Ma were obtained (Higgins et al., 1997). Importantly, the large Elkahatchee Quartz Diorite batholith is largely younger (certain phases or the main melt phase in general) than the 490 Ma determined by Russell et al. (1987). A single sample yielded a concordant age of 373 +/- 3 Ma (C. Holm-Denoma, 2010 unpub. data), similar to other recent microprobe ages of the Elkahatchee (Tull et al., 2009). It is difficult to determine if rocks of the Zana and Kowaliga formed at 460 Ma, and the zircons suffered later Pb-loss at ~430 Ma, or at 373 Ma during emplacement of the Elkahatchee, or if the rocks formed at 430 Ma and the older ages represent Pb-loss of inherited grains. A 430 Ma event is documented in detrital zircon deposited in the SiluroDevonian(?) Cat Square Basin (Merschat et al., 2010), though a link between the granitoids mentioned here and detritus shed into the Cat Square basin would be highly speculative at this point.

Emuckfaw/Jackson's Gap Groups and Opelika Group Correlation

Near the Gulf Coastal Plain unconformity, the trend of rocks of the Emuckfaw Group and its younger granitoid intrusive bodies, as well as the trend of rocks of the Brevard Zone (Jackson's Gap Group) curves south and then southeastward around the hinge of the Tallassee synform, ultimately extending northeast into the Opelika Group along the southeast flank of the Inner Piedmont (Bentley and Neathery, 1970, Figs. 2 and 8) (Appendix A). At Tallassee, in the core of the synform, Bentley and Neathery (1970) mapped the Jackson's Gap Group in stratigraphic contact with, and structurally underlain by part of the Opelika Group, which extends northeastward structurally beneath the Dadeville complex (Bentley and Neathery, 1970; Sears et al., 1981). The Opelika Group is divided into two lithostratigraphic units: 1) the ~1.25 km thick structurally upper Loachapoka Formation (Loachapoka Schist of Bentley and Neathery, 1970) that is composed mainly of metapelite (locally graphitic) interlayered with metaorthoquartzite, and minor amphibolite, and 2) the underlying ~2.5-3 km thick Auburn Formation (Auburn Schist/Gneiss of Bentley and Neathery, 1970), an interlayered metapelite (muscovite-biotite schist) and metagreywacke (coarse-grained biotite gneiss) succession, also with minor amphibolite (Sears et al., 1981). The group is tectonically bounded above (to the northwest) by the Inner Piedmont's Dadeville complex along the "Stonewall Line" fault, and to the southeast by the Towaliga fault (Bentley and Neathery, 1970; Sears et al., 1981) (Appendix A). Bentley and Neathery (1970) defined the Stonewall Line and suggested that this surface could be a fault. Griffin (1971) suggested that the structure could be a major "tectonic slide," and later Keefer (1992) reported that the Stonewall Line was a ductile shear zone. Grimes et al. (1993) suggested correlation of the Loachapoka Formation with the Jackson's Gap Group, a correlation strengthened by the presence of apparently correlative quartzite sequences: the Martin Dam (Devil's Backbone) quartzite in the Jackson's Gap on the northwest flank of the Tallassee synform, the Tallassee quartzite in the Jackson's Gap at Tallassee, and the Saugahatchee quartzite (Bentley and Neathery, 1970; Sears et al., 1981) in the Loachapoka Formation. The Jackson's Gap Group consists mainly of pelitic schists, but also contains metagreywacke, metaconglomerate, rare marble and layers of amphibolite (Wielchowsky, 1983; Sterling, 2006) in a stratigraphy that suggests basin shallowing in the upper part of the sequence.

Lenses of the Farmville metagranite stitch the contact between the Loachapoka and

Auburn Formations, and contain the dominant metamorphic fabrics found in the surrounding Opelika Group (Sears et al., 1981; Goldberg and Burnell, 1987). On the basis of an elevated initial Sr ratio and peraluminous character, Goldberg and Burnell (1987) suggested that the granitoid bodies are the product of crustal anatexis and have the characteristics of S-type granites. Goldberg and Burnell (1987) and Goldberg and Steltenpohl (1990) reported Rb/Sr whole-rock ages of the Farmville as 369 ± 5 Ma, and interpreted this as the time of syntectonic emplacement and crystallization of the Farmville magmas. Steltenpohl et al. (2005) reassessed the age of the Farmville metagranite using sensitive high resolution ion microprobe (SHRIMP). They report complex U-Pb systematics from the Farmville, with $^{206}Pb/^{238}U$ ages ranging from 425 ± 18 Ma to 477 ± 20 Ma, and interpreted this spread of ages to represent crystallization of the Farmville at ~477 Ma, with younger ages representing subsequent partial lead loss. The sample also included an inherited grain with a $^{207}Pb/^{206}Pb$ age of 1476 ± 34 Ma, and one with a $^{206}Pb/^{238}U$ age of 564 ± 24 Ma, coeval with Rodinian rifting. These ages, along with a whole-rock Nd depleted-mantle age of 1.12 Ga, suggest anatexis of Laurentian crustal rocks during magma genesis.

Following the interpretation of Bentley and Neathery (1970), we correlate the Emuckfaw Group of the Alabama eastern Blue Ridge with part (Auburn Formation) of the lithologically-similar Opelika Complex of the Alabama Piedmont. This interpretation requires that the Emuckfaw-Opelika basin extends at least 63 km beneath the Dadeville Complex allochthon. Although the Emuckfaw Group is separated from the overlying Jackson's Gap Group by the Abanda Fault northwest of the allochthonous Dadeville Complex, the apparent stratigraphic contact between the Loachapoka and Auburn Formations suggests that the Emuckfaw and Jackson's Gap Groups were originally in stratigraphic contact. Therefore, we suggest that the Jackson's Gap Group (and equivalent Loachapoka Formation) were among the youngest parts of the Ordovician basin under discussion.

New Georgia and Sandy Springs Groups/Dahlonega Gold Belt

The stratigraphy of the Emuckfaw and Wedowee Groups in Alabama can be traced northeastward into rocks of the 'western Sandy Springs' and New Georgia Groups (McConnell and Abrams, 1984; German, 1989), at the southwestern end of the Dahlonega Gold belt. Mapping at the juncture of the two belts – Ashland-Wedowee-Emuckfaw belt in Alabama and Dahlonega Gold belt in Georgia – has been limited and largely reconnaissance in nature. Additionally, different uses of stratigraphic nomenclature from both Alabama and Georgia have complicated the literature as to the nature of correlations between the two belts. For example, where we and Bentley and Neathery (1970) trace the Wedowee and overlying Emuckfaw across the state line, Hurst (1973) maps rocks of the Emuckfaw as "Wedowee Formation" and rocks we assign to the Wedowe Group as "Ashland Group". Merschat et al. (2005, p. 1253) extended the Dahlonega Gold belt southwestward into Alabama, not as the Emuckfaw, but instead as the Wedowee and underlying Ashland Supergroup. Hatcher et al. (2007) and Hatcher (2010) portray the Dahlonega Gold belt (New Georgia Group) as not extending into Alabama, but instead as lying within a window in western Georgia beneath the Wedowee Group and above a lower window containing the Emuckfaw and 'western Sandy Springs' units. Hatcher et al. (2007) refer to the lower window containing the Emuckfaw as the "Dog River window" (see below for discussion). The window-bounding faults in each case were mapped as unfaulted stratigraphic contacts by McConnell and Abrams (1984) and German (1984).

Recent detailed mapping at the juncture between the two belts (Barineau, 2011; Gilmer and Barineau, 2012) suggests that units assigned to the 'western Sandy Springs' Group can be traced southwest across the AL-GA state line and are correlative with rocks of the Wedowee and Emuckfaw Groups. In agreement with interpretations of Bentley and Neathery (1970) and German (1989), we see no apparent evidence for a major fault, as proposed by Hatcher et al. (2007) and Hatcher (2010), separating the two regions. As it crosses the AL-GA state line, the northeastward trending Emuckfaw-Wedowee contact turns northward, similar to interpretations by Heuler (1993). As a result, the stratigraphic section of the Emuckfaw between its lower stratigraphic contact with the Wedowee and upper tectonic contact along the Abanda fault, significantly expands in Georgia, such that higher stratigraphic levels of the Emuckfaw are progressively exposed. At the location of the Mulberry Rock recess, the

Wedowee is truncated against the Allatoona fault, and Emuckfaw-equivalent units become faulted against the Talladega belt farther northeastward. Rocks of higher stratigraphic levels in Georgia have been assigned to the Andy Mountain and Bill Arp Formations (McConnell and Abrams, 1984; German, 1988; 1989) of the 'western Sandy Springs' Group. Rocks of the 'western Sandy Springs' were correlated by McConnell and Abrams (1984) with the eastern Sandy Springs Group (Higgins and McConnell, 1978) which resides in the structurally higher Chattahoochee thrust sheet, east of the Dahlonega Gold belt. However, correlation of strata across the Chattahoochee thrust fault is tenuous, as rocks of the Chattahoochee thrust sheet are migmatitic and at a higher metamorphic grade (Holm-Denoma, 2006; Hatcher et al., 2007). We suggest, therefore, that the 'western' Sandy Springs Group nomenclature should be abandoned and formation level units should be subsumed into adjacent group level units (Holm-Denoma, 2006; Gilmer and Barineau, 2012). Unlike Holm-Denoma (2006), however, we do not assign all units of the 'western' Sandy Springs Group to the New Georgia Group, but instead suggest that rocks of the New Georgia Group correlate with the Emuckfaw Group, with units of the 'western' Sandy Springs correlating with both Emuckfaw and Wedowee Group stratigraphy.

Rocks of northwestern Georgia in Carroll, Haralson, Paulding, and Douglas counties have typically been assigned to the New Georgia Group or one of three units considered part of the 'western' Sandy Springs. McConnell and Abrams (1984) interpreted the Dog River Formation, consisting of metagraywacke and garnet muscovite schist with thin layers of banded iron formation, as the stratigraphic base of the 'western' Sandy Springs. Workers in Georgia have generally considered this unit to occupy the core of a northeast-plunging map-scale (wavelength >25 km) anticline (McConnell and Abrams, 1984; German, 1988; 1989). The overlying Andy Mountain Formation, composed of garnet muscovite biotite schist, graphitic schist, and quartzite, and Bill Arp Formation, composed of schist and gneiss (possibly metagraywacke), are interpreted as occupying the northwestern and southeastern limbs of the antiform in this interpretation. Gilmer and Barineau (2012), however, argue that rocks on the northwestern side of the 'anticline' are lithologically distinct from those on the southeastern side, dividing rocks mapped as undifferentiated Andy Mountain-Bill Arp into two separate stratigrahic units. Based on their mapping, rocks previously mapped as Andy Mountain, Bill Arp, and/or Sandy Springs undifferentiated on the northwest side of German's (1989) 'anticline' correlate with the Wedowee Group, whereas rocks of the New Georgia Group and Andy Mountain-Bill Arp Formations, whose type sections lie on the southeastern flank of German's (1989) 'anticline', correlate with the Emuckfaw Group in this interpretation. We adopt a similar interpretation here and argue that rocks assigned to the Wedowee Group in Alabama continue northeastward across the AL-GA state line where they occupy the immediate hanging wall of the Allatoona fault structurally above the Talladega belt, whereas rocks of the Emuckfaw Group correlate with those of the New Georgia Group – especially its lowermost statigraphy. McConnell and Abrams (1984) characterized the New Georgia Group (interpreted as incorporating all of the Emuckfaw Group in Alabama) as an intercalated sequence of felsic and mafic metavolcanic and subvolcanic rocks, plutonic rocks, and lesser metasedimentary rocks. The group has been subdivided into a number of formations (McConnell and Abrams, 1984) (Appendix A). At the stratigraphic base of the New Georgia Group, the Mud Creek Formation consists of amphibolite interlayered with garnet biotite schist and gneiss, banded iron formation (Cedar Lake Quartzite), and metadacite. A body of biotite-quartz-oligoclase gneiss known as the Villa Rica Gneiss is interpreted as a dacitic subvolcanic intrusive intruding the Mud Creek Formation (McConnell and Abrams, 1984). A 458±3 Ma U-Pb zircon age (Thomas, 2001) of the Villa Rica provides a minimum depositional age of the Mud Creek Formation. In a similar stratigraphic position to the Mud Creek, the Pumpkinvine Creek Formation (McConnell, 1980; McConnell and Abrams, 1984; Holm-Denoma, 2006; Holm and Das, 2010) consists of amphibolites (metabasalt) interlayered with felsic gneiss (metadacite, Galts Ferry Gneiss Member), and graphitic aluminous schist (Holm-Denoma, 2006). Metasedimentary rocks above the Pumpkinvine Creek Formation comprise the Canton Formation, consisting mostly of pelitic schist and metasandstone (metagreywacke), and are likely correlative to the stratigraphically younger sections of the New Georgia Group in the Dahlonega Gold belt to the northeast.

Because the New Georgia Group in Georgia, established by McConnell and Abrams (1981), can be correlated with the Emuckfaw in Alabama, established by Neathery and Reynolds (1975) and revised by Guthrie and Dean (1989), we argue that the earlier nomenclature (Emuckfaw) take precedence over the later (New Georgia) and propose that the entire sequence in Alabama and Georgia be referred to as the Emuckfaw Group. Importantly, the nature of the Emuckfaw Group back-arc basin changes character along strike, transitioning from a sediment rich-volcanic poor unit in Alabama to a volcanic rich-sediment poor basin in Georgia – most likely a function of the original rift architecture of the Laurentian margin inherited from Rodinian rifting.

Otto Formation

Along strike of the Dahlonega gold belt northeastward from Dahlonega, Georgia and into North Carolina, is the equivalent(?) Helen Group of Gillon (1982) and the Otto Formation of Hatcher (1988) – a unit dominated by staurolite-kyanite schist and two-mica, two feldspar metasandstone. Notably, <10% of the sequence contains mafic and mafic-ultramafic rocks (German, 1985; Hopson, 1989). Between Dahlonega and Waynesville, North Carolina, the Dahlonega Gold belt (Otto Formation) lies structurally above the western Blue Ridge, but lies spatially between the central Blue Ridge (Cowrock and Cartoogechaye terranes) on the west and the eastern Blue Ridge (western Tugaloo terrane) on the east, both of which are interpreted to occupy structurally higher thrust sheets. North of Franklin, North Carolina, the Dahlonega Gold belt and Otto Formation is covered by central Blue Ridge thrust sheets until its reemergence within the Great Balsam Mountains Window to the northeast (Hatcher et al., 2007). Grenville-aged detrital zircons from the Otto Formation (Bream, 2003) and interpretations of its subsurface contact with rocks of the western Blue Ridge to the northwest led Hatcher et al. (2007) to interpret the Otto Formation as a more outboard facies of the Great Smoky Group.

Chauga River/Poor Mountain Formation

Southeast of the Brevard Zone, the western Inner Piedmont of South Carolina contains the Tallulah Falls and Chauga River Formations, overlain by the garnet-staurolite grade Poor Mountain Formation (Bream, 2003). The Tallulah Falls contains a lower metagraywacke–amphibolite sequence and upper metagraywacke units separated by aluminous schist (Hatcher, 1978), and is overlain by graphitic phyllite, muscovite–chlorite phyllite, quartzite, and impure marble of the Chauga River Formation (Hatcher, 1969). Both units contain Grenville-aged detrital zircons and are unconformably overlain by the Poor Mountain Formation. The Poor Mountain Formation is the youngest recognized unit in the western Inner Piedmont. It is composed of relatively thick sequences of laminated to massive amphibolite and garnet mica schist, and grades upward into feldspathic micaceous quartzite interlayered with amphibolite and marble (Hatcher, 1969; Bream, 2003; Merschat, et al., 2005). Bream (2003) interpreted the Poor Mountain Quartzite to be a metamorphosed felsic volcanic or volcaniclastic unit based on Sr concentrations, rare earth element patterns and geochemical tectonic discrimination diagrams, and reported pooled U-Pb ages of 459 ± 4 and 445 ± 4 Ma for two zircon subsets, suggesting that it did not contain a single age population. At least part of this sequence is correlative with the lithologically similar Jackson's Gap Group (see above) in Alabama to the southwest (Grimes et al., 1993), which is probably the youngest preserved part of the basin in that area and also contains a similar sequence that has marble in the upper part of the section.

METAVOLCANIC ROCKS AND THEIR TECTONIC SETTING

A number of the units described above, which we believe were part of an extensive Early-Middle Ordovician back-arc basin that formed on the seaward edge of the Laurentian plate, contain bimodal volcanic assemblages of tholeiitic metabasalt and subordinate interstratified calc-akaline meta-rhyodacite. Metabasalts exhibit intermediate geochemical characteristics between those of arc basalts and MORB, typical of suprasubduction setting back-arc rocks (e.g. Holm-Denoma and Das, 2010). Some kilometer or greater-thick sections are overwhelmingly dominated by metavolcanic rocks (e.g., Hillabee Greenstone, Pumpkinvine Creek Formation), with some mafic sequences containing minor occurrences of ultramafic rocks (German, 1989; Spell and Norrell, 1990), but volcanic rocks are sparse within other sections of the basin. We consider essentially all of the volcanic rocks to be submarine because they are intercalated with deep-water sedimentary sequences. Locally, pillows and amygdules are preserved in some of the metabasalts (Hurst and Jones, 1973; McConnell and Abrams, 1984; Spell and Norrell, 1990; Holm-Denoma, 2006).

Hillabee Greenstone

The Hillabee Greenstone, is exposed for >230 km along strike on the southeast flank (structural top) of the Talladega belt (Appendix A). It is an ~2.6 km thick metavolcanic assemblage composed of tholeiitic basalt pyroclastics and lavas intermixed with lesser amounts (~25%) of calc-alkaline dacitic ash flows that are up to 150 m thick. Geochemical and geochronologic (U-Pb zircon) studies (Russell, 1978; Tull et al, 1998; Tull et al., 2007; McClellan et al., 2007) and the presence and abundance of quartz dacites (Rogers and Ragland, 1977) suggest that the Hillabee formed in the earliest Middle Ordovician (ca. 470 Ma) suprasubduction setting, most likely as part of a back-arc along the continental margin (Tull et al., 2007). Geochemical data support a suprasubduction zone setting for Hillabee volcanism and chemical analyses of immobile elements (e.g., Ti, Zr, Y) used for tectonic discrimination (e.g. Cabanis and Lecolle, 1989) suggest that mafic phyllites and greenstones of the Hillabee are geochemically similar to a hybrid of arc and ocean-floor basalts. Modest enrichment of large-ion lithophile elements, typical of suprasubduction environments, and flat rare earth element patterns, typical of a mid-ocean ridge basalt indicate geochemistry intermediate between the two settings, typical of volcanic rocks erupted in the back-arc portion of an arc setting (B-type subduction) (Tull et al., 2007). Evidence for involvement of older crust in the generation of the Hillabee Greenstone metadacites is evident in the Hf isotopic compositions of the zircons. Initial Hf isotopic compositions for five grains based on an age of 468 Ma and the Hf parameters of Patchett et al. (2004) ranged from -4 to -8 epsilon units and yielded depleted mantle model ages of 1.0–1.1 Ga,) (Tull et al., 2007). The low initial epsilon values clearly suggest that older isotopically evolved lithosphere, probably Mesoproterozoic, was involved in the generation of the felsic Hillabee Greenstone magmas. A back-arc setting for Hillabee volcanism has been suggested by Tull and Stow (1980), Durham (1993), Tull et al. (1998), and Tull et al. (2007), and the suggestion of Grenville-aged inherited components indicates the volcanic complex most likely formed just outboard of the Laurentian shelf edge.

Following its formation, the Hillabee Greenstone remained essentially undeformed for a significant time interval (>90 m.y.), until latest Devonian to mid-Mississippian (Neo-Acadian to early Alleghanian) emplacement directly upon the middle Paleozoic Laurentian shelf. The tectonic base of the Hillabee, a cryptic thrust fault (Hillabee thrust), had a flat-on-flat geometry and was probably active prior to ca. 330 Ma, but possibly as early as ca. 375 Ma (Tull et al., 2007). Importantly, no vestiges of an intervening accretionary prism or volcanic arc separate this volcanic sequence from the underlying trailing margin rocks deposited along the Laurentian shelf (see below), supporting the interpretation that the Hillabee formed within a back-arc basin proximal to the Laurentian shelf (Talladega belt). For more in depth descriptions and discussions of the Hillabee Greenstone the reader is referred to: Tull, et al., 1978; Tull and Stow, 1980; Tull and Stow, 1982; Tull, et al., 1998; and Tull, et al., 2007.

Pumpkinvine Creek Formation and other New Georgia Group Metavolcanics

The Pumpkinvine Creek Formation at the base of the New Georgia Group is a bimodal volcanic sequence intercalated with pelitic schist that has similar geochemical characteristics to the Hillabee Greensone (McConnell, 1980; Holm-Denoma and Das, 2010). It extends northeastward from Paulding County, Georgia for >118 km along strike at least to Dahlonega, Georgia, and consists of amphibolites interlayered with felsic gneiss (metadacite) of the Galts Ferry Gneiss and graphitic aluminous schist (McConnell, 1980: German, 1989; Holm-Denoma, 2006). German (1989) extended the Pumpkinvine Creek in a very narrow belt from Canton to Dahlonega, Georgia, identifying felsic gneiss interpreted as metadacite (Barlow Gneiss Member) intercalated with mafic rocks. Farther to the northeast within the Dahlonega Gold belt, Settles et al. (2002) described the Sally Free mafic complex, which includes felsic metavolcanic units of the Cane Creek Gneiss. Felsic volcanic phases of the Pumpkinvine Creek Formation and equivalent units to the northeast have been dated by U-Pb zircon analyses (ion microprobe and ICP-MS) and yielded Early to Middle Ordovician crystallization ages as follows: ~460 Ma (Galts Ferry Gneiss-Thomas, 2001); 466.1 ± 5.2 Ma and 461.8 ± 3.3 Ma (Galts Ferry Gneiss-Holm-Denoma and Das, 2010); 463 ± 3 Ma and 466 ± 5 Ma (Barlow Gneiss-Thomas, 2001); 482 ± 7 Ma (Cane Creek felsic gneiss-Settles, 2002 and Bream, 2003). Metabasalt geochemistry from the Pumpkinvine indicates compositions derived from a suprasubduction setting, and have generally been interpreted as suggesting formation within a back-arc. εNd values of +3.3 to +7.7 and initial $^{87}Sr/^{86}Sr$ ratios of 0.7044–0.7069 indicate a juvenile source for the metabasalts, while εNd values of −3.2 to +4.65 and initial $_{87}Sr/_{86}Sr$ ratios of 0.709–0.722 provide evidence for involvement of older crust in the generation of the Pumpkinvine felsic units, and suggest incorporation of an evolved crustal component interpreted as Laurentian continental lithosphere (Holm-Denoma and Das, 2010). This interpretation is supported by T_{DM} ages between 1.2 and 2 Ga for the Cane Creek Gneiss (Bream (2003). Like the Hillabee Greenstone, a back-arc setting for Pumpkinvine Creek/Dahlonega Gold belt volcanism was suggested by many authors, including: McConnell (1980), McConnell and Abrams (1984), German (1989), Hopson, (1989), Spell and Norrell (1990), Thomas (2001), Settles (2002), Bream (2003), Holm-Denoma (2006), and Holm-Denoma and Das (2010). Spell and Norell (1990) concluded that other metavolcanic sequences (mostly mafic) in the Mud Creek Formation of the New Georgia Group in the Villa Rica area were also erupted in a back-arc setting.

Preliminary Geochemical Results from AWEB Amphibolites

The AWEB is volumetrically dominated by deep-water metasedimentary rocks. However, minor orthoamphibolites occur throughout the entire AWEB and are generally interpreted as tholeiitc ocean-floor basalts and associated sills intercalated with rift-related sediments (submarine fan and anoxic basin deposits) (Drummond, 1986; Allison, 1992; Tull et al., 2007). While the Ashland Supergroup and lower Wedowee Group may have been deposited along the rifted margin of Laurentia during the Neoproterozoic-earliest Ordovician, there is evidence that the upper Wedowee and Emuckfaw basin formed in a back-arc setting during the Early-Middle Ordovician (see detrital zircon discussion below) and is further supported by occurences of well dated Ordovician backa-rc sequences (Hillabee Greenstone and Pumpkinvine Creek Formation). Preliminary geochemical studies of amphibolites from the AWEB (Holm-Denoma upub. data, 2012) include those from the Poe Bridge Mountain Group (Ashland Supergroup) and Wedowee and Emuckfaw Groups. All amphibolites from this sample set have tholeiitic basalt compositions and exhibit geochemical values between those of volcanic arc rocks and normal mid-ocean ridge basalts (MORB) Generally, these rocks are moderately enriched in large-ion lithophile elements (LILE) and have high-field strength element (HFSE) compositions similar to MORB, a common signature of flux melting (Fig. 1A).. The enrichment of LILE's is typically due to dehydration of the subducting slab and emancipation of volitiles, or mobile elements (e.g. Ba, Rb, Th) into the asthenosphere. Volcanic arc rocks are typically more differentiated than MORB rocks and have high enrichment of LILE's, while typically depleted in HFSE's. In back-arc eruptive environments, the melt typically retains the signature of MORB in regards to immobile HFSE and rare earth elements (Fig. 1B), but is slightly enriched in volatiles derived from the subducting slab.

In addition to typical 'spider diagram plots (Figs. 1A and 1B), tectonic discrimination diagrams can be useful for distinguishing between petrologic processes associated with magmagenesis in different tectonic environments. Useful elements include Ti and V for determining the tectonic setting of basalts, as they behave differently from one other during magmagenesis but are not typically affected by hydrothermal alteration or medium to low-grade metamorphism. Variability of V is a function of oxygen activity in the magma (reduced vs. oxidized), while Ti only exists in one state (Ti4+). Variations in V concentrations relative to Ti can thus be linked to the environment of eruption (Shervais, 1982). AWEB amphibolites plot gererally in the back-arc basin basalt/MORB field, similarly to amphibolites of the Dahlonega Gold belt and Hillabee Greenstone (Fig. 1C). There is overlap between Poe Bridge Mountain Group amphibolites and those of the Emuckfaw Group. However, an average Ti concentration of amphibolites analyzed suggest higher concentrations of Ti in Poe Bridge Mountain amphibolite relative to Ti concentrations in Emuckfaw amphibolites. This gives Poe Bridge Mountain amphibolites a slightly more "within-

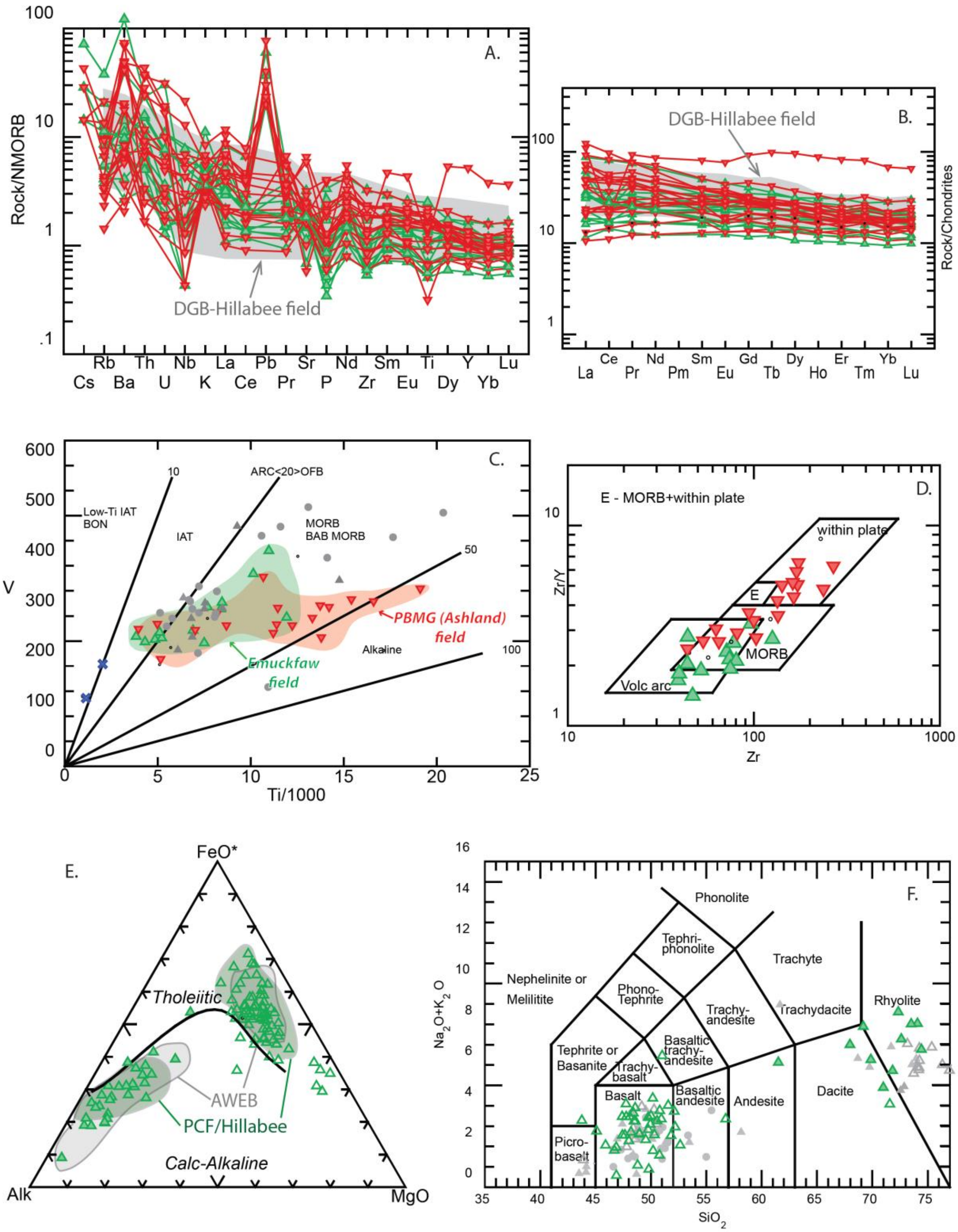

Figure 1 Geochemical plots of Ashland-Wedowee-Emuckfaw belt (AWEB) (Holm-Denoma, unpubl. Data, 2012) and Dahlonega gold belt (DGB) amphibolites and Hillabee Greenstones (plus minor metarhyodacites). Figures A-D: green triangles-Emuckfaw amphibolites; red triangles-Poe Bridge Mountain Group (PBMG) amphibolites.Figures A and B, DGB-Hillabee field derived from Thomas (2001), Settles (2002), and Holm-Denoma and Das (2010 and references therein). (A) Spider plot of amphibolites normalized to NMORB (normal mid-ocean ridge basalt) of Sun and McDonough (1989). (B) Rare Earth element spider diagram of amphibolites normalized to chondrite of Sun and McDonough (1989). (C) Ti-V tectonic discrimination diagram of Shervais (1982). Gray circles from Otto Formation (DGB) Settles (2002); Gray triangles represent data from the Pumpkinvine Creek Formation (DGB) of Holm-Denoma and Das (2010). BlueX –Rpes Creek amphibolite. IAT-island arc tholeiite; BON-boninite; MORB-mid-ocean ridge basalt; BAB-backarc basin; OFB-ocean floor basalt. (D) Zr/Y-Y basalt discrimination diagram of Pearce and Norry (1979). Volc arc-volcanic arc. (E) AFM diagram of Irvine and Barrager (1971). Open triangles- all compiled amphibolites/greenstones from DGB and AWEB; Closed triangles- metarhyodacites associated with amphibolites. Alk-total alkalis; FeO*-total Fe. (F) Total alkalis-silica diagram of Le Maitre et al. (1989). Green open triangles- AWEB amphibolites; Green closed triangles- AWEB metarhyodacites. Gray circles and triangles from same sources as (C).

plate" character than Emuckfaw amphibolites overall – which tend to resemble amphibolites of the Dahlonega Gold belt (Fig. 1C). Zr is often used as a fractionation index and, plotted against Zr/Y, can be used to differentiate basalts from island arcs, MORB and within-plate settings (Pearce and Norry, 1979). Overall, Poe Bridge Mountain amphibolites have a much more within-plate affinity than Emuckfaw amphibolites (Fig 1D). Further geochemical and geochronological studies should provide better constraints on processes that occurred in the AWEB and research is ongoing in this area.

Two samples of Ropes Creek amphibolite from the Dadeville complex were analyzed as part of this preliminary work. Interestingly, these rocks have compositions more similar to low-Ti island arc basalts or boninites, which are typical of forearc intrusive rocks, when plotted on a Ti vs. V diagram (Fig. 1C). It is possible that amphibolites of the Ropes Creek in the Dadeville Complex may have formed as part of a volcanic arc *senuo stricto*, but further work, especially constraints on the crystallization age for these rocks, are needed to make any type of correlation with the suprasubduction back-arc system discussed here.

Metavolcanic rocks of the Dahlonega Gold belt (including the Otto and Pumpkinvine Creek Formations), the Hillabee Greenstone and AWEB have minor felsic components and are thus bimodal in nature. The felsic rocks are calc-alkaline and are typically rhyolitic to dacitic in composition (Fig. 1E and F), with a silica gap between 53% and 68% SiO_2. Intermediate rocks typical of volcanic arcs *sensu stricto* are notably absent in the AWEB and Dahlonega gold belt.

Poor Mountain Formation

Hatcher et al. (2007) suggested that the Poor Mountain Amphibolite on the west flank of the Inner Piedmont in North and South Carolina was an arc-associated sequence. The sequence is dominated by a basal amphibolite (Poor Mountain Amphibolite) unit that grades up into a quartzofeldspathic unit, the Poor Mountain Quartzite, and a local marble unit. Trace element chemistry suggests a likely mafic volcanic arc or MORB setting for the amphibolite sequence (Davis, 1993; Yanagihara, 1994; Bream, 2003; Kalbas, 2003). The Poor Mountain Quartzite (metatuff?) is interpreted to have a felsic volcanic or volcaniclastic protolith, and zircons from this unit yield U-Pb ages of 459 ± 4 and 445 ± 4 Ma in two data subsets (Bream, 2003). Thus, the entire Poor Mountain sequence likely has a Middle to Late Ordovician age.

METALLIFEROUS DEPOSITS

Stratabound metalliferous deposits are hosted by a number of units within the basin, most prominently the New Georgia Group and the Hillabee Greenstone, but also by the Dog River Formation and the Wedowee and Jacksons Gap Groups. In the New Georgia Group, gold, sulfide, magnetite, and manganese deposits were formed contemporaneously (syngenetically) within a dominantly bimodal volcanic sequence and are related spatially and genetically (McConnell and Costello, 1982; McConnell and Abrams, 1984; German, 1989). Deposition of metals was contemporaneous with deposition of host rocks. Metals were leached by convecting thermal waters and precipitated in siliceous horizons (chemically precipitated exhalites) or incorporated into contemporaneous tuffs, flows, and sediments (German, 1989). Later, during metamorphism, gold was remobilized and redeposited in siliceous layers where it occurs in either structurally controlled ore shoots or gold-bearing quartz bodies ("sweat-outs"). Massive and disseminated sulfide deposits are also closely associated with the gold deposits, occurring within the same units (Abrams and McConnell, 1984, 1986). Most of these deposits are associated with oxide and sulfide facies Algoma-type banded iron-formation and lithologies interpreted as metamorphiosed alteration zones (Abrams and McConnell, 1984, 1986). German (1989) concluded, based upon whole-rock and trace element geochemistry of mafic metavolcanic host rocks and the presence of abundant interlayered metasediments, that rocks of the Dahlonega and Carroll County gold deposits formed in a back-arc basin environment.

Conformable zones of strata-bound massive sulfide deposits that occur near the structural base of the Hillabee Greenstone in Alabama (Pyriton) and Georgia (Tallapoosa) are several meters thick and extend laterally for 10's of kilometers (Tull and Stow, 1982). These sulfide deposits are interpreted as syn-sedimentary sea-floor deposits. The deposits are similar to other volcanogenic massive sulfide deposits in suprasubduction settings with respect to geometry, structural history, associated rocks, base metal abundances, and

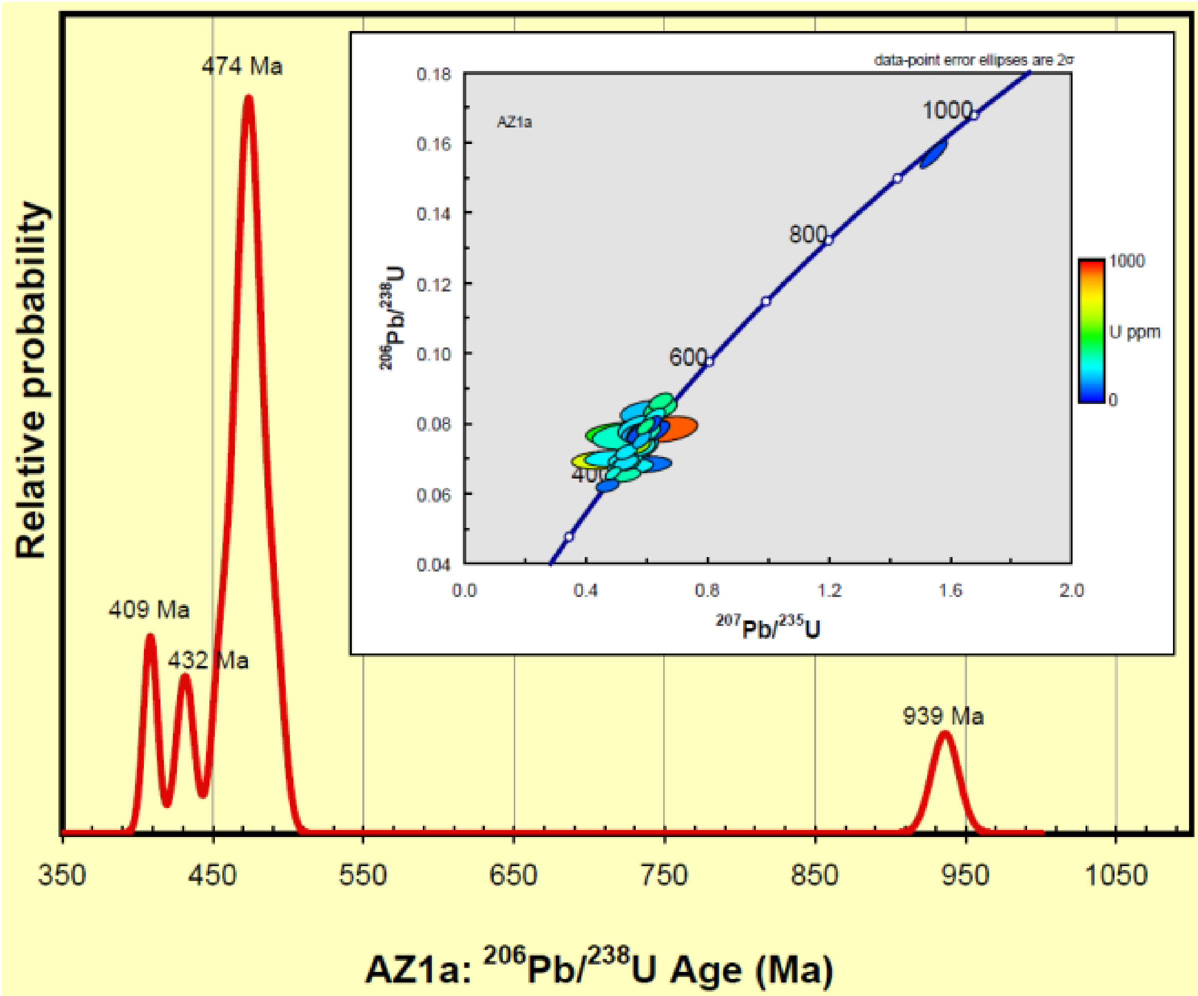

Figure 2 Concordia diagram and Pb206/U238 pooled ages for detrital zircons from the lowermost Emuckfaw Group (Josie Leg Member).

igneous character of the host rocks (Stow and Tull, 1982). They are interpreted as the primitive type of exhalative, strata-bound, Type I Zn-Cu-pyrite volcanogenic deposits associated with suprasubduction processes (Hutchinson, 1980). These deposits show poor metal zoning, lack of wall-rock alteration, and significant Zn and Cu values. Such deposits typically form at consuming plate margins during early island arc volcanism, are Zn-Cu-rich, and are associated with tholeiitic to calc-alkaline marine volcanic rocks and immature sedimentary and volcanoclastic rocks. These types of deposits are similar to metalliferous hydrothermal deposits in a number of failed- or intra-crustal rifts as seen in the massive sulfide ores of the Hokuroku district, Japan (Ohmoto and Skinner, 1983). The Pyriton deposits are strongly associated with the primitive type of deposits exhibiting significant Zn and Cu contents. Banded iron formation and rare gold occurrences have also been reported from the Hillabee Greenstone.

DETRITAL COMPONENT SOURCES

The thick and extensive sedimentary basinal sequences described above represent a significant depocenter filled with voluminous amounts of immature, mostly fine-grained, rhythmically bedded, flysch-like (turbidite) deposits. Understanding sediment provenance is an important key to interpreting their tectonic setting. One of the most powerful tools in sedimentary provenance analysis is determination of the age of the suite of detrital zircons contained in the coarser-grained components. Fortunately, several investigators have acquired detrital U-Pb zircon ages from a number of the units within the basin described above.

The Otto Formation in North Carolina yields detrital U-Pb zircon ages between 712 Ma and 1,600 Ma, whereas two samples of metasediments in the Dahlonega Gold belt near Dahlonega, Georgia yielded detrital U-Pb zircon ages of between 633 and 2,900 Ma (Bream et al., 2004). Farther southwest, in the Dahlonega gold belt near Canton, metasandstone in the Canton Schist yields detrital U-Pb zircon ages between 513 and 1,582 Ma (Holm-Denoma and Das, 2010). A sample from the Bill Arp Formation (designated "Emuckfaw Formation") in the 'western' Sandy Springs Group ~25 km west of Atlanta yields detrital U-Pb zircon ages of 850 to 1,933 Ma (Merschat et al., 2010). All of the samples discussed above have detrital zircon age population peaks (950-1200 Ma) typical of sediments derived from "Grenville" crust and older components common to older crustal domains of North America. Still farther south, in Alabama, metagreywacke in the Josie Leg Formation, near the base of the Emuckfaw Group, yields a preponderance of Mesoproterozoic detrital U-Pb zircon ages (Fig. 2), but importantly, also a significant population of ca. 474 Ma zircons (Barineau et al., 2012; C. Holm-Denoma, unpublished data, 2011). Additionally, the euhedral, morphology of many of the grains within this metagreywacke unit suggests a proximal source. A more physically and chemically mature meta-sedimentary sample from the Wedowee was analyzed for detrital zircon U-Pb age populations (Figs. 3 and 4). Detrital zircons ranged in age from 475 to 1,475 Ma, with a typical "Grenville" peak between 900 and 1,180 Ma. A small zircon population of "young" 457 Ma detrital zircons provide a maximum age of deposition (Barineau et al., 2012; C. Holm-Denoma unpublished data, 2012). The Josie Leg and Wedowee samples confirm the presence of an Ordovician or younger age for the back-arc basin(s). These latter ages are the youngest detrital zircons thus far obtained from the eastern Blue Ridge basinal sequence under discussion. Southeast of the Emuckfaw, the Tallassee Quartzite in the Jackson's Gap Group yields detrital U-Pb zircon ages between 944 and 1,544 Ma (Steltenpohl et al., 2005).

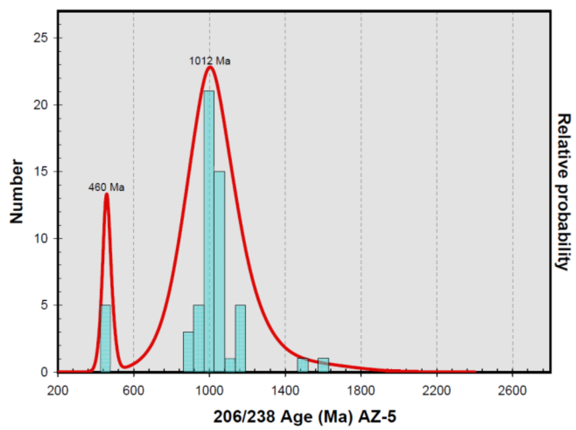

Figure 3 Pb206/U238 pooled ages for detrital zircons extracted from the upper Wedowee Group.

It is not always clear whether or not detrital zircon analyses are statistically representative of the source terrane, and some ages do not imply a unique source. However, for all of the units analyzed thus far from this basin, Mesoproterozoic (1.3-1.0 Ga) detrital zircons are overwhelmingly the dominant population. These ages do not imply a unique source but are typical of Laurentian crustal materials formed during the Grenville orogeny (Rodinian collision) and most likely represent sediment derived from the adjacent Laurentian continental margin or exposed rifted-margin basement blocks along that margin. Older age peaks between ~1.3 and 1.5 Ga are not uncommon, and correspond to ages of Laurentia's eastern Granite-Rhyolite province (Becker et al., 2005). The few Paleoproterozoic (1.9–2.2 Ga) zircon ages could suggest a more exotic origin, such as the Amazonian craton, although they could have been derived from Amazonian-linked southern Appalachian basement massifs, or alternatively from the Laurentian Penokean orogen (Merschat et al., 2010). Some of the younger spectra of ages in the detrital zircon suites may be related to synrift (Iapetan rifting) igneous rock. In summary, the

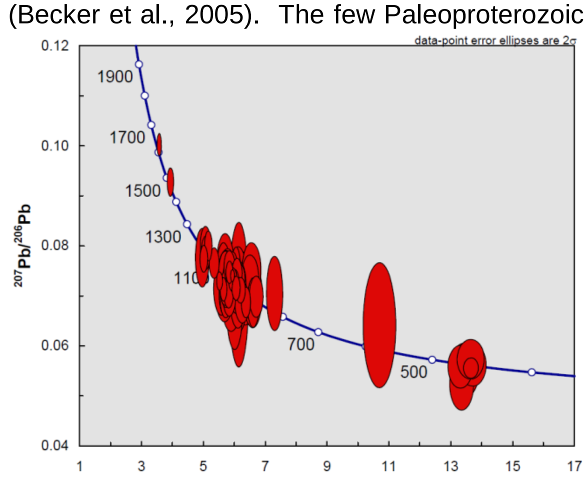

Figure 4 Concordia diagram for detrital zircons from the upper Wedowee Group.

detrital zircon data are consistent with a Laurentian source for the basin sediments.

As noted above, isotopic compositions of felsic volcanic rocks erupted into the basin lead to a similar conclusion. For the Hillabee Greenstone, for example, initial Hf isotopic compositions of zircons ranged from -4 to -8 epsilon units and yielded depleted mantle model ages of 1.0–1.1 Ga, suggesting that older litho-sphere (probably Mesoproterozoic) was involved in the generation of the felsic Hillabee magmas (Tull et al., 2007). In the case of the Pumpkinvine Creek felsic volcanics, ΣNd values of −3.2 to +4.65 and initial $_{87}Sr/_{86}Sr$ ratios of 0.709–0.722 also provide evidence for involvement of older crust in the generation of the Pumpkinvine magmas (Holm and Das, 2010), an interpretation supported by T_{DM} ages between 1.2 and 2 Ga for the Cane Creek Gneiss (Bream (2003).

WHY A BACK-ARC BASIN, AND WHY LAURENTIAN?

In the preceding sections we summarized why we feel that a back-arc basin along the eastern Laurentia continental margin tectonic model best fits the environments of deposition for the rocks of the Jackson's Gap Group, Emuckfaw Group, Opelika Group, Hillabee Greenstone, New Georgia Group, Pumpkinvine Creek Formation, Otto Formation, and Poor Mountain Formation. We also outlined the abundant evidence indicating that rocks of this basin are Early to Middle Ordovician in age, and must be tied to Early-Middle Ordovician extensional accretionary orogenesis. Although most workers (e.g. Tull et al., 2007) have historically considered rocks of the Emuckfaw Group as well as the entire Ashland-Wedowee-Emuckfaw belt to be part of the Neoproterozoic to Cambrian Laurentian rifted margin slope/rise sequence, this does not appear to be the case. The overwhelming opinion of the numerous researchers who have worked on the volcanic rocks found within the basin described here is that they are volcanic arc-related, and more specifically, back-arc-related (McConnell, 1980; McConnell and Abrams, 1984; German, 1989; Hopson, 1989; Spell and Norrell, 1990; Tull et al., 1998; Thomas, 2001; Settles, 2002; Bream, 2003; Holm-Denoma, 2006; Tull et al., 2007; Holm-Denoma and Das, 2010). Although no single line of evidence conclusively links these rocks to a back-arc setting, the collective dataset on the rocks described above display the following characteristic of back-arc basin volcanic sequences: 1) metabasalts that display both MORB and volcanic arc geochemical trends, 2) bimodal volcanism, with a predominance of mafic over felsic (rhyo-dacitic) volcanics, 3) Cu-Zn-dominated base-metal deposits and metalliferous hydrothermal deposits commonly associated with failed or intra-crustal rifts, particularly extensional back-arc regions (Ohmoto and Skinner, 1983), 4) the presence of subvolcanic felsic plutons (e.g., Villa Rica Gneiss-McConnell and Abrams, 1986) within the volcanic pile, and 5) abundant chemical sediments, like banded iron formation. The fact that multiple units in the overall stratigraphic section contain metavolcanics may suggest multiple episodes of backarc basaltic magmatism.

The abundance of detrital zircon ages typical of Laurentian crust indicates a proximal basement source, and not a juvenile arc source. Grenvillian, Granite/Rhyolite province, Yavapai/Mazatzal, and trans-Hudson/Penokean-age detrital zircon from the basin's metasedimentary rocks, and isotopically evolved Nd signatures in the Pumpkinvine Creek Formation metadacites (Holm-Denoma and Das, 2010), and isotopically evolved Hf in zircons from the Hillabee (Tull et al., 2007) suggests the presence of rifted Laurentian basement beneath or along the basin flanks.

This Ordovician basin is most likely not an arc accretionary prism or volcanic arc proper because the basin fill is mostly deep-water metasediments, with a volcanic fraction of <20% of the total section. In addition, the older, underlying Neoroterozoic-Eocambrian(?) AWEB strata (e.g., the Ashland Supergroup and perhaps the lower Wedowee Group (?) in Alabama) does not appear to have received subduction-generated magmas associated with a continental arc during the span of basin formation.

Finally, among the most compelling arguments that this sequence formed in a Laurentian-margin back-arc are the structural setting and geochemical characteristics of the Hillabee Greenstone. The Hillabee occurs structurally above the late Early Devonian to earliest Mississippian(?) Jemison Chert/Erin Slate of the Talladega Group along the cryptic Hillabee thrust. In order to emplace the Hillabee atop rocks of the Talladega Group in a flat-on-flat geometry, which post-dated back-arc volcanism by > 90 m.y., there must have been little or no prior deformation of hanging or footwall units (Tull et al., 2007). Age constraints on these sequences suggest emplacement of the Hillabee along a pre-metamorphic fault during the latest Devonian or earliest Mississippian (Tull et al., 2007; McClellan et al., 2007; Barineau, 2009). These constraints on the emplacement of the Hillabee, in addition to the isotopic signatures (e.g., **ε**Hf) of its zircons, suggest that its Ordovician palinspastic position was relatively proximal to the Laurentian margin prior to its Devonian-Mississippian emplacement (Tull et al., 2007). This is in contrast to an arc-continent collisional model for the Hillabee, i. e., an exotic (non-Laurentian) volcanic arc setting (A-type subduction) (e.g., McCellen et al., 2007), in which Laurentian cover rocks would have been overlain first by a thick thrust-emplaced accretionary prism complex, perhaps complete with mélange and low temperature-high pressure rocks, then by the overriding arc complex proper, and finally by any back-arc-basin sequences.

It is unlikely that an Ordovician back-arc complex formed on an overriding exotic plate of an A-type subduction zone (i.e. eastward subduction of the Laurentian margin beneath an exotic arc), was obducted <u>over</u> a broad arc, forearc, and accretionary prism, to lie directly on the Laurentian shelf, with no vestiges of the arc-forearc-accretionary prism in between. In our model, arc rocks *sensu stricto* would have developed outboard and east of the proposed back-arc terrane, and would have been rifted away from the Laurentian margin, similar to the separation of Japan from the Asian mainland during formation of the Sea of Japan (Kim et al., 2007). This model for the initial phases of the Taconic orogeny in the southern Appalachians would explain the position of rocks interpreted as an accretionary prism in North and South Carolina and north Georgia (parts of the Cartoogechaye-Cowrock-and western Tugaloo terranes; Raymond et al., 1989; Hatcher et al., 2007; Anderson and Moecher, 2009) and arc plutons (Persimmon Creek Gneiss – Cowrock terrane; Whiteside pluton – western Tugaloo terrane), which must be palinspastically restored to a position outboard of the Dahlonega Gold belt (Hatcher et al., 2007), atop rocks which originated in the back-arc. An additional candidate for part of the arc complex itself is the Dadeville complex in Alabama, which occurs structurally atop the eastern Blue Ridge back-arc sequence along the Stonewall Line and the Brevard zone (Appendix A). The Dadeville complex is an extensive mafic and ultramafic complex in Alabama's Inner Piedmont, with metanorites, metagabbros, and metaorthopyroxenites intrusive into metabasalts of the Ropes Creek and intercalated with pelitic metasedimentary rocks (Bentley and Neathery, 1970, Sears et al., 1981; Stow et al., 1984; Neilson and Stow, 1986). Abundant geochemical evidence strongly indicates formation of this complex within a volcanic arc environment (Stow et al., 1984; Neilson and Stow, 1986). Unfortunately, at present there is very little absolute age data to constrain the age of the complex.

REFERENCES (See Combined References)