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# Geology of the Jacksonville 7.5 Minute Quadrangle and U–pb and (U–th)/HE Reveal Sediment Routing and Uplift in the Southern Appalachian Valley and Ridge Province

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# GEOLOGY OF THE JACKSONVILLE 7.5 MINUTE QUADRANGLE AND U–PB AND (U–TH)/HE REVEAL SEDIMENT ROUTING AND UPLIFT IN THE SOUTHERN APPALACHIAN VALLEY AND RIDGE PROVINCE

A Master's Thesis

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In Partial Fulfillment

Of the Requirements for the Degree

Master of Science, Geography and Geology

By

Derek L Spurgeon

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**ABSTRACT**

The southern Appalachian Mountains have experienced multiple deformation events having undergone two full Wilson cycles. The foreland Valley and Ridge province is composed of sedimentary Paleozoic rock that range in age from earliest Cambrian to Middle Pennsylvanian. This sedimentary basin was intensely folded and faulted during the collision of Gondwana during the Middle to Late Carboniferous Period. From previous geologic structural mapping that has taken place, some large-scale structures in the Valley and Ridge Province seem to be out of sequence. To better understand the relationships in these structures, geologic mapping in high detail at the 1:24,000 scale coupled with detrital zircon U—Pb and (U—Th)/He data can provide a better insight into the sequence of these structures as well as sediment routing during the transition from a passive margin to an active convergent plate boundary and on to full continent on continent collision. For this study the Jacksonville East 7.5minute quadrangle was studied due because of its exposure of Cambrian siliciclastic strata as well as its proximity to the Talladega-Cartersville fault which separates the sedimentary rocks of the Valley and Ridge Province and the metamorphic rocks of the Inner Piedmont Province.

**KEYWORDS**: Alabama, structural geology, geologic mapping, thermochronology, geochronology, zircon, sedimentology

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# OVERVIEW

The southern Appalachian Mountains have experienced multiple deformation events having undergone two full Wilson cycles. In Alabama, the rocks and structures that belong to the Appalachian orogenic belt can be broken up in distinct physiographic provinces (Figure 1). The foreland Valley and Ridge province is composed of sedimentary Paleozoic rock that range in age from earliest Cambrian to Middle Pennsylvanian. This sedimentary basin was intensely folded and faulted during the collision of Gondwana during the Middle to Late Carboniferous Period. Typical orogenic wedge construction dictates that the beginning of deformation begins in the hinterland near the orogenic collision (Graveleau et al., 2012). As the stress builds, it is propagated farther into the foreland (Hatcher Jr et al., 1989; Dahlen, 1990). From previous geologic structural mapping that has taken place, some large-scale structures in the Valley and Ridge Province seem to be out of sequence. To better understand the relationships in these structures, geologic mapping in high detail at the 1:24,000 scale coupled with detrital zircon U—Pb and (U—Th)/He data can provide a better insight into the sequence of these structures as well as sediment routing during the transition from a passive margin to an active convergent plate boundary and on to full continent on continent collision. For this study the Jacksonville East 7.5minute quadrangle was studied due because of its exposure of Cambrian siliciclastic strata as well as its proximity to the Talladega-Cartersville fault which separates the sedimentary rocks of the Valley and Ridge Province and the metamorphic rocks of the Inner Piedmont Province.

**PART 1: GEOLOGY OF THE JACKSONVILLE EAST 7.5—MINUTE QUADRANGLE**

## Abstract

The Jacksonville 7.5-minute quadrangle in eastern Calhoun and northwestern Cleburne County, Alabama, is in the Weisner Ridges district of the Alabama Valley and Ridge and the Piedmont Uplands physiographic provinces (Figure 1). The rocks that are exposed in the quadrangle are sedimentary clastic and carbonate rocks part of the Appalachian thrust belt and low grade metamorphic rocks that are part of the Appalachian piedmont of the Appalachian orogen (Plate 1). The Appalachian thrust belt consists of Paleozoic sedimentary and metamorphic rocks that range from Cambrian to Pennsylvanian in age. Alleghenian aged northeast-striking, northwest directed thrust faults and thrust related folds and include, the Pell City fault, the Whites Gap window, Jacksonville fault, Dugger Mountain fault, Dugger Mountain syncline, and Talladega-Cartersville fault. Formal sedimentary units in the valley and ridge include the Nichols Formation; Weisner and Wilson Ridge Formations undifferentiated; Shady Dolomite; Rome Formation; Conasauga Formation; Knox Group undifferentiated; Athens Shale and Floyd Shale undifferentiated; and Parkwood Formation and Floyd Shale undifferentiated. The metamorphic stratigraphy of the Alabama piedmont includes the Kahatchee Mountain Group; Heflin Phyllite; and Lay Dam Formation.

In the northwestern section of the Jacksonville East quadrangle the Pell City fault emplaces the Pell City thrust sheet in the hanging wall on the Helena thrust sheet in the footwall. In the southwestern section of the quadrangle the Whites Gap window exposes rocks belonging to the Floyd Shale and Athens Shale undifferentiated from beneath the Pell City thrust sheet. The Jacksonville fault is located near the base of Choccolocco Mountain in the western edge of the quadrangle. The Jacksonville fault carries the Early Cambrian rocks of the Choccolocco thrust complex upon the Pell City thrust sheet in the footwall. Choccolocco Mountain thrust complex is

formed by a duplex composed of Chilhowee Group thrust sheets. The thickness of these thrust sheet varies widely due to the amount of interbedded shale layers that allow the detachment to vary from sheet to sheet. In the central part of the map lies the Dugger Mountain thrust complex. Similar to the Choccolocco Mountain thrust complex, this area is composed of a duplex of Chilhowee Group and Shady Dolomite rocks. These rocks are in the hanging wall of the Dugger Mountain fault and rest directly above the Jacksonville thrust sheet. In the southeast part of the quadrangle, the Jacksonville thrust sheet is cut by the Talladega-Cartersville fault. The Talladega-Cartersville fault places metamorphic rocks that range from slates, phyllites, and quartzites in the hanging wall above sedimentary rocks of the Valley and Ridge in the footwall.

**Introduction**

The Jacksonville East 7.5-minute quadrangle is within eastern Calhoun and northwestern Cleburne counties, Alabama. While the easternmost portions of the city of Jacksonville are located along the western limit of the quadrangle, the Jacksonville quadrangle contains mostly rural land and forest, with a few small crossroad communities at White Plains, Rabbittown, and Nances Creek. Alabama Highway 21 is present in the northwest corner of the Jacksonville East quadrangle and connects the cities of Jacksonville (to the west) to Piedmont (to the northeast). Alabama Highway 9 runs north-south through the central portion of the quadrangle connecting the city of Piedmont to the Interstate 20 corridor to the south. Calhoun County Road 57 (Cottaquilla Road) and Whites Gap Road cut through a mountain pass along the Choccolocco Mountain ridge, connecting the AL-9 corridor with Jacksonville.

**Location**

Jacksonville East 7.5-minute quadrangle (33°45′00″ to 33°52′30″ latitude; 85° 37′ 30″ and 85 °45′ 00″ longitude) (Figure 1) contains the border between the Weisner Ridges district of the Alabama Valley and Ridge and the Northern Piedmont Upland district of the Alabama Piedmont (Sapp and Emplaincourt, 1975). The Jacksonville East 7.5-minute quadrangle is dominated by three major ridges and low valleys that are located between them. Choccolocco Mountain is the easternmost of these prominent ridges. Choccolocco Mountain is a prominent ridge that trends north-south in the western portions of the map and bends towards the northeast near Chimney Peak. There are several prominent peaks along Choccolocco Mountain, Hurricane Mountain (1876 feet elevation above sea level), Chimney Mountain (1272 feet elevation above sea level), and the Chimney Peak (1700 feet elevation above sea level). Dugger Mountain ridge, a prominent ridge that dominates the eastern half of the map, trends north-south, parallel to Choccolocco Mountain. Several prominent peaks along the Dugger Mountain include Red (1500 feet of elevation) and Berry Mountains (1460 feet elevation above sea level) which are located in the north portion of the ridge. The southernmost extent of the Dugger Mountain ridge is Cottaquilla Mountain, a set of smaller ridges that terminate to the south in the Choccolocco Creek, Cottaquilla Creek valley. In the southeastern section of the quadrangle the topography changes from linear ridges and valleys to lower relief ridges within a deranged drainage pattern of hills.

Choccolocco Mountain is largely within the Talladega National Forest, while Dugger Mountain is a wilderness area within the national forest. The southeast corner contains the Choccolocco Wildlife Management Area and the Mountain Longleaf National Wildlife Refuge is to the southwest on the adjacent Anniston and Choccolocco quadrangles. An abandoned iron

mining operation is located near Red Mountain and Kings Gap. Several open gravel pits are located throughout the quadrangle. Other notable features that are located on the Jacksonville East quadrangle is the Pinhoti Trail located along the very northern portion of the quadrangle which connects the Alabama Appalachian Mountains to the Appalachian Trail. Whitesides Mill Lake which is used for recreational uses is located in the southeastern corner of the quadrangle.

The city of Jacksonville contains the largest population center in the quadrangle map. Jacksonville is ~25 miles southeast of the city of Gadsden. Jacksonville is located on the west central most portion of the map. Small communities within the field area include Nance's Creek, White Plains, and the small community of Rabbittown.

**Geologic Setting**

The southern Appalachian fold and thrust belt consists of Paleozoic sedimentary rocks that were deformed during the Alleghenian orogeny (Hatcher et al., 1989). Juxtaposed to the fold and thrust belt is the Talladega slate belt, a province characterized by low-grade metamorphic rocks (Hayes, 1891; Bearce, 1973). Appalachian mountain building created a series of northeast-southwest striking thrust faults and fault-related folds. Major geologic structures that are located on the Jacksonville East quadrangle include, the Jacksonville fault, Choccolocco thrust complex, Whites Gap window, Dugger Mountain thrust complex, Talladega-Cartersville fault and, the Pell City fault.

**Previous Investigations**

The regional geology of the Jacksonville East quadrangle was first mapped by Smith et al., (1894) and some of the larger structures that affect the area were described by Hayes (1891).

Adams and others (1926) Geologic Map of Alabama (1:500,000 scale) compiled and summarized detailed mapping and more accurate descriptions of units of previous surveys. The adjoining report Paleozoic Rocks in Alabama by Butts (1926) provided further description of units and paleontological data for age correlation.

More detailed mapping was done by Warman and Causey (1962in countywide mapping of Calhoun County at 1:63,360 scale. More detailed work into the composition and structure of the Talladega slate belt in the vicinity was described by Bearce (1973). A detailed investigation into the Jacksonville fault and the stratigraphy related to the Jacksonville area were reported on by Osborne and Szabo (1984). The most recent state geologic map was compiled by Osborne and Szabo (1988). Nearby1:24,000 scale mapping has been conducted for the adjacent Jacksonville West (Jackson et al., 2015) and Piedmont Northwest 7.5 minute quadrangles (Jackson, 2016) but remain as of 2020 unpublished.

**Stratigraphy**

The Jacksonville East quadrangle is underlain by Paleozoic rocks that range from Early Cambrian to Late Mississippian in Age with extensive Quaternary alluvial sediments covering major stream valleys (Figure 2). Formal sedimentary units in the Valley and Ridge include the Nichols Formation; Weisner and Wilson Ridge Formations undifferentiated; Shady Dolomite; Rome Formation; Conasauga Formation; Knox Group undifferentiated; Athens Shale and Floyd Shale undifferentiated; and Parkwood Formation and Floyd Shale undifferentiated. The metamorphic stratigraphy of the Alabama Piedmont includes the Kahatchee Mountain Group; Heflin Phyllite; and Lay Dam Formation.

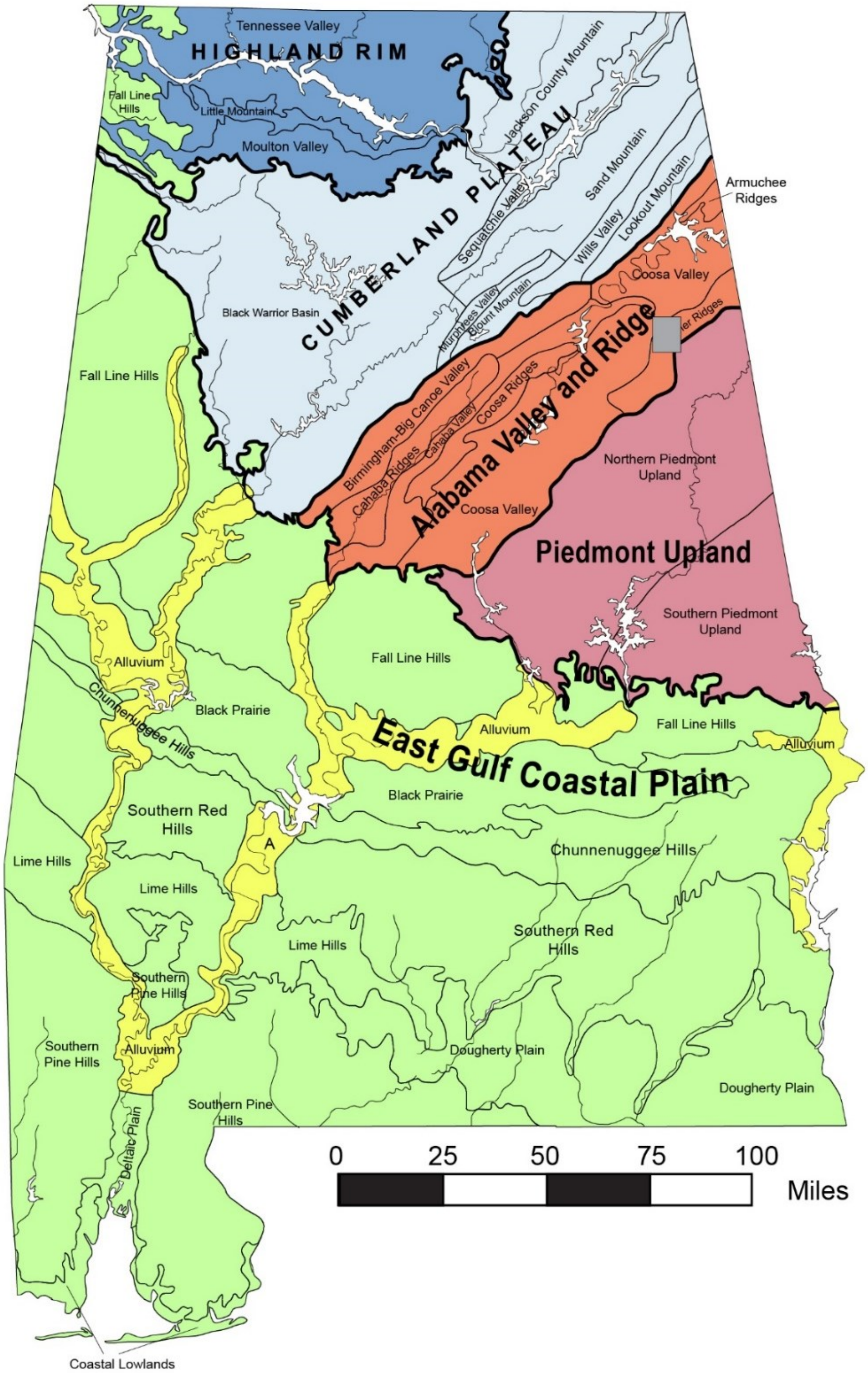


Figure 1. Physiographic map of Alabama displaying major geologic provinces as well as the Jacksonville East 7.5 minute quadrangle, Calhoun and Cleburne counties (modified from Sapp and Emplaincourt, 1975).

**Cambrian**

**Chilhowee Group**. Rocks that belong to Chilhowee Group were first described in Alabama as the Weisner Formation after the cliff forming quartzite that outcrops on Weisner Mountain (Butts et al., 1926). The Chilhowee Group and associated rocks in Alabama are correlated with similar age and lithology to the northwest of the Chilhowee Group and are included as southeast equivalents of Overall thickness is not known because the Chilhowee Group members are not present in outcrop together and the units are severely faulted (Mack, 1980), but estimates from the nearby Wilson Ridge 18 km to the northeast suggest that the depositional thickness of the Chilhowee Group is at least 600 meters in northeastern Alabama (Mack, 1980). The environment of deposition for the Chilhowee Group is interpreted to record a passive margin during the early Cambrian (Hatcher, 1972). Arkose rich sediment was first

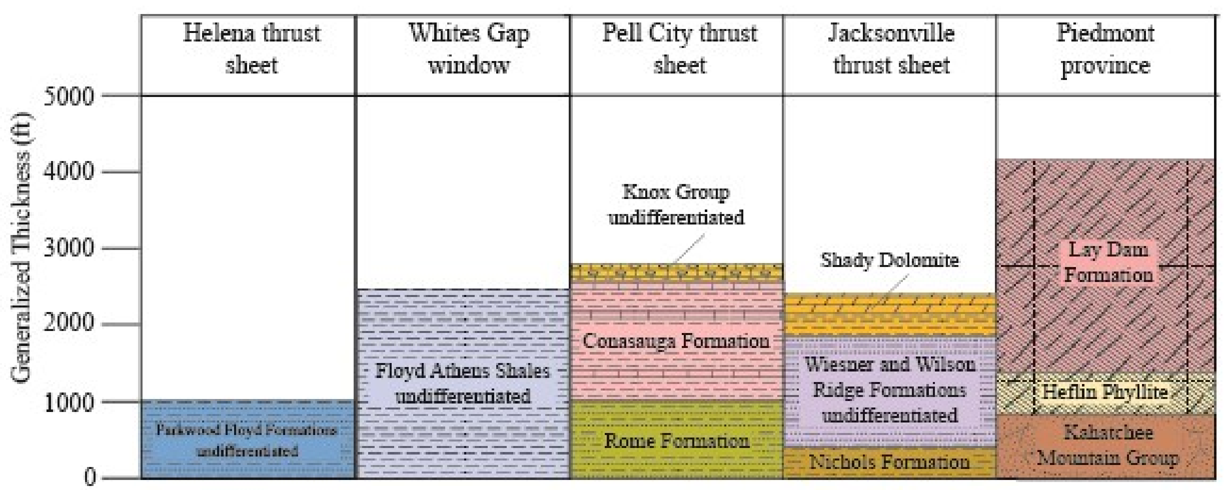


Figure 2. Generalized stratigraphic column of the Jacksonville East 7.5-minute quadrangle.

deposited in fluvial channels while sea level was at relatively low (Read, 1989). Later as sea level rose the sediment that was deposited transitioned to nearshore muds and more quartz-rich sands (Read, 1989) The Chilhowee Group in eastern Alabama is composed of four formations, the Cochran Formation, the Nichols Formation, the Wilson Ridge Formation, and the Weisner Formation.

**Nichols Formation.** The Nichols Formation is stratigraphically above the Cochran Formation, which does not appear on this map, and below the Wilson Ridge Formation (Mack, 1980). The contact between the Nichols and the Cochran Formation is very poorly exposed so it is not well described (Mack, 1980). The Nichols Formation was first described by Keith (1895) for the USGS Knoxville Folio. The Nichols Formation is found along the western edge of the Blue Ridge in Tennessee and the innermost portion of the Valley and Ridge in Alabama and Georgia (Whisonant, 1974; Mack, 1980; Tull et al., 2010). On the Jacksonville East Quadrangle, the Nichols Formation is located along the westward facing slopes of Choccolocco Mountain and Dugger Mountain. The Nichols Formation is exposed along Forney Road on the western side of Choccolocco Mountain (Figure 3). The Nichols Formation is generally a green grey to black micaceous mudstone (Raymond et al., 1988) weathered exposures may be tan to light grey. The Nichols Formation contains evidence of bioturbation (Read, 1989). Some small siltstone and sandstone beds are approximately 6 to 18 inches are sparsely present. Silt and sandstone beds contain wave and current ripples The Nichols Formation is compatible with being formed in an offshore, mud-dominated clastic sedimentary system. (Read, 1989).

The Nichols Formation on the Jacksonville East Quadrangle is highly variable in thickness ranging from 2100 feet to 100 feet. Its reported stratigraphic thickness is approximately 400 feet (Mack, 1980). The variability observed on the quadrangle is due to thrust sheets on

Choccolocco and Dugger Mountain structurally thickening due to the low cohesion of the unit. The age of the unit is Early Cambrian (Mack, 1980; Read, 1989).

**Weisner and Wilson Ridge Formations Undifferentiated.** The Nichols Formation grades upward into the Wilson Ridge Formation. The Wilson Ridge Formation was first described by Mack (1980). The type section for the Wilson Ridge is 20 miles along strike of the field area in the north of the City of Piedmont (Mack, 1980). The Wilson Ridge Formation has a variable composition with a thickness of 450 meters (Mack, 1980). The lower sections are composed of dark silty mudstones. The mudstone is interbedded with feldspathic quartz arenite beds (Figure 4). Sedimentary structures that are located within the mudstone beds include ripple laminations, flame tongues, and sparse mudcracks (Mack, 1980). Sedimentary structures located within the sand rich layers include lenticular beds with some crossbeds, ripple marks and occasional *Skolithos* (Mack, 1980).

Above the Wilson Ridge Formation is the Weisner Formation. The first description of this rock was by Butts et al. (1926), named for the quartz-rich sandstone that outcrops on Weisner Mountain in Alabama. The name was applied to all the siliciclastic units that were stratigraphically below the type section (Butts et al., 1926; Mack, 1980). That sequence was later divided and the Weisner Formation retained for highest stratigraphic unit in the Chilhowee Group in Alabama (Mack, 1980). The Weisner Formation is above the Wilson Ridge Formation, where it forms a sharp contact (Mack, 1980). The Weisner Formation outcrops along the ridges on Choccolocco Mountain and Dugger Mountain. The Weisner is composed of interbedded layers of fine to very coarse quartz arenite and quartz pebble conglomerate. Most sandstone beds are between 3 feet and 10 feet thick. There are also minor interbeds of tan fissile shale of 10 feet. The first instance of a conglomerate bed forms the contact between the Wilson Ridge and the

Weisner Formation (Mack, 1980). The lack of exposure, high structural complexity, and similarity of the two units, the Weisner and Wilson Ridge Formations will be mapped together undifferentiated.

Figure 3. Outcrop of Nichols Shale exposed in excavation of a parking lot near Jacksonville (NE1/4SW1/4 sec 18, T. 14 S., R. 9 E.) in the Jacksonville East 7.5 minute quadrangle, Calhoun and Cleburne Counties Alabama.


Figure 4. Multiple exposures of the Wilson Ridge and Wiesner Formations found along Dugger Mountain. (sec 6, T. 14 S., R. 10 E.) in the Jacksonville East 7.5—(Resser, 1938) minute quadrangle, Calhoun and Cleburne Counties Alabama. A) Large iron ore breccia. B) Inclined sandstone beds along Dugger Mountain.

**Shady Dolomite.** The Shady Dolomite was first described as the Shady Limestone in Alabama (Butts et al., 1926). The lower contact with the Weisner Formation is highly variable; the dissolution of the dolomite regularly leaves behind a residuum that forms iron deposits

(Figure 5). The upper contact with the Rome Formation is poorly understood because the contact is rarely found (Butts et al., 1926; Raymond et al., 1988). The Shady Dolomite has been dated to Early Cambrian due to the presence of *Archeocyathid* fossils prominently found in the unit (Bearce and McKinney, 1977). The interpreted environment of deposition is a shallow shelf carbonate platform (Read, 1989). The Shady Dolomite is composed of members of thickly bedded dolomite and limestone that are fine to coarsely crystalline (Pfeil and Read, 1980). The Shady Dolomite is typically yellowish grey to orange-brown. In Calhoun County the Shady Dolomite is described as yellow siltstone (Raymond et al., 1988). The Shady dolomite has been reported to have thicknesses up to 1000 feet (Raymond et al., 1988) The Shady Dolomite does

Figure 5. Brecciated Shady Dolomite with white chert clasts. (SW1/4 NE1/4 sec 18, T. 14 S., R. 10 E.) in the Jacksonville East 7.5 minute quadrangle, Calhoun and Cleburne Counties Alabama.

not outcrop well and is most prevalently found along the eastern base of Dugger Mountain. The outcrops consisted of mostly calcareous mudstone transitioning into breccia consisting of chert clasts (Figure 5).

**Rome Formation.** The Rome Formation was first named the Montevallo Shale in Alabama (Squire and Smith, 1890). The unit was later named the Rome Formation for its exposure near

Figure 6. Rome shale that has been ductilly deformed. (SW1/4 SE1/4 sec 23, T. 14 S., R. 9 E.) in the Jacksonville East 7.5 minute quadrangle, Calhoun and Cleburne Counties Alabama.

Rome, Georgia, because the name became more prevalent along the rest of the Southern Appalachians (Hayes, 1891). The lower contact with the Shady Dolomite is not well understood (Butts et al.,1926; Raymond et al., 1988). The thickness for the Rome Formation is highly variable, but near the field area it is recorded to be near 290 feet (Butts et al., 1926; Raymond et al., 1988). Early Cambrian fossil assemblages containing *Olenellus thomsoni* have been observed in the Rome Formation to the northwest in the Helena thrust sheet (Butts et al., 1926; Resser, 1938). The environment of deposition is interpreted to be nearshore muds and sandstones that formed from a drop in sea level that allowed sediment reach the shelf (Read, 1989). The Rome Formation contains thinly bedded, red-brown to greyish green mudstone, shale, siltstone, and sandstone (Butts et al., 1926; Raymond et al., 1988) (Figure 6). Dolomite, limestone, and anhydrite interbeds are found locally, including within subsurface cores (Raymond et al., 1988). On the Jacksonville East quadrangle, the Rome Formation is found along Choccolocco Creek on the eastern portion of map and on the southeastern portion of the map north of the Whites Gap window.

**Conasauga Formation.** The Conasauga Formation was first named the Coosa Shale (Squire and Smith, 1890; Hayes, 1891). Thicknesses for this unit are highly variable because of the structural weakness of the unit (Thomas, 2001). The Conasauga Formation ranges from 300 feet to over 9000+ feet (Raymond et al., 1988; Thomas, 2001). The Conasauga Formation forms the detachment layer for many of the thrust sheets in the lower Valley and Ridge Province (Thomas, 2001). The Conasauga Formation has been labeled a "MUSHWAD" (Malleable, Unctuous Shale, Weaklayer Accretion in a Ductile duplex), because it is a relatively thick unit with very little structural integrity (Thomas, 2001). During a deformation event these MUSHWAD units deform internally forming what is called a ductile duplex (Thomas, 2001).

The Conasauga Formation has been dated to the Middle to Late Cambrian (Raymond et al., 1988; Read, 1989). The environment of the Conasauga Formation represents a transition from deep water facies to a carbonate platform on the continental shelf (Read, 1989). Lower beds of the Conasauga include dark greenish grey to pale olive shales (Raymond et al., 1988). Up

Figure 7. Outcrop of Conasauga limestone. (NE1/4 SW1/4 sec 25, T. 13 S., R. 8 E.) in the Jacksonville East 7.5 minute quadrangle, Calhoun and Cleburne Counties Alabama.

section, the Conasauga Formation transitions into a medium to dark grey limestone and dolomite (Figure 7). Limestones are typically an oolitic to oncolitic mudstone that often contains *Brooksella* and other species of trilobites (Butts et al., 1926; Raymond et al., 1988; Ciampaglio, 2006). The Conasauga Formation has previously been interpreted to be located in the valleys of the Jacksonville East 7.5--minute Quadrangle.

### Cambrian and Ordovician

**Knox Group Undifferentiated.** The Knox Group is a thick succession of Late Cambrian and Early Ordovician carbonate rock found in most of the Southern Appalachians. The formations associated with the Knox Group in Alabama include Copper Ridge Dolomite, Chepultepec Dolomite, Longview Limestone, Newala Limestone, and Odenville Limestone (Butts et al., 1926; Raymond et al., 1988; Read, 1989; Read and Repetski, 2012). On the Jacksonville East Quadrangle, the Knox Group is found of the western edge of the Jacksonville fault. The Knox Group in the study area is not well exposed. When present, the Knox Group is characterized by an orange residuum with large white chert blocks. The lack of exposure differentiation of the Knox Group. Chert clasts within the residuum are white and granular and very blocky in places reaching boulder sizes in places.

### Ordovician and Mississippian

**Athens Shale and Floyd Shale Undifferentiated.** The Athens Shale is described by Butts et al. (1926) as a black thinly bedded shale that is exposed in parts of the Valley and Ridge from Tennessee to northeastern Alabama. The shale is very calcareous and in some places, it contains areas of grey to black limestone beds (Butts et al., 1926). In Alabama, the Athens Shale

also includes a thin fossiliferous limestone at the base The Athens Shale that is most known for its highly fossiliferous nature, particularly its graptolites, *Nemograptus gracilus* (Butt et al., 1926; Finney, 1985). These graptolites are very common in some beds (Butts et al., 1926). The Athens Shale also contains the Ordovician the trilobites *Telephus gelasonsa* and *Robergia athenia* (Butts et al., 1926). Locally the Athens Shale can be found on the southwestern side of Choccolocco Mountain as Whites Gap Window. The Floyd Shale is a dark grey clay shale with minor limestone and sandstone beds.

**Mississippian and Pennsylvanian**

**Parkwood Formation Floyd Shale Undifferentiated.** The Parkwood Formation and the Floyd Shale were first described in the 19th century (Squire and Smith, 1890; Hayes, 1891). These two units have been consistently grouped together because it is difficult to distinguish the two without paleontological evidence (Butts et al., 1926). The lower contact is usually with the Mississippian Tuscumbia Limestone and the upper contact is with the Pennsylvanian Pottsville Formation (Butts et al., 1926) These units together have a thickness of over 4300 feet, but the Floyd Shale is highly variable (Thomas, 1976). The environment of deposition for these units is interpreted as the transition from a carbonate platform to a prograding delta (Thomas, 1976). These units represent the latest Mississippian to earliest Pennsylvanian rocks (Butts et al., 1926; Thomas, 1976). From previously mapped areas it is interpreted that a small amount of this unit is exposed in the northwest corner of the mapping area (Jackson Jr. et al., 2016). The Floyd Shale is described as a dark grey clay shale (Raymond et al., 1988). The Floyd Shale contains some thin limestone and sandstone (Raymond et al., 1988). The Parkwood Formation is a more silt rich shale with thicker beds of fine-grained sandstone interbedded.

## Metamorphic Rocks

Metamorphic rocks of the Talladega slate belt are present near Whitesides Mill Lake in the southeastern portion of the quadrangle (Butts et al., 1926; Tull, 1982). Talladega slate belt rocks are composed of low grade slates, phyllites, metasiltstones, and metasandstones that are within the greenschist facies. These units all appear in the hanging wall of the Talladega-Cartersville fault that is also present in the study area. These units include the Kahatchee Mountain Group, Heflin Phyllite, and Lay Dam Group.

**Kahatchee Mountain Group Undifferentiated.** The Kahatchee Mountain Group is present as the basal unit of the Talladega slate belt (Tull, 1982). It is most prevalent farther south near the town of Columbiana where these units were first described in detail (Butts, 1940). The units that are part of the Kahatchee Mountain Group include the Waxahatchee Slate, Brewer Phyllite, and Wash Creek Slate (Butts, 1940; Tull, 1982). The Kahatchee Mountain Group in general is a thick sequence of metasedimentary rocks that consist of thinly bedded phyllites metasandstones and in some locations carbonate rocks (Butts, 1940; Tull, 1982). The Kahatchee Mountain Group has been correlated to rocks within the Chilhowee Group that are found in the Valley and Ridge Province, due to its stratigraphic position in the Piedmont and lithologic similarities (Tull et al., 2010). Locally on the Jacksonville East quadrangle the Kahatchee Mountain Group represents a small ridge immediately above the Talladega-Cartersville fault. The group is represented by coarse grained metasandstone to metaconglomerate that has a fine chlorite matrix. The larger clasts consist mostly of stretched quartz pebbles. The reported thickness with all its units can be up to 14,000 feet, but in the study area it is only 1000 feet

(Tull, 1982).. If the Kahatchee Mountain Group correlates to the Chilhowee Group the Kahatchee Mountain Group, then it is likely Neoproterozoic-Cambrian in age (Tull et al., 2010).

**Heflin Phyllite.** The Heflin Phyllite consists of a massively bedded grey-green phyllite. Structurally above the Kahatchee Mountain Group is the Heflin Phyllite. The Heflin Phyllite was first described in an outcrop near Alabama Highway 78 near the town of Heflin (Bearce, 1973). The Heflin Phyllite was later redefined as a lower member of the Lay Dam Formation (Tull, 1982). The Heflin Phyllite is poorly exposed in the field area and forms a valley that runs northeast-southwest from the headwaters of Choccolocco Creek to Whitesides Mill Lake. The best exposure of the unit is along Cinch Creek just north of Whitesides Mill Lake (NW1/4 SW1/4 sec 36, T. 14 S., R. 9 E.). The thickness of the Heflin can reach up to 650 feet and from its stratigraphic location in the Talladega Slate Belt, the age of the Heflin Phyllite is constrained between Cambrian and Devonian in age (Bearce, 1973; Raymond et al., 1988).

**Lay Dam Formation**. Stratigraphically above the Heflin Phyllite is the Lay Dam Formation (Tull, 1982). These units were first described by Butts et al., (1926) as the Talladega Slate and described in detail by Carrington (1973 in Chilton, Shelby and Talladega Counties. The Lay Dam Formation can be over 8200 feet in thickness (Tull et al., 1988). The proposed protolith of the Lay Dam Formation are submarine fans that formed off of an island arc pre-collision (Hatcher, 1972; Tull et al., 1988). The Lay Dam Formation in the study area consists of interbedded tan to grey micaceous slates and phyllites and tan to buff quartzites. The phyllite and slates appear massively bedded and can be up to 100 ft thick. The quartzite appears in thinner beds, being typically 10 to 20 feet thick, but in some locations like along Scarborough Creek exposures of quartzite can be up to 60 to 70 feet (Figure 8). The age of these units has not been

completely constrained, but the upper portion of the Lay Dam Formation contains Silurian conodonts and Mississippian (Tull et al., 1988).

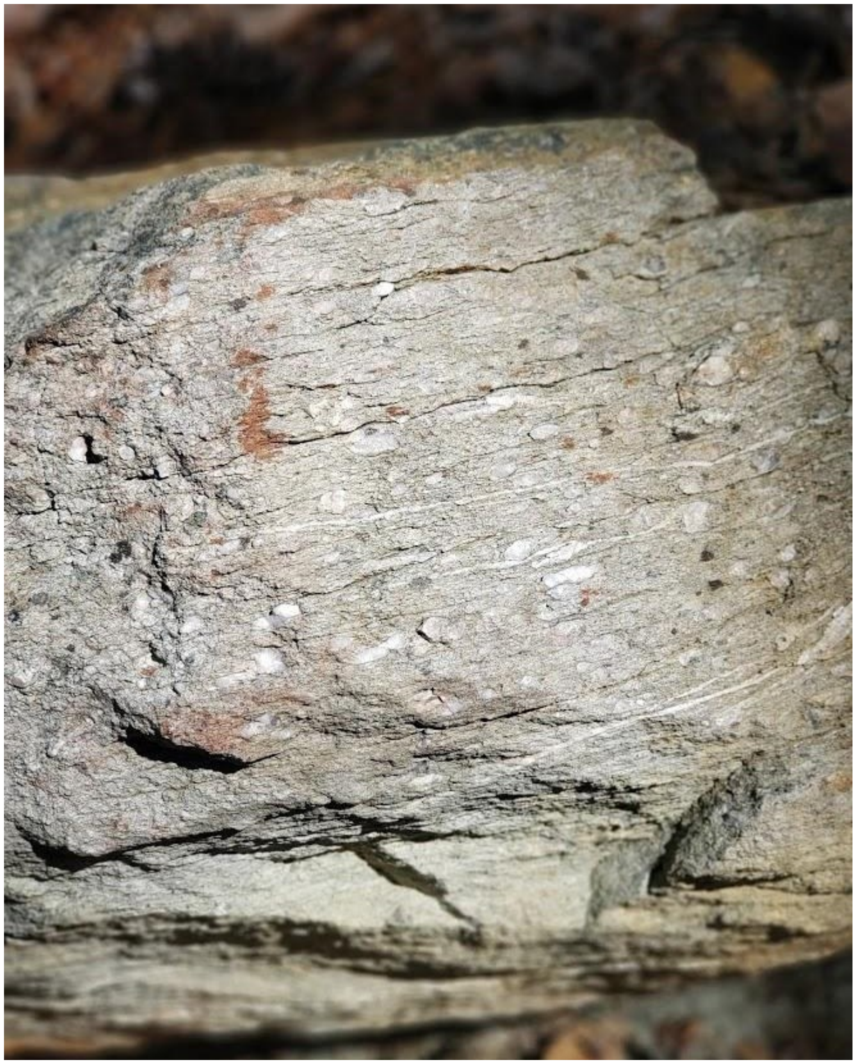

Figure 8. Exposure of Lay Dam Formation. (SE1/4 SW1/4 sec 31, T. 14 S., R. 10 E.) in the Jacksonville East 7.5 minute quadrangle, Calhoun and Cleburne Counties Alabama.

**Quaternary**

**Alluvium.** The alluvium found in the Jacksonville East quadrangle consists of unconsolidated sands, clays, and gravels. Most alluvium is found in the valleys between the Choccolocco Mountain and Rattlesnake Mountain, and it obscures the contact between the Rome

and Conasauga Formation in the Dugger Mountain syncline. Alluvium is deposited when streams spill over its banks causing vertical accumulation of sediments. These sediments include medium to fine sands and clay beds. Many of the beds include gravel of various sizes. The gravel is locally derived from nearby units consisting of chert and sandstone. Large amounts of these deposits are found along Nances Creek and Choccolocco Creek, as well as near Whitesides Mill Lake.

## Structural Geology

**Pell City Fault.** The Pell City fault is a southeast dipping, northwest moving, thrust fault that separates the Pell City thrust sheet in the hanging wall and the Helena thrust sheet in the foot wall. The Pell City fault is interpreted to be located in the northwest corner of the Jacksonville East quadrangle (Jackson, 2016). Rocks found in the hanging wall include the Rome Formation; Conasauga Formation; and the Knox Group undifferentiated. Rocks found in the foot wall on the quadrangle include the Parkwood Formation and Floyd Shale undifferentiated. The Pell City thrust sheet is interpreted to be structurally underneath the Jacksonville thrust sheet and truncated by the Talladega-Cartersville fault (Jackson et al., 2015).

**Whites Gap Window.** The Whites Gap window is structural window located in the southwest portion of the Jacksonville East quadrangle that exposes the Athens Shale and Floyd Shale undifferentiated. The rocks associated with the Whites Gap window are typically beneath the rocks belonging to the Pell City thrust sheet and the rocks belonging to the Choccolocco thrust complex (Osbourne and Szabo, 1984; Jackson et al., 2015).

**Jacksonville Fault**. The Jacksonville fault is present near the western side of Choccolocco Mountain (Osborne and Szabo, 1984; Bearce, 2001). The rocks associated with the

footwall of the Jacksonville fault include the Knox Group, Conasauga Formation, and the Rome Formation. The rocks that are associated with the hanging wall of the fault include the Nichol Formation, the Weisner Wilson Ridge Formation, the Shady Dolomite, the Rome Formation, and the Conasauga Formation. The Jacksonville fault has been interpreted of the Pell City fault and that this section of the fault brings up a deeper stratigraphy then the rest of the stratigraphy that is typically associated with the Pell City thrust sheet (Osborne and Szabo, 1984). An alternative interpretation is that the Jacksonville fault represents a higher thrust sheet that is derived from farther out in hinterland (Bearce, 2001). The U Th/He cooling ages from Chapter 2 of this study suggest the alternative interpretation.

**Choccolocco Mountain Thrust Complex.** The Choccolocco Mountain thrust complex are repeated thrust sheets, dissociated by a series of southeast dipping, northwest moving, tightly imbricated thrust faults. The area encompasses the high relief mountainous region east of the city Jacksonville. The area has been interpreted in several ways. The rocks that make up this region include those of the Early Cambrian Chilhowee Group specifically the Nichols Formation and the Weisner and Wilson Ridge Formations undifferentiated. The thick packages of shale that are part of the Nichols Formation form the detachment for most of the individual thrust sheets. Where the Nichols Formation thins or is not present, the detachment is likely present at the Nichols-Weisner/Wilson Ridge contact.

Rocks in the southern section of the Choccolocco Mountain thrust complex strike northward and have an on average dip of 50 degrees. In the northern quarter of Choccolocco Mountain, the strike changes to a more NE-SW strike. The sudden shift in strike correlates to the Anniston transverse zone (Thomas & Bayona, 2002), where many of the faults along the western half of the Choccolocco Mountain thrust complex

**White Plains Syncline.** The Dugger Mountain syncline consists of folded strata associated with the Jacksonville thrust sheet and folds the Jacksonville and Dugger Mountain faults. This structure is similar to the folded Pell City fault found on the Jacksonville West quadrangle (Jacksonville et al., 2015). The core of the syncline allows enough accommodation space for the Chihowee Group rocks of the Dugger Mountain thrust complex. The syncline's interpreted plunge is to the northeast and due to the loss of Chilhowee Group rock in the south.

**Dugger Mountain Fault.** The Dugger Mountain fault is a thrust fault that bounds the Dugger Mountain thrust complex from rocks associated with the Jacksonville thrust sheet. The footwall of the Dugger Mountain fault is comprised of rocks that are part of the Jacksonville thrust sheet and include Nichols Formation, the Weisner and Wilson Ridge Formations undifferentiated, the Shady Dolomite, the Rome Formation and, the Conasauga Formation. The hanging wall of the Dugger Mountain fault includes similar rocks as part of the Dugger Mountain thrust complex and the small klippen that are found in the valley between Dugger Mountain and Rattlesnake Mountain. These rocks include the Nichols Formation, the Weisner and Wilson Ridge Formations undifferentiated, and the Shady Dolomite. The Dugger Mountain fault is interpreted to be folded as part of the White Plains syncline.

**Dugger Mountain Thrust Complex.** The Dugger Mountain thrust complex is a series of southeast dipping, northwest moving thrust faults. The complex encompasses the ridges of Dugger Mountain and Cottaquilla Mountain in the central portion of the Jacksonville East quadrangle. It is bounded on both sides by the folded Dugger Mountain fault. Unlike the Choccolocco Mountain thrust complex the thrust sheets that compose the Dugger Mountain Thrust Complex are much more continuous, forming long linear ridges and do not appear to be internally dissected by internal faults. The rocks present in this region belong to the Nichols

Formation and the Weisner Wilson Ridge Formation undifferentiated, and the Choccolocco Mountain thrust complex including rocks of Shady Dolomite in minor amounts. The southern section of the complex is made up of what is called Cottaquilla Mountain. This section is formed by three thrust sheets that form low relief ridges that truncate and disappear just north of the town of White Plains. The ridges are formed from a thicker package of the Nichols Formation and a lower section of the Weisner and Wilson Ridge Formations undifferentiated. Near (NE1/4 NW1/4 sec 12, T. 14 S., R. 9 E.) the relativity north-south trending thrust sheets rotate and truncate into the eastern-most sheet and the imbricates north of the transition area instead stack to the west.

The rocks that are part of Cottaquilla Mountain have a general north south trend to strike and an average dip of 46 degrees to the east. North of the same oroclinal bend that was described in the Choccolocco Mountain thrust complex section, the strike in the northern rocks shifts to a NNE-SSW strike and a dip ~60 degrees to the SE. Near the oroclinal bend, the structural thickness of the Dugger Mountain thrust complex is much thicker. Outcrops in the area along Kings Gaps road suggest that the Nichols has been structurally thickened as a ductile duplex.

**Talladega-Cartersville Fault.** The Talladega-Cartersville fault is a thrust fault that separates rocks belonging to the Valley and Ridge province and the Inner Piedmont the Alabama and Georgia Appalachian Mountains. The fault was first named by Hayes (1891) as the Cartersville fault in Georgia and McCalley (1896) as the Talladega fault in Alabama, but the name has been joined to describe the continuous fault that runs from Alabama to Georgia (Tull et al., 2012). The Talladega-Carterville fault is a southeastward dipping, northwestward directed thrust fault. On the Jacksonville East quadrangle, the Talladega-Cartersville fault is present in the southeast portion of the map. The northernmost exposure of the fault is along Alabama Highway

9 near the Burns trailhead and the southern close to 1000 feet west of Whiteside Mill lake. The fault juxtaposes the metamorphosed Talladega slate belt rocks in the hanging wall with the sedimentary rocks belonging to the Jacksonville fault.

**Timing of Deformation.** Within Alabama, the deformation related to the Appalachian orogens is fully expressed in the youngest rocks (Pottsville Formation) while it is best preserved within the Appalachian thrust belt (Thomas and Neathery, 1980). Within the Jacksonville East quadrangle, the relative timing of deformation can be interpreted using crosscutting relationships as well as (UTh)/He zircon ages from Choccolocco Mountain to help constrain an more absolute date of deformation. Transport along the Pell City fault was most likely initiated first, with movement along the Jacksonville fault coming next truncating the Pell City thrust sheet. Next to be formed was the Dugger Mountain fault. After these sedimentary rocks were emplaced then movement along the Talladega-Cartersville fault, the uplift of this metamorphic suite of rocks deformed the Jacksonville fault and the Dugger Mountain fault forming the Dugger Mountain syncline. The (U-Th)/He data collected on the quadrangle have an age of earliest uplift for the Chilhowee group rocks being around 330 Ma in age (Table 1 & Figure 9). This would suggest an Late Mississippian deformation of the localized area.

Table 1. (U-Th)/He data from Jacksonville East survey.

| Full Sample Name | Northing | Easting | rs (mm) | 4He (nmol/g) | U (ppm) | Th (ppm) | Sm (ppm) | Th/U | Ft | Corrected Date (It) (Ma) | Analytic Unc. (Ma)2s |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 16AL01_zr1 | **617178** | **3744467** | 30.28 | 250.803 | 161.43 | 232.58 | 1.95 | 1.441 | **0.631** | 331.94 | 4.33 |
| 16AL01_zr2 | | | 29.23 | 204.913 | 184.87 | 88.99 | 2.23 | 0.481 | **0.627** | 287.08 | 8.46 |
| 16AL01_zr3 | | | 35.27 | 221.445 | 176.15 | 132.96 | 2.23 | 0.755 | 0.684 | 282.59 | 4.39 |
| 16AL01_zr4 | | | 26.93 | 145.077 | 150.29 | 100.74 | 0.95 | 0.670 | **0.597** | 253.46 | 5.67 |

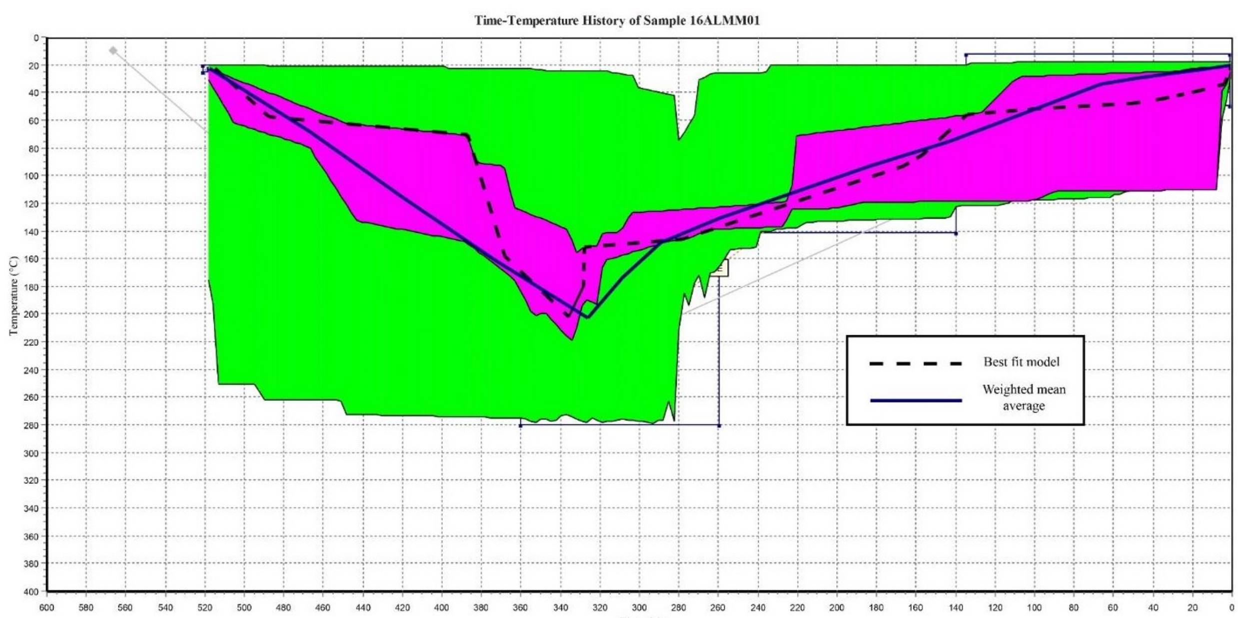


Figure 9. Time-Temperature History of Chilhowee Group rock on Jacksonville East quadrangle constructed on HeFTy. Green paths represent acceptable time-temperature paths. Pink paths represent well-fitting time temperature paths.

# PART 2: SEDIMENT ROUTING AND UPLIFT IN THE SOUTHERN APPALACHAIN VALLEY AND RIDGE PROVINCE USING ZIRCON U—PB AND (U—TH)/HE DATA

**Abstract**

Based on geologic mapping and crosscutting relationships in the state, large scale structures in the Valley and Ridge Province of the southern Appalachian Mountains seem to have a hinterland breaking sequence in the thrust fault can make up this region. This is uncharacteristic to the construction of most mountain belts which typically break towards the foreland. To investigate this anomaly as well as provide greater better understanding into how deposition of sediment in the basin changed during construction, samples were collected from sandstones from footwall of major thrust faults in the area. After extracting detrital zircons from the sample and using Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) U—Pb and (U—Th)/He data.

Detrital zircon U—Pb data collected is interpreted to show a Cambrian passive margin that drained the majority of the interior of Laurentia that transitions to a more restricted basin during the Taconic orogen that comes from almost only Grenville derived zircon. Then by the Mississippian period there is a reappearance of continent derived zircon. This is interpreted as Acadian and Neoacadian orogens onward uplift that brought further hinterland strata back to the surface and recycled in the foreland basin.

The (U—Th)/He data, due to the lack of thermally reset zircon, had to be focused on the Cambrian Chilhowee Group for thermal modelling. Sample 18ALWJ1, which was collected near Weisner Mountain, has an uplift age of 350 Ma associated with the Neoacadian orogeny. Samples 17AL19 and 16ALMM01, being sampled further in the hinterland near the Talladega-Cartersville fault, had an uplift age of 315 Ma and 325 Ma, respectively and are associated with the Alleghanian orogeny. While this does suggest a hinterland breaking sequence, more data is needed to make more general conclusions.

## Introduction

The Appalachian Mountains record evidence of the complexities of mountain-building processes. The geology of the Southern Appalachians has been mapped at broad scales since the first published geologic map of Alabama in 1849 (Tuomey and Mallet, 1850; Adams et al., 1926; Szabo and Wheat, 1988) and some of the earliest thrust faults to ever be described were in large scale structures in the Southern Appalachians (Hayes, 1891) which provided basic content for large scale relationships  In the Southern Appalachian Mountains, major thrust faults separate physiographic provinces of the Valley and Ridge and Piedmont. Thrust faults also juxtapose structural blocks that include major stratigraphic facies changes (Sapp and Emplaincourt, 1975), suggesting significant transport along structural boundaries. Fold and thrust belts form from expansion of deformation into the foreland basin of an orogenic wedge (Dahlen, 1990). The buildup of accretionary material builds up in the hinterland, forming a cohesive block that is stable while compressional forces are present during the collision (Dahlen, 1990; Hoth et al., 2007). When these blocks reach critical taper, or the maximum angle at which the block is gravitationally stable, stress is then propagated farther foreland in the form of a new thrust fault (Dahlen, 1990); Therefore, a fold and thrust belt typically propagates towards the foreland. Within the Appalachian Valley and Ridge province, cross cutting relationships suggest an out of sequence timeline for many major thrust sheets (Szabo and Wheat, 1988). Qualitatively, out of sequence thrusting appears to be Alleghanian due to highest stratigraphic rock effected by Appalachian structures being the Early Pennsylvanian Pottsville Formation (Szabo and Wheat, 1988). Absolute ages for Valley and Ridge deformation, however, are lacking. To investigate the age of deformation and provide absolute, quantitative age controls, I present U—Pb zircon geochronology and (U—Th)/He zircon thermochronologic ages from Cambrian through

Pennsylvanian Alabama Valley and Ridge strata. I further explore the implications of these data and discuss protracted, complex deformation in the southernmost Appalachian Mountains.

## Geologic Setting

**Construction of Laurentia.** The Laurentian continent was constructed in the Pre-Cambrian by a series of collisions of microcontinents (Anderson et al., 1993; Bickford et al., 1986). The construction of Laurentia by these microcontinents left distinct provinces with individual populations of ages (Figure 10) (Anderson et al., 1993; Bickford et al., 1986). The oldest of these provinces are the Wyoming and Superior Cratons (>2500 Ma), which presently form the basement rock under Wyoming, Montana, and Minnesota (Anderson et al., 1993). The collision of these two microcontinents formed the Trans Hudson orogen as well as other accretionary events like the Penokean orogen (Corrigan et al., 2009). The general ages that are derived from these provinces range from 2000-1800 Ma (Anderson et al., 1993). The Yavapai-Mazatzal province comprises most of the basement rock underneath the southwest portion of the United States and contains rocks with ages between 1800 and 1600 Ma (Anderson et al., 1993). The Granite-Rhyolite province is composed of rocks that range in age from 1500-1300 Ma and forms the basement of the midcontinental U.S. (Anderson et al., 1993). The Grenville orogen was the last of the Precambrian continent-building events in Laurentia which dates to 1200-900 Ma (Blum and Pecha, 2014). The Grenville orogen was formed from the collision of other Pre-Cambrian continents forming the super continent of Rodinia (McLelland et al., 1996). Grenville rocks likely form the basement rock of the east coast of the United States and Canada (Anderson et al., 1993). Rodinia began to rift around ~750 Ma and continued forming the Iaepetus Ocean by 540 Ma (Thomas, 2005; Aleinikoff et al., 1995).

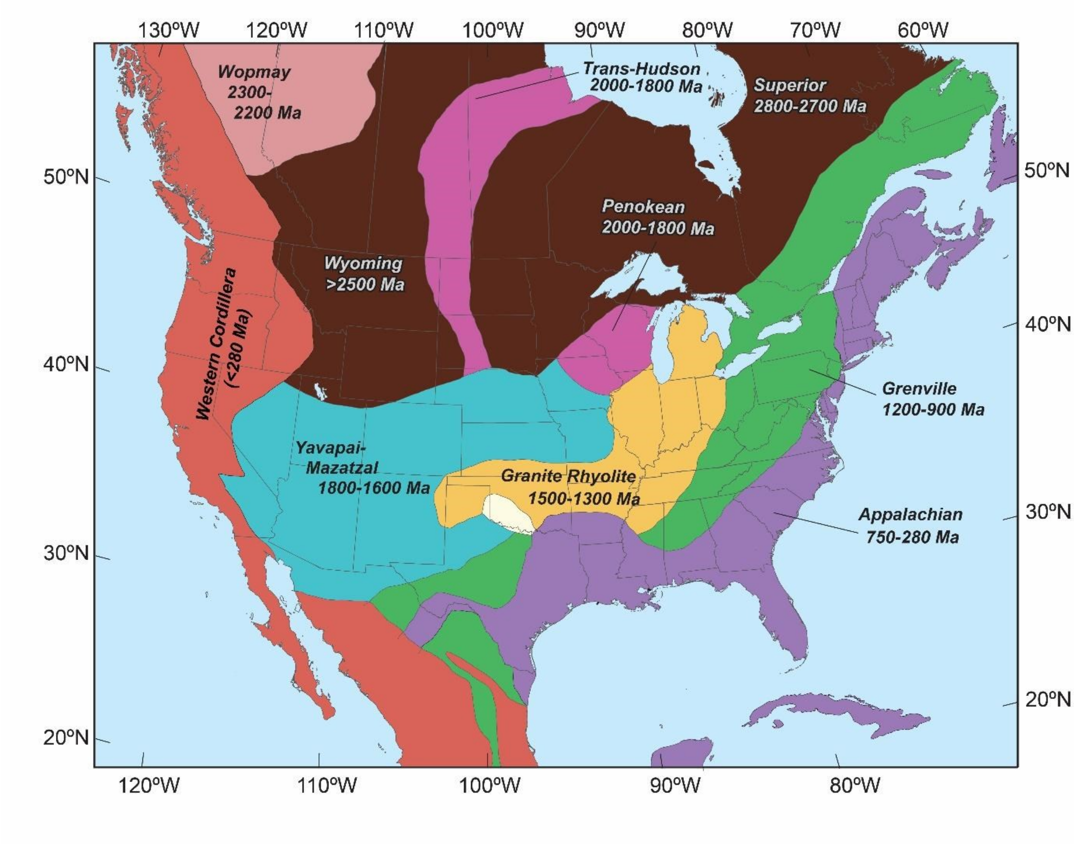


Figure 10. Major geologic provinces of North America based on generalized age domains. Modified from Fildani (2016).

**Appalachian Orogens.** Alabama has five physiographic provinces that are made up of smaller subsections that are typically defined by similar stratigraphy and structure (Sapp and Emplaincourt, 1975) (Figure 11). This study will focus on the three that have structures related to the Southern Appalachian Mountains. Going from east to west is the Piedmont Uplands or the Inner Piedmont, the Valley and Ridge province, and the Cumberland Plateau (Sapp and Emplaincourt 1975). The Piedmont Uplands geology is characterized by low to high grade metamorphic rock that was metamorphosed during the Acadian and Taconic orogenic events and were brought to the surface during the Alleghanian orogen (Hatcher et al., 1989). The geology of the Valley and Ridge province is characterized by complexly folded and faulted sedimentary

rock that forms parallel ridges and valleys that trend in strike in a northeast-southwest direction (Sapp and Emplaincourt, 1975). The last province is the Cumberland Plateau which is formed from relatively horizontal strata and gentler folding (Sapp and Emplaincort, 1975).

By the Early Cambrian, the Laurentian coast had transitioned from an active to a passive margin (Hatcher, 1972). Clastic sedimentation along a passive margin includes coarse to medium quartz sandstones and shales, which transitioned into a carbonate platform in the late Cambrian into Ordovician time (Pfeil and Read, 1980; Mack, 1980; Read, 1989). The carbonate platform in the southernmost Valley and Ridge province is coeval with the Taconic orogeny preserved in structural deformation in the Appalachian Piedmont that is interpreted to record accretion of volcanic arcs to Laurentia during renewed subduction (Read, 1989; Hatcher, 2005; Tull et al., 2010; Read and Repetski, 2012). In the Alabama Valley and Ridge Province, some clastic sediment has been interpreted to originate from uplift associated with the Taconic orogeny, including Ordovician dark calcareous shale units (Drake et al., 1989) and quartz arenites of the Colvin Mountain Sandstone (Gutiérrez-Marco et al., 2011). In the Inner Piedmont, the Taconic orogeny is associated with the Katy Creek fault and plutons associated with the Dadeville Complex (Drake Jr et al., 1989; Tull et al., 2018). After a period of tectonic quiescence recorded by the carbonate and shale in the Appalachian basin, terranes potentially originated from and be rifted from the supercontinent Gondwana began accretion to Laurentia, resulting in the Acadian orogeny (Hibbard, 2000; Bradley, 1983). The Acadian orogen ranges from Silurian to late Devonian (Osberg et al., 1989; Hatcher Jr et al., 2005), and may extend into the early Mississippian (Stowell et al., 2019). In the Southern Appalachians, this orogen is represented by volcanic units in the Lay Dam Formation of the Piedmont (Drake Jr et al., 1989). The Alleghanian orogen marks the final phase of collisional tectonism in the construction of the

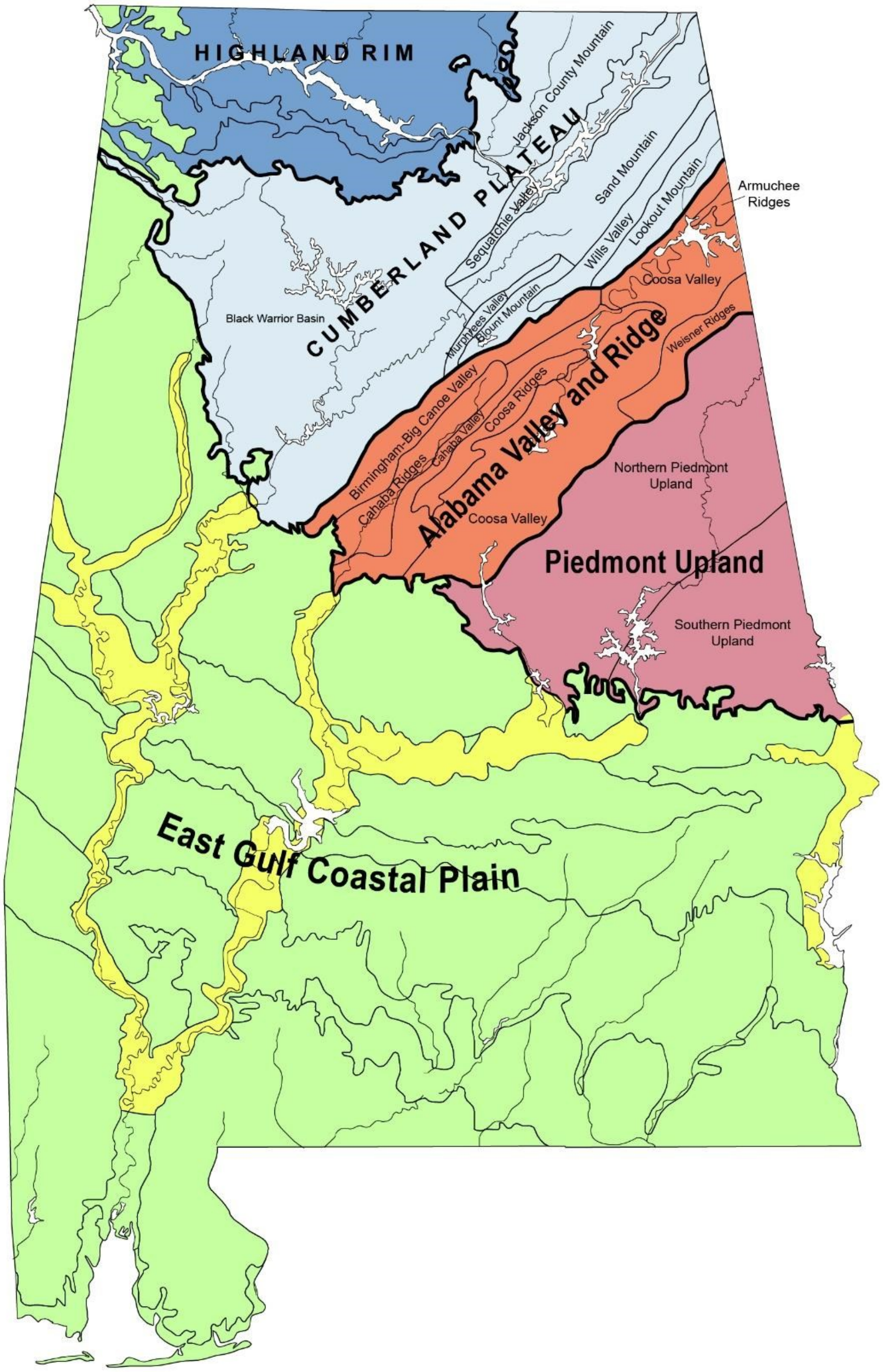


Figure 11. Physiographic provinces Alabama with minor provinces labeled. (Sapp and Emplaincourt, 1975)

Appalachians. The Alleghanian orogen records the collision of Gondwana and Laurentia during the Carboniferous through Permian (Hatcher Jr et al., 1989; Hatcher, 1972) and resulted in the structures that control the majority of the physiographic provinces and topographic trends in the modern Appalachian Mountains. By the Triassic Period, Laurentia and Gondwana were accreted to form the super continent of Pangea, which was soon followed by rifting of the Atlantic Ocean and opening of the Gulf of Mexico in the southern Appalachians (Hatcher, 2005).

Using the state geologic map of Alabama, problems arise from the supposed timing of when thrust sheets were active relative to one another. A traditional fold and thrust belt has large thrust sheet activation beginning in the hinterland of the orogenic belt and translate out in the foreland (Dahlen, 1990). From large state-map-scale structures in Alabama this might not be the case, which can be seen in Figure 12. Starting in the northeast, major folds like the Chandler Mountain syncline are cut by the Big Canoe Valley fault, which brings up the Gadsden Mushwad (Thomas, 2001). The Gadsden Mushwad is then cut by the Helena thrust sheet, which in turn truncates into the Coosa Deformed Belt (Szabo and Wheat, 1988; Thomas, 2001). Structures of the Coosa Deformed Belt are then cut by the Choccolocco thrust complex. This order of cross cutting would suggest out-of-sequence thrusting in the Alabama Appalachian fold and thrust belt.

## Methods

**Sample Preparation.** Samples were collected from siliciclastic units in the hanging wall of major thrust sheets in the Valley and Ridge province of Alabama (Figure 12). Samples were collected immediately adjacent to faults in an attempt to sample rocks that experienced tectonic

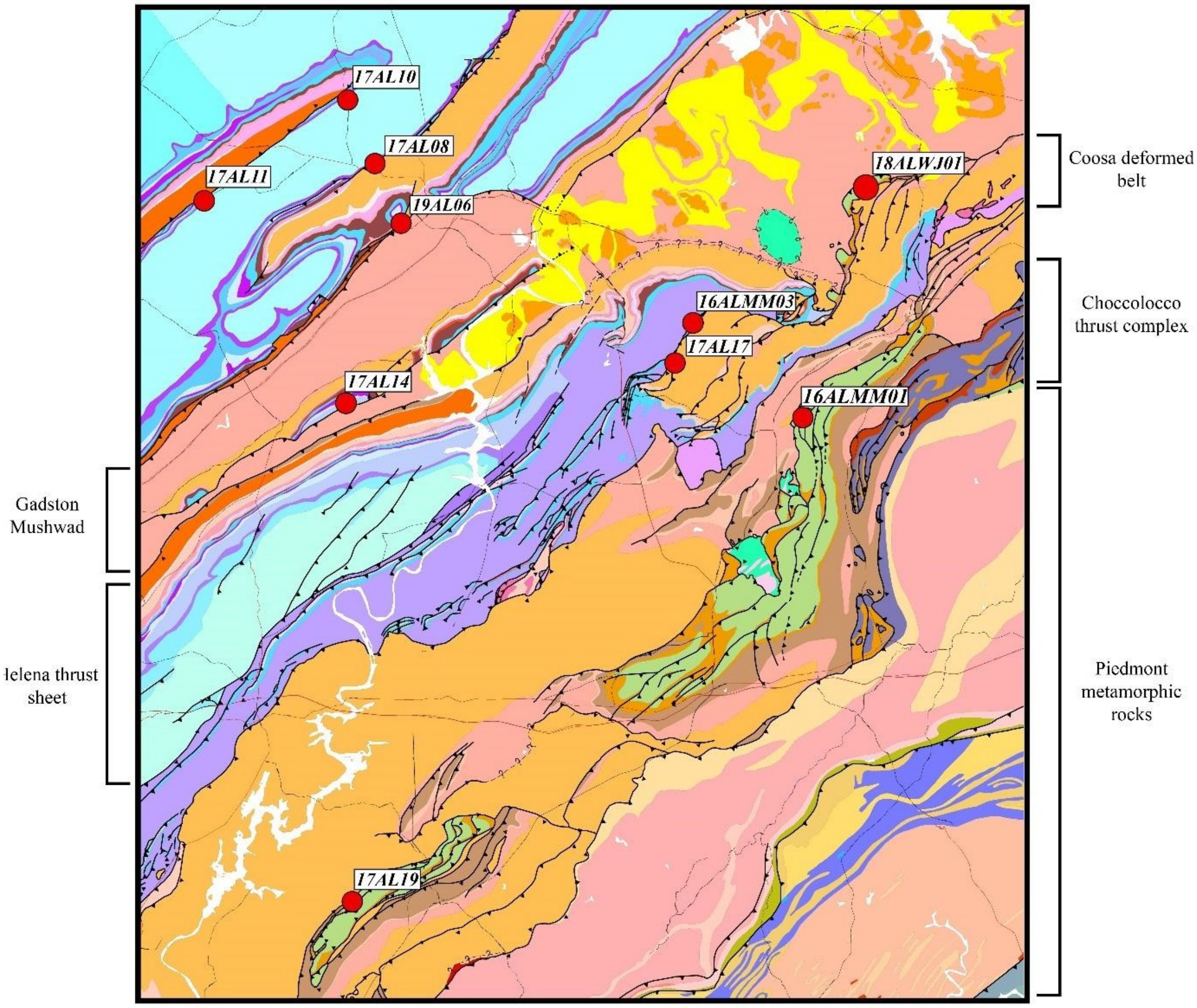


Figure 12. Generalized geologic map of northeast Alabama with sample locations. Major geologic regions that are important for the study are labeled in brackets.

burial and/or exhumation associated with fault displacement (Osborne et al., 1989). The mineral zircon was extracted using mineral separation techniques including non-magnetic. Dense mineral separates were then segregated from low-density minerals (SG<2.85) using floatation separation in lithium sodium tungstate (LST) and picked to isolate potential zircons from non-zircon mineral phases. Grains were picked and placed on double-sided tape, with particular care to avoid biasing the sample, by picking all grains regardless of size and shape, that fit the basic

characteristics of zircon (transparent to translucent, tetragonal prismatic). The number of zircon (n) was then picked from each sample in an attempt to reach a minimum of 120 in order to detect smaller age populations and recognizing that many non-zircon phases were likely included in an effort to create a non-biased, representative sample.

**Laser Ablation ICP-MS.** Zircon from each sample were analyzed at the University of Arkansas Trace Element and Radiogenic Isotope Laboratory on an iCAP Quadropole ICP-MS, which is a laser ablation inductively coupled plasma mass spectrometer (LA-ICPMS) for U–Pb age dating, Plesovice zircon were used as a primary standard (Sláma et al., 2008), and R33 (Black et al., 2004) and 91500 (Wiedenbeck et al., 1995) as secondary standards. Zircon grains were ablated using a 25 µm beam was used for most grains and a 15µm beam on smaller zircon (Košler and Sylvester, 2003). The data were then reduced using Iolite software Geochron4 data reduction scheme.  Final ages were then produced from the 206Pb/238U and 206Pb/207Pb ratios. For accuracy ages below 900 Ma are reported in 206Pb/238U and ages older than 900 are reported in 206Pb/207Pb. U–Pb age spectra from detrital samples are displayed as kernel density estimation plot (KDE) (Figure 13) with the age domains from crystalline basement rocks Blum and Pecha (2014) superimposed.

**(U-Th)/He.** The zircon (U–Th)/He analytical method was selected due to the zircon's closure temperature ~200°C (Reiners, 2005). This closure temperature was imperative to the study mainly, because the goal was to study the orogenic uplift and not erosion (Reiners and Brandon, 2006).  Samples were then sent to the University of Connecticut for (U–Th)/He isotopic analysis and processed using an integrated Santa Cruz Laser Microfurnace helium gas extraction and measurement system with a Pfeiffer PrismaPlus quadrupole mass spectrometer. The Fish Canyon Tuff was reference material for a standard (Reiners et al., 2002).

To ascertain the temperature path taken by the zircon, modeling was conducted using the program HeFTy using calibrations from Guenthner et al. (2013). Constraints were determined based on depositional age, maximum burial age estimates, and present temperatures. Each model was run to test with 10,000 potential paths. Modeled input ages are based on maximum depositional ages and depositional index fossils. The depositional age from U-Pb zircon for the Chilhowee Group rocks has been determined to be between 521 and 514 Ma based on trilobite biostratigraphy in the correlative Murray Shale of the Tennessee Chilhowee Group (Mack, 1980; Webster and Hageman, 2018). The maximum burial age was purposefully set at a larger range of temperatures and times to allow for HeFTy to simulate greater range of potential time-temperature paths. U-Pb ages were provided as a crystallization age for the zircon when there is one available, and assuming that the Chilhowee Group could not have reached its highest temperature unit at least 360 Ma during the beginning of the Mississippian Period. The minimum age was set at 260 Ma, which is near the end of the Alleghanian orogeny. The paths are then constrained on the cooling path via boxes that further help constrain potential path to help the program run faster. This ensures that HeFTy while constrained has plenty of space to run potential time temperature paths.

## Results

**Geochronology.** Sample 18ALWJ1 was collected from the Chilhowee Group in Cherokee County, Alabama. The sample consisted of a very coarse, poorly sorted quartz arenite yielding few zircons (n=86) and a significant population of discordant zircons. This sample has

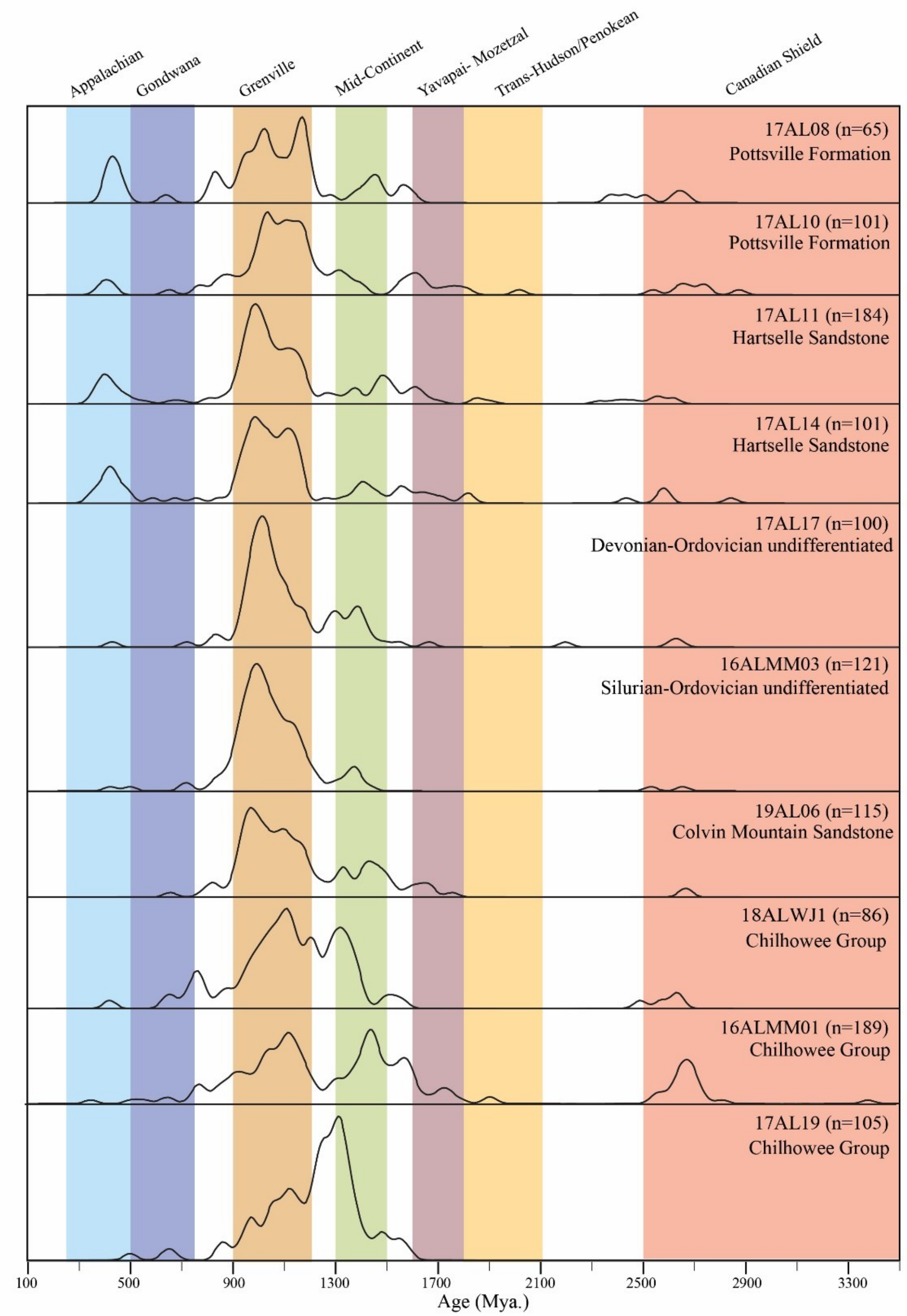


Figure 13. Normalized Kernel Density Plots of detrital zircon ages from the Appalachian fold and thrust orogenic belt. Samples are arranged by relative age listed youngest to oldest.

two prominent peaks at 1100 and 1300 Ma corresponding with the Grenville Province and the Mid-Continent Granite and Rhyolite Province, respectively. There are minor peaks present at 750 Ma and 2700 Ma that correspond to Gondwanan terranes and Canadian Shield derived zircon.

Sample 16ALMM01 was collected out of the Chilhowee Group and was collected on Dugger Mountain in Calhoun County, Alabama. The unit sampled was a course grained quartz arenite that was abundant in zircon (n=189). The sample yielded two prominent peaks at 1100 Ma. and 1500 Ma. There is also a significant population of >2500 Ma derived zircon. There are also minor peaks that correspond to 250-500 Ma, 500-750 Ma as well as a peak at 1550.

Sample 17AL19 was collected from Sleeping Giants Mountain in Talladega County. The sample was collected from a coarse-grained quartz arenite that belongs to the Chilhowee Group. The sample yielded one prominent peak at 1350 Ma. Several less prominent peaks are located from 1200 to 1000 Ma. Minor peaks from the sample include two 700 Ma and 500 Ma.

16ALMM03 (n=125) was sampled from an Ordovician-Silurian undifferentiated formation from within the Coosa deformed belt, a reddish-brown medium to fine grained sandstone (Raymond et al., 1988). The zircon U-Pb ages consisted of one dominant peak at 900 Ma with a much smaller peak at 1350 Ma.

Sample 17AL11 (n=184) is from the Mississippian Hartselle Sandstone. The formation consists of a medium grained quartz arenite. The detrital zircon U-Pb spectra includes populations of zircons at 400 and 1000 Ma. There are minor populations of zircons at 1400, 1750, and 2500 Ma.

Sample 17AL14 (n=101) is also from the Mississippian Hartselle Sandstone. The formation consists of a medium grained quartz arenite. The detrital zircon U-Pb signature has

significant populations of zircons at 400, and 1000 Ma. There are minor populations of zircons at 1400, 1750, and 2500 Ma.

Sample 17AL08 is a medium grained quartz arenite from the Pennsylvanian Pottsville Formation. The sample (n=71) has several predominant peaks at 400, 900, and 1400 Ma.  It also presents smaller peaks at 650 (Gondwana), 1600 and dispersed 2000+ Ma grains.

Sample 17AL10 (n=101) is from the Pennsylvanian Pottsville Formation. The sample was collected from a medium grain quartz arenite in the formation. The sample contains a significant population of zircon near 1000 Ma in age. Minor populations from the sample include peaks at 400, 1300, 1600,1700, and 2800 Ma.

**Thermochronology.** The U-Th/He ages from the Chilhowee Group rocks provide a wide range depending on its strike lateral position, effective radius of the crystal and the effective Uranium content of the zircon (Table 2). For the study only some samples had double dates for both the U-Pb crystallization age and the (U-Th)/He cooling age for the same zircon crystal. Reported in this section is the corrected cooling ages that were provided by the University of Connecticut Basin Analysis and Helium Thermochronology Laboratory.

Sample 16ALWJ01 contained five different cooling ages which were pulled from five different zircon. The first 16ALWJ01-72 had a cooling age of 507 Ma and a U-Pb age of 2390 Ma. 16ALWJ01-109 has a cooling age of 463 Ma. 16ALWJ01-51 had a cooling age of 354 Ma

Table 2. (U—Th)/He zircon data that was collected from the Alabama Valley and Ridge Province

| Sample | Grain | Northing | Easting | Lithology | Th/U | Effective Radius (mm) | U (ppm) | Th (ppm) | Sm (ppm) | eU | 4He (nmol/g) | Ft | Corrected Date (It) (Ma) | Analytic Unc. (Ma)2s |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 17AL19 | 17Al19-78 | 575441 | 3699937 | Weisner and Wilson Ridge Formations Undifferentiated | 0.296 | 72.38 | 223.63 | 66.08 | 955.71 | 239.2 | 125.059 | 0.836 | 110.73 | 9.42 |
| | 17Al19-131 | | | | 0.334 | 56.33 | 340.88 | 113.77 | 318.67 | 367.6 | 228.657 | 0.790 | 142.99 | 9.86 |
| | 17Al19-109 | | | | 0.352 | 62.35 | 203.04 | 71.54 | 40.56 | 219.8 | 167.327 | 0.817 | 169.88 | 23.91 |
| | 17Al19-113 | | | | 0.350 | 105.00 | 152.10 | 53.25 | 122.41 | 164.6 | 225.637 | 0.887 | 277.89 | 44.10 |
| | 17Al19-108 | | | | 0.645 | 78.37 | 217.31 | 140.07 | 1.91 | 250.2 | 360.517 | 0.847 | 307.09 | 11.03 |
| | 17Al19-62 | | | | 0.242 | 66.70 | 153.44 | 37.06 | 0.17 | 162.1 | 229.507 | 0.829 | 307.98 | 24.11 |
| | 17Al19-73 | | | | 0.706 | 73.24 | 108.34 | 76.46 | 3.56 | 126.3 | 187.557 | 0.836 | 320.26 | 9.04 |
| 18ALWJ1 | WJ1-105 | 624125 | 3766739 | Weisner and Wilson Ridge Formations Undifferentiated | 0.728 | 57.00 | 93.62 | 68.15 | 0.75 | 109.6 | 143.475 | 0.798 | 296.36 | 7.84 |
| | WJ1-10 | | | | 0.747 | 43.64 | 69.29 | 51.77 | 0.85 | 81.5 | 110.222 | 0.740 | 329.37 | 20.57 |
| | WJ1-51 | | | | 0.547 | 71.76 | 101.09 | 55.28 | 1.00 | 114.1 | 188.385 | 0.839 | 353.81 | 11.40 |
| | WJ1-109 | | | | 0.949 | 45.19 | 89.21 | 84.67 | 2.30 | 109.1 | 212.093 | 0.747 | 463.47 | 29.67 |
| | WJ1-72 | | | | 0.883 | 83.87 | 72.58 | 64.10 | 1.42 | 87.6 | 215.460 | 0.860 | 507.33 | 21.42 |
| 16ALMM01 | 16AL01_zr1 | 617149 | 3744486 | Weisner and Wilson Ridge Formations Undifferentiated | 1.441 | 30.28 | 161.43 | 232.58 | 1.95 | 216.1 | 250.803 | **0.631** | 331.94 | 4.33 |
| | 16AL01_zr2 | | | | 0.481 | 29.23 | 184.87 | 88.99 | 2.23 | 205.8 | 204.913 | **0.627** | 287.08 | 8.46 |
| | 16AL01_zr3 | | | | 0.755 | 35.27 | 176.15 | 132.96 | 2.23 | 207.4 | 221.445 | 0.684 | 282.59 | 4.39 |
| | 16AL01_zr4 | | | | 0.670 | 26.93 | 150.29 | 100.74 | 0.95 | 174.0 | 145.077 | **0.597** | 253.46 | 5.67 |
| 16ALMM03 | 16AL03_zr1 | 606870 | 3752736 | Silurian-Devonian Sandstone | 0.436 | 41.53 | 138.83 | 60.57 | 0.94 | 153.1 | 253.918 | 0.730 | 406.28 | 11.08 |
| | 16AL03_zr2 | | | | 0.438 | 42.88 | 179.81 | 78.76 | 0.75 | 198.3 | 403.704 | 0.739 | 489.17 | 10.73 |
| | 16AL03_zr3 | | | | 0.711 | 54.56 | 165.64 | 117.75 | 1.56 | 193.3 | 388.271 | 0.781 | 458.36 | 7.45 |
| | 16AL03_zr4 | | | | 0.743 | 45.78 | 104.31 | 77.52 | 0.86 | 122.5 | 209.188 | 0.752 | 406.37 | 13.42 |
| 17AL08 | 17LAL08_zr1 | 576965 | 3768023 | Lower Pottsville Formation | 0.535 | 42.65 | 344.58 | 184.41 | 4.35 | 387.9 | 415.107 | 0.736 | 263.52 | 44.33 |
| | 17LAL08_zr2 | | | | 0.443 | 48.26 | 123.05 | 54.46 | 0.82 | 135.8 | 201.548 | 0.766 | 348.38 | 35.22 |
| | 17LAL08_zr3 | | | | 0.365 | 41.79 | 152.06 | 55.53 | 1.24 | 165.1 | 228.853 | 0.732 | 340.45 | 57.00 |
| | 17LAL08_zr4 | | | | 0.361 | 42.69 | 150.05 | 54.15 | 0.24 | 162.8 | 340.071 | 0.738 | 501.71 | 63.50 |

and a crystallization age of 1003 Ma. 16ALWJ01-10 has a Helium cooling age of 329 Ma and a crystallization age of 1263 Ma. Finally, zircon 16ALWJ01-105 has Helium cooling age of 296 Ma.

Four zircons were chosen from sample 16ALMM01 for (U-Th)/He analysis. 16ALMM01-01 has a zircon has a Helium cooling age of 332 Ma. Zircons 16ALMM01-2 and 16ALMM01-3 has a cooling age of 287 and 282 Ma respectively. The last zircon, 16ALMM01-4 had a cooling age of 253 Ma. No U-Pb data were collected from these samples.

Sample 17AL19 had seven zircons used for Helium cooling ages with four of the zircons having U-Pb crystallization ages. 17AL19-73 was found to have a cooling age of 320 Ma. 17AL19-62 had a cooling age of 308 Ma and crystallization of 959 Ma. Zircons 17AL19-108 and 17AL19-113, has a cooling age of 307 and 278 Ma respectively. Zircon 17AL19-109 has a calculated cooling age of 170 Ma and a crystallization age of 1380 Ma. Zircon 17AL19-131 has a Helium cooling age of 143 Ma and a crystallization age of 1220 Ma. Zircon 17AL19-78 has a cooling age of 111 Ma and a crystallization age of 1323 Ma.

The last two samples 16ALMM03 and 17AL08 were part of the preliminary data that were collected and therefore does not have U-Pb data associated with the individual zircons used for the (U-Th)/He study.

## Discussion

**Geochronology.** From the Early Cambrian samples, age assemblages depict a drainage system that encompasses both the Canadian Shield and the Mid-Continent Granite and Rhyolite province. The samples were collected along north-south exposures of Weisner and Wilson Ridge Formations undifferentiated. The assemblage is interpreted as coming from the northern portion

of Laurentia from the presence of old (>2500 Ma) zircon derived from the Canadian Shield, and the western interior of the continent from the presence of some Yavapai-Mazatzal derived zircon and Mid-Continent Granite and Rhyolite province. The wide range of zircon ages, especially older zircon that are derived from more distal provinces, implicates a large intricate drainage ending in a passive margin (Cawood et al., 2012).

The Ordovician sandstones, notably, lack a population of Canadian Shield aged zircon and contain a much more diminished population of Mid-Continent zircon, while zircon of Grenville age were greatly enriched. The lack of abundant continent-derived zircon suggests a drastic change in drainage along Appalachian margin. The absence of older zircon populations and the focusing of more proximal Grenville derived zircon, represents the change from a passive margin to a convergent plate boundary (Cawood et al., 2012). The Silurian rocks carry the same trend as the Ordovician rocks, having a sizable population of Grenville zircon and Midcontinent derived zircon and small other populations. The continuation of these trends shows the continuation of a convergent plate boundary, and due to lack of Appalachian derived zircon, major collision had not begun yet (Cawood et al., 2012).

The first significant evidence of collision is sample 17AL11 which is from the Mississippian Hartselle Sandstone. This sample contains significant amounts of Appalachian derived zircon as well as older zircon. The transition of zircon populations of only Grenville and Mid-Continent to sediment that is from a more diverse population represents a drastic change in where sediment was being routed. The amount of Mid-Continent derived zircon in these samples is greatly reduced, but they do have a greater influx of older Canadian Shield aged zircon. This is the first sample with a sediment signature that represents a foreland basin (Cawood et al., 2012). This means that drainage has shifted from a southeast transport direction to a western direction.

In the Pottsville, there are populations of zircons from much more varied sources. Initially, the source variation can be interpreted as sediment draining into the foreland basin from the interior of the continent; however, this explanation is not likely because of the uplift that had occurred, which subsequently cut off rivers from reaching the coast. A more likely explanation is that the older sedimentary rocks that had contained these zircons had been uplifted by the Alleghanian orogen and were being eroded, while the sediment was recycled into the new foreland basin. This interpretation is supported by previous detrital zircon work in the Pottsville (Thomas et al., 2004).

From these findings, a transition from eastward to westward drainage can be seen from the detrital record in Early Cambrian. Since the samples were collected on a single traverse perpendicular to strike, these interpretations cannot be extrapolated laterally because the stratigraphy is highly variable even between thrust sheets (Rodgers, 1971; Osberg et al., 1989; Hatcher Jr et al., 1989). For some samples that were collected, the number of zircons was <100 grains analyzed which decreases the ability to see accurate populations of ages (Gehrels, 2014). To get a better picture of the sediment routing in the Southern Appalachians, more sampling along strike would produce a more robust look. To raise overall numbers of zircon analyzed, larger samples from the same area could be taken or some of the separate that was not used could be reused to provide more zircon.

**Thermochronology**. From the samples that had viable zircons available to model, there are trends that can be observed from them. Samples 17AL19 and 16ALMM01 are from Chilhowee Group sandstones that are located along strike from one another as well as located in

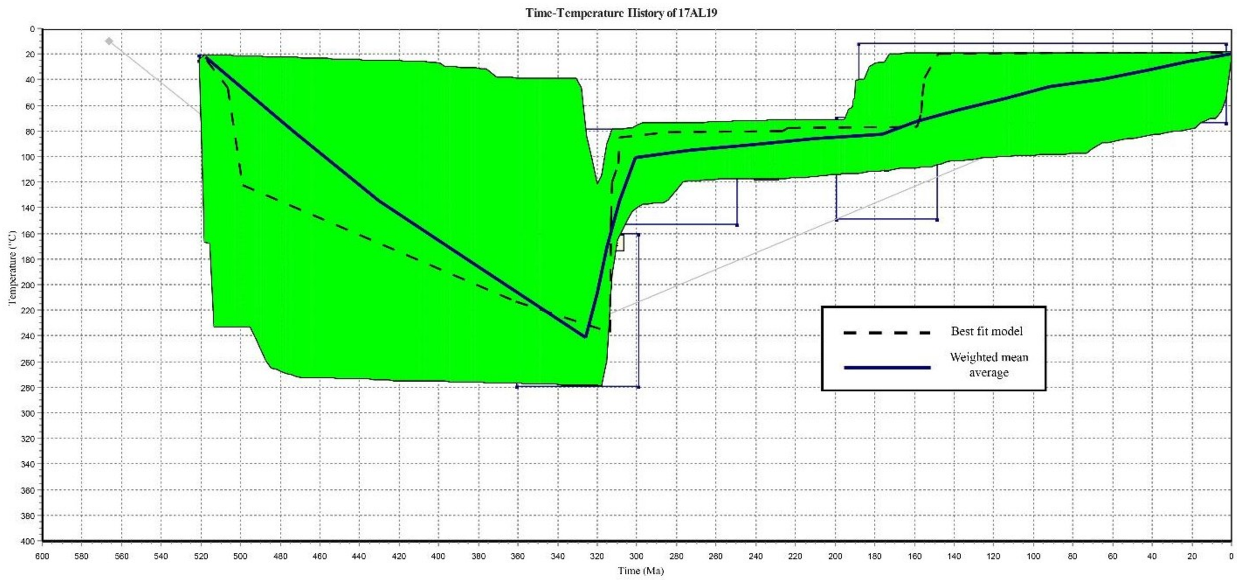


Figure 14. Time-Temperature History of Chilhowee Group rock from Sleeping Giants Mountain constructed on HeFTy. Green paths represent acceptable time-temperature paths with best fit model and weighted mean average overlaid.

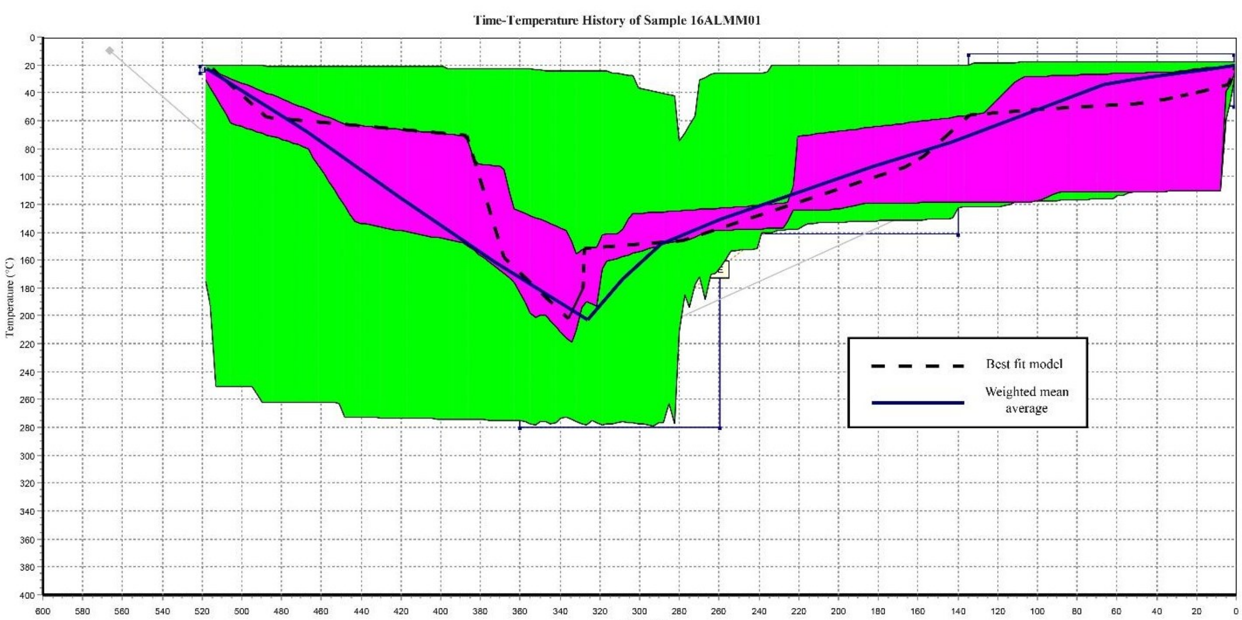


Figure 15. Time-Temperature History of Chilhowee Group rock from Choccolocco Mountain constructed on HeFTy. The green field represent acceptable time-temperature paths. The pink field represent well-fitting time-temperature paths with best fit model and weighted mean average overlaid.

the same relative structural position. From the models (Figure 14 & 15), the two samples have similar time-temperature paths. The burial age based on the weighted average on 17AL19 is~315 Ma with the minimum age of all theoretical paths ending around 310 Ma. Sample 16ALMM01 had a burial age based on the weighted mean average of ~325 Ma and a minimum age of uplift age of 280 Ma with much more variability in the time temperature models. The upward movement of these units can be attributed to the Alleghenian orogen (Hatcher Jr et al., 1989). The sample 18ALWJ1 is from a Chilhowee Group sandstone from Weisner Mountain. The Chilhowee Group sandstones at the sample location is the farthest foreland exposure in the Alabama Valley and Ridge Province (Osborne et al., 1989). Movement of this rock began much earlier than the first two samples (Figure 16). From the model, the rock had upward movement at a minimum of 350 Ma. This older movement can be attributed to the Neo Acadian or Acadian Orogeny (Osberg et al., 1989; Hibbard, 2000).

**Conclusion**

Detrital zircon geochronology is a dependable method of determining a broad sense of sediment provenance in most siliciclastic rocks. The emerging field of zircon Thermochronology can be used to determine cooling ages that take place due to tectonic uplift. By combining the two methods, as well as strategic sampling of targeted rocks in the major structures through the Appalachian fold and thrust belt, a better model of the Appalachian orogen was formed.

Detrital zircon U–Pb data provide detailed snapshots in how sediment transitioned from a Cambrian passive margin to the foreland basin of the Appalachian orogens where sediment was

restricted to mainly Grenville derived zircon. By the Mississippian Period, uplifted materials derived farther in the hinterland brought recycled zircons back into the foreland basin.

The original purpose of collecting zircon cooling ages was to help provide a geochronologic solution to what seems to be out-of-sequence thrust in the Appalachian fold and thrust belt. Previously this theory was only collaborated by cross cutting relationships, and this study sought to add more conclusive data. Preliminary samples proved that the zircon (U–Th)/He thermochronologic methods are severely limited based on the burial depth and eliminate most upper stratigraphic rocks from further analysis. The Cambrian units are the only rocks deep enough to be thermally reset, provided key data in the timeline of uplift. Furthest foreland sample had a Neo-Acadian (360 Ma) reset age, while the farthest hinterland samples have Alleghanian signature of uplift (310-280 Ma). While this does seem to prove that at least a portion of the Alabama fold and thrust belt was breaking backwards, more extensive testing of other Cambrian units is needed to provide a more extensive timeline of uplift in the area.

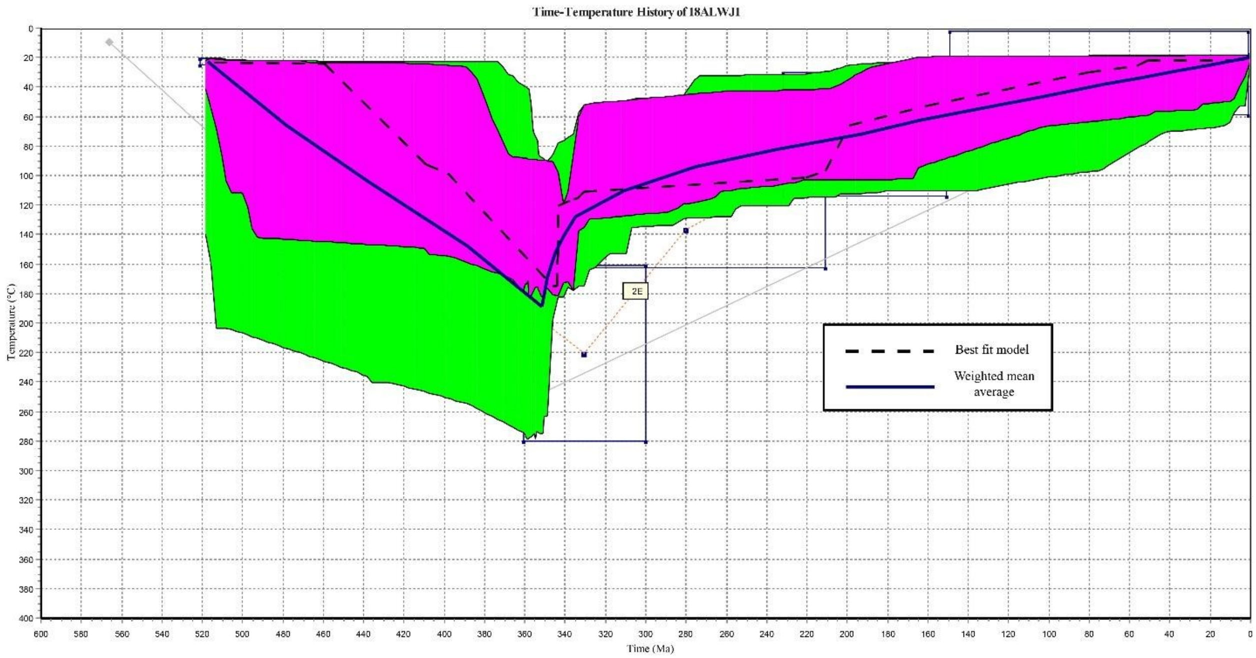


Figure 16. Time-Temperature History of Chilhowee Group rock from Weisner Mountain constructed on HeFTy. The green field represent acceptable time-temperature paths. The pink field represent well-fitting time-temperature paths with best fit model and weighted mean average overlaid.

# SUMMARY

## Part 1: Summary

Recent mapping of the Jacksonville East 7.5-minute quadrangle (33°45′00″ to 33°52′30″ latitude; 85° 37′ 30″ and 85 °45′ 00″ longitude) at the 1:24,000 scale has allowed for a more comprehensive understanding of the geologic structure as well as providing more accurate constraints on the locations of stratigraphic contacts. The Paleozoic bedrock belongs to both the Southern Appalachian Valley and Ridge and the Piedmont provinces. Within the Valley and Ridge includes sandstones, limestones and shales. Within the quadrangle, the rocks that are exposed range from Early Cambrian to Early Pennsylvanian in age. Formal stratigraphic units include sedimentary units in the Valley and Ridge include the Nichols Formation, Weisner and Wilson Ridge Formations undifferentiated, Shady Dolomite, Rome Formation, Conasauga Formation, Knox Group undifferentiated, Athens Shale Floyd Shale undifferentiated, Parkwood Formation, and Floyd Shale undifferentiated. The Metamorphic lithologies of the Alabama Piedmont include the Kahatchee Mountain Group, Heflin Phyllite, and Lay Dam Formation. These sedimentary rocks have been deformed northeast and north-south striking, along northwest translated thrust faults and thrust related folds. Much of the deformation took place during the Alleghanian orogenic event. Oroclinal bends and east-west striking faults zones are attributed to lateral ramps in the subsurface.

In the northwest portion of the quadrangle a small amount of Parkwood Formation and Floyd Shale undifferentiated is exposed in the footwall of the Pell City fault. In the southwest corner of the quadrangle a structural window exposes the Mississippian-Ordovician Floyd Shale and Athens Shale undifferentiated.  In the valley east of Dugger Mountain structural klippen of

Weisner Formation and Wilson Ridge Formation undifferentiated suggest that the Dugger Mountain thrust sheet is also a klippe making it the remnants of a thin thrust sheet above the Jacksonville fault stratigraphy.

The Pell City thrust sheet contains rocks that are Early Cambrian to Early Ordovician in age and is bound by the Pell City fault. Rocks that belong to this thrust sheet are exposed along the western base of Choccolocco Mountain. The Pell City thrust sheet is truncated in the east by the Jacksonville fault where it is in the foot wall of the fault. The Jacksonville fault brings up a much lower stratigraphy that includes earliest Cambrian-aged rocks belonging to the Chilhowee Group. To the east, the Dugger Mountain fault places the rocks found on Dugger Mountain on top of the Jacksonville thrust sheet. Both thrust sheets are deformed and then truncated by the Talladega-Cartersville fault to the NE. The Talladega-Cartersville juxtaposes metasedimentary with Cambrian to Devonian protoliths.

**Part 2: Summary**

The southern Appalachian Valley and Ridge Province has undergone multiple deformational events. The Appalachian orogens started in the Late Cambrian and ended in the Permian period. High detail geologic mapping as well as detrital zircon geochronologic and thermochronologic data can improve the model of orogenic construction in the Southern Appalachians Mountains of Alabama. From the geologic mapping, a much better look at smaller structures of the Valley and Ridge Province was achieved. The structure of the Jacksonville East 7.5—minute quadrangle gives evidence of later Alleghenian deformation. The quadrangle provides concrete structural evidence and displays how complex the fold and thrust belt structures can be. From the detrital zircon geochronologic data that is from rocks throughout the Appalachian foreland basin, it can be better understood where the sediment was derived from

and the route it took until deposition. Collectively these samples show how sediment routing in the Appalachian foreland basin changes from a passive margin that contains significant populations of Canadian Shield and older continent derived zircon, to an active margin that has lost the continental signal and instead contains a large singular population of proximal Grenville zircon. The margin then transitions into a continent on continent collision that has a renewed source of diverse zircon that contain Canadian Shield and distal continental derived zircons. The detrital zircon (U—Th)/He data can provide valuable data on the first amounts of uplift from samples collected along major thrust faults. From preliminary data that was collected from the detrital samples, only the lowest stratigraphic unit, the Cambrian Chilhowee Group, was buried deep enough to have all sampled zircons that were thermally reset. The three samples collected from the Chilhowee Group vary in structural position along the southern Appalachian fold and thrust belt. Using the thermal modelling software HeFTy the (U—Th)/He, along with geologic constraints provides a potential time-temperature path of each sample during deformation. Sample 18ALWJ1 which came from Weisner Mountain further in the foreland, has an approximate uplift age of 350 Ma and correlates to the Acadian orogen. samples 17AL19 and 16ALMM01 are closest to the Talladega-Cartersville Fault and had an approximate uplift age of 315 Ma and 325 Ma respectively which correlates to the peak of the Allaghenian orogen. While this does give some credence to the out of sequence thrusting in the Alabama fold and thrust belt, more data is needed.

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