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GEOLOGIC MAP OF THE ATLANTA 30′ x 60′ QUADRANGLE, GEORGIA

By Michael W. Higgins,[1] Thomas J. Crawford,[2] Robert L. Atkins,[3] and Ralph F. Crawford[4]

INTRODUCTION

The Atlanta 30′ x 60′ quadrangle is located in northern Georgia and is roughly centered on the city of Atlanta. The northwestern corner of the quadrangle is in the Valley and Ridge province, and the rest of the quadrangle is in the Piedmont-Blue Ridge province (fig. 1; Crawford and others, 1999). Two assemblages of rock crop out in the Atlanta quadrangle, the *parautochthonous Laurentian continental margin assemblage* and the *allochthonous oceanic assemblage* (hereafter the parautochthonous and allochthonous assemblages, respectively). The allochthonous assemblage was obducted upon the parautochthonous assemblage during Middle through Late Ordovician time, so that the assemblages are separated by what were once nearly horizontal thrust fault boundaries that were folded after Early Silurian time. During Middle Silurian to Permian time the folded thrust stacks were in turn separated by a dextral wrench fault system similar to the San Andreas fault system in California (Crowell, 1962, 1974; Dibblee, 1977) and other large wrench fault systems (for example, Wilcox and others, 1973). Folding accompanied wrench faulting or strike-slip faulting, and in many places this faulting was accompanied by thrust/high-angle reverse faulting that cut through the Ordovician thrust system.

Although saprolite allows detailed mapping in the Piedmont-Blue Ridge in Georgia, contacts, including faults, are rarely exposed, so details of the nature of these contacts are only locally known. Therefore, in many places even with detailed mapping and even where exposures are good, the early thrust faults are difficult to separate from the later wrench/strike-slip related thrust/high-angle reverse faults. Every fault contact on the map has some kind of mylonite or cataclastic rock along it. Mylonitic rocks are, for the most part, continuous along most faults in and northwest of the Brevard fault zone. Southeast of the fault zone mylonite only has been observed in a few widely scattered localities along most faults because of poor exposure and because streams with alluvial deposits along them tend to follow contacts, faults, and fault zones. Faults are extremely difficult to map through the Bill Arp Formation (O€b) because the faults form less competent mylonites from the pelites in the Bill Arp and these generally weather more than the unfaulted rocks around them.

MAP CONSTRUCTION

The geologic map of the Atlanta quadrangle was compiled from our geologic maps of the 32 7.5-min quadrangles that it encompasses. Most of these quadrangles were mapped in detail, but because of lack of exposures detailed maps in the city of Atlanta lack the control of most suburban and rural quadrangles. Approximately 70 percent of the Atlanta quadrangle can be described as urban-suburban, with rapid growth taking place in most other areas. Geologic mapping was done intermittently between April 1963 and October 1976, and semi-continuously between October 1976 and January 1993. Thus we were able to take advantage of the great growth of the Atlanta metropolitan area, where new roads and other construction provided an increasing percentage of exposure that was in many places covered after construction was completed. All of the mapping compiled into the geologic map was done by the authors, except as follows. We extensively field checked the geologic map of the Stone Mountain-Lithonia district by Herrmann (1954) and modified it as new exposures became available; similarly, because of the many new exposures since 1965, we have modified the geologic map of the Brevard fault zone near Atlanta by Higgins (1968), maps of the Brevard fault zone and Deep Creek structure southwest of Atlanta by J.H. Medlin and T.J. Crawford (unpub. data), the map of the Austell-Frolona anticlinorium by Medlin and Crawford (1973), the map of the Kellytown quadrangle by Jordan (1974), and the geologic map of the Kennesaw Mountain-Sweat Mountain area by Hurst (1952). We did not use the geologic map of the Greater Atlanta region by McConnell and Abrams (1984) because much of our own mapping was used in that compilation and much of our mapping has since been modified and made considerably more detailed.

GEOLOGIC CROSS SECTIONS

The geologic cross sections for the Atlanta quadrangle are admissible (Elliott, 1983) but not balanced. The structures drawn on the sections are like those that can be seen in the geologic map, in roadcuts, railroad cuts, quarries, and natural outcrops. The cross sections cannot be balanced because (1) we don't know original thicknesses of the units, most of which are at metamorphic grades higher than greenschist facies. Thicknesses have been distorted during faulting, folding, and metamorphism. (2) Nowhere does a complete undeformed section of rock exists. (3) The nearest pin is located in the foreland in the Cumberland Plateau province, more than 40 km across strike from the Emerson fault at the northern-northwestern edge of the Piedmont-Blue Ridge. (4) The sections cross wrench fault zones with probable large displacements such as the Dahlonega and Brevard fault zones. The sections incorporate faults with both strike-slip and normal displacements in which the magnitude of the displacements is unknown. More important than all these reasons, however, is the fact that there were at least two periods of metamorphism and deformation during the Paleozoic, and sections cannot be legitimately balanced where rocks have been deformed during two different metamorphic and (or) deformational events. The topographic sections for the geologic sections appear nearly flat at 1:100,000 scale, because relief in the

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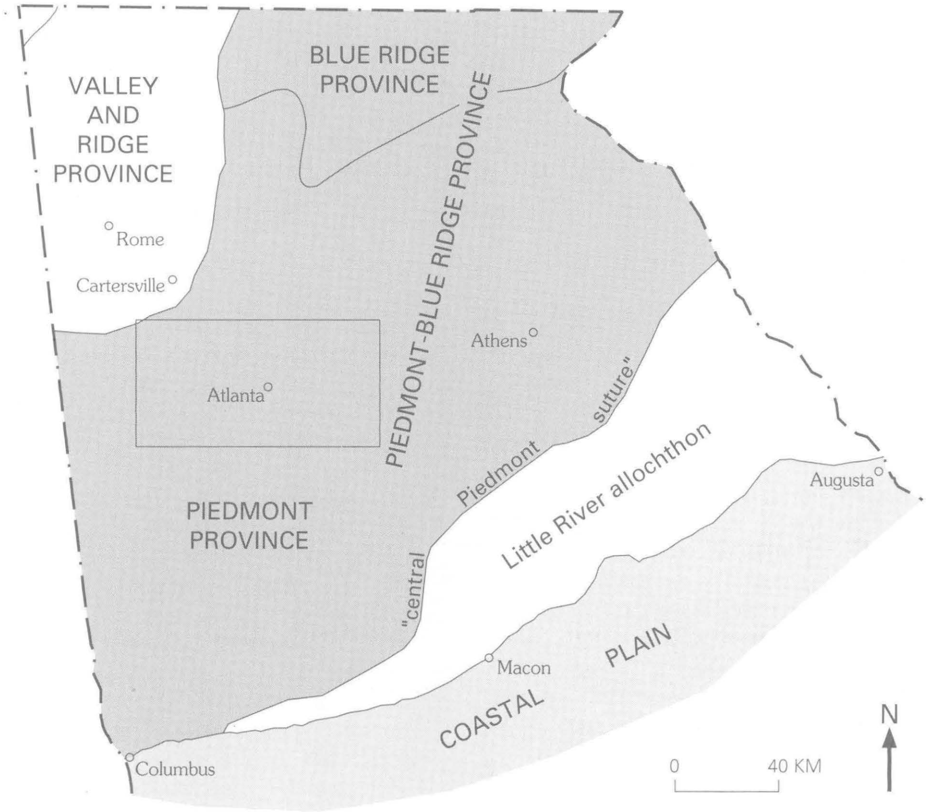

Figure 1.—Geologic and physiographic provinces in northern Georgia; geologic provinces from Higgins and others (1997). Southern boundary of Piedmont-Blue Ridge province from Hatcher and others (1990); Little River allochthon from Higgins and others (1988); physiographic provinces from Fenneman (1938, pl. 3).

Atlanta quadrangle (excluding the monadnocks—Kennesaw Mountain, Lost Mountain, and Pine Mountain in Cobb County; and Stone Mountain and Pine Mountain in DeKalb County) is very low; maximum relief is about 80 m. The interpretations presented in this map supersede those in Higgins and others (1988). We have divided the rocks in the Atlanta quadrangle in a different manner for this map than for plate 1 in Higgins and others (1988) because our continued research has modified our concepts of how the rocks should be grouped, their distribution, and how they arrived in their present structural positions. However, more detailed mapping has only reinforced our earlier conclusion that there is no scientific basis for dividing the Piedmont-Blue Ridge in Georgia into "belts" or into separate Piedmont and Blue Ridge provinces because the same rocks are found throughout, except for the area east of the "central Piedmont suture" of Hatcher and others (1990) (area underlain by Little River allochthon of Higgins and others, 1988) (fig. 1).

ACKNOWLEDGMENTS

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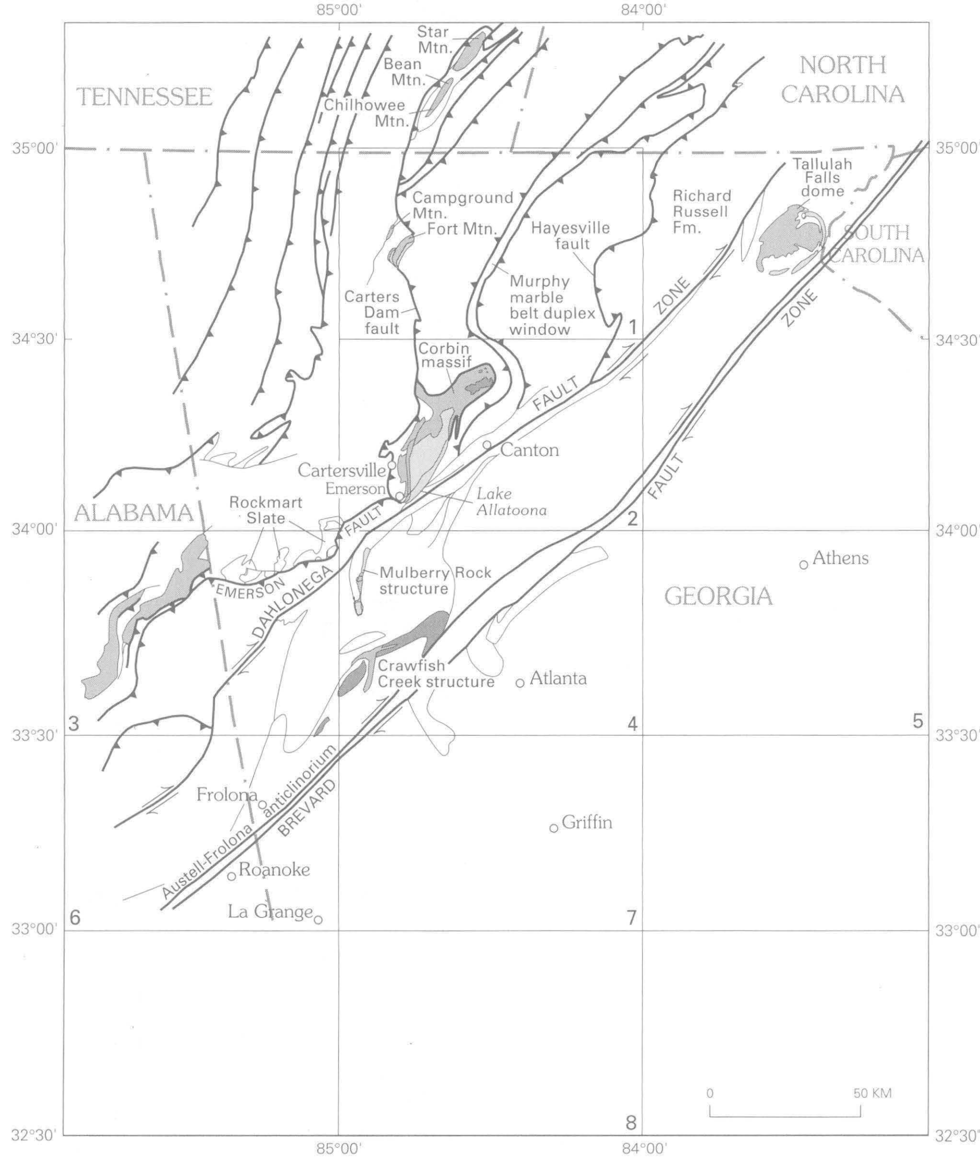
CHRONOLOGY

Until recently, fossils had not been found in any of the rocks southeast of the Emerson fault (formerly part of the Cartersville fault) or east of the Carters Dam fault (formerly part of the Cartersville fault or the Great Smoky fault) in Georgia (fig. 2). Therefore the ages of units are based on their relation to and (or) correlation with fossiliferous rocks of the Valley and Ridge province northwest of the Emerson fault and west of the Carters Dam fault and their relation to the Middle(?) to Late Proterozoic Corbin Metagranite (ZYc) and to the Early Silurian Austell Gneiss (Sa).

VALLEY AND RIDGE PROVINCE

The age, stratigraphic relations, and structural relations of four units in the Valley and Ridge province in Georgia have direct bearing on age assignments in the Piedmont and Blue Ridge.



EXPLANATION

- Austell Gneiss
- Basal clastic sequence
- Corbin Metagranite and correlative rocks
- Contact
- Thrust fault—Sawteeth on upper plate
- Strike-slip fault—Arrows indicate relative displacement

30' x 60' QUADRANGLES

1 Dalton	5 Athens
2 Cartersville	6 La Grange
3 Anniston	7 Griffin
4 Atlanta	8 Thomaston

Figure 2.—Generalized tectonic map of northern Georgia showing quadrangles and features mentioned in text.

Two of these units, the Middle Ordovician Rockmart Slate (Or) and the Lower Mississippian Fort Payne Chert (Mf) crop out in the Atlanta 30′ x 60′ quadrangle. The other two, the Lower and Middle Devonian Frog Mountain Sandstone and the Middle Ordovician Tellico Formation, crop out a short distance to the north in the Cartersville 30′ x 60′ quadrangle.

Middle Ordovician Rockmart Slate

Throughout the Appalachian Valley and Ridge province Middle Ordovician dark slates are found resting in sharp contact upon Middle Ordovician shelf carbonate units that are the same age within a few graptolite zones (Rodgers, 1968). In Georgia one of the dark slates is the Rockmart Slate (Or) (Cressler, 1970), which is only exposed in western Georgia and in the vicinity of the recess in the Piedmont-Blue Ridge part of the orogen at Emerson, southeast of Cartersville (fig. 2). Elsewhere in Georgia (Cressler, 1970, 1974; Cressler and others, 1979; Georgia Geological Survey, 1976), southern Tennessee (Hardeman and others, 1966), and Alabama (Osborne and others, 1989), the Middle Ordovician dark slate interval is represented by the Athens Shale. The age of these dark graptolitic shales and slates is critical to establishing the time of beginning of the convergence that produced an upper Middle Ordovician to Lower Silurian clastic wedge and foreland basin sequence and what has been called the "Taconic" or "Taconian orogeny" (for example, King, 1951; Rodgers, 1967, 1970). Before deposition of the dark pelites, from the Early Cambrian to the Middle Ordovician, the rocks now beneath the dark pelites were deposited on an extensive carbonate shelf.

The Rockmart Slate (Or), which crops out in the northwestern corner of the Atlanta quadrangle, is a dark-gray to nearly black, tan- to yellowish-brown- to pink-weathering, fine-grained, generally calcareous slate, about 90 m thick, but without marker beds. It has well-developed folds and cleavages and a Middle Ordovician graptolite fauna (Cressler, 1970; Bergström, 1973; Finney, 1980). The Rockmart (Or) rests in sharp contact upon the regional angular unconformity at the top of the Upper Cambrian to Middle(?) Ordovician Knox Group (Cressler, 1970; Mussman and Read, 1986) and upon the disconformity at the top of the warm, shallow-water Middle Ordovician Lenoir Limestone. The Lenoir is very nearly the same age as the Rockmart.

Dewey and others (1986, p. 5–9, figs. 2 and 4) formulated a model for a generalized orogen based on several major orogens, but especially the Alpine/Himalayan convergent system. One of the orogenic features in their model is a lithospheric flexure ("peripheral bulge") that occurs in the foreland near its border with the more active parts of the developing orogen (hinterland). Crampton and Allen (1995) call this peripheral bulge a "forebulge," and the unconformity that results from erosion of the bulged-up rocks a "forebulge unconformity." The foreland or peripheral bulge is in turn overridden and buried by sediments, thrust belts, and molasse basins from the adjacent hinterland. The Knox unconformity probably resulted from early outward migration of the peripheral bulge (Dewey and others, 1986) or forebulge (Crampton and Allen, 1995) of the Appalachian orogen.

We interpret the contact between the Rockmart and the underlying rocks of the carbonate shelf sequence to be a thrust fault in many places, with the Rockmart having been thrust, or having slid, upon the Middle Ordovician Knox unconformity upon which it was deposited. The Rockmart (Or) is confined to the western side of the bend in the orogen at Cartersville, Ga. Conodont data indicate that the base of the Rockmart is older than the base of its near counterpart, the Athens Shale, and that the Rockmart was probably deposited farther from the craton than the Athens (Bergström, 1973; Finney, 1980). Higgins and others (1988) suggested that the Rockmart Slate may have had a more complicated history than the Athens Shale. Elsewhere in the Appalachian orogen, dark, graptolitic Middle Ordovician pelites have been interpreted to have been deposited upon Middle Ordovician shelf carbonates when the shelf sank (Rodgers, 1968; Stanley and Ratcliffe, 1985), and Chowns and Renner (1989) have interpreted the Rockmart Slate this way. We agree with that interpretation, but we think the evidence (summarized by Higgins and others, 1988) is strong that the lower contact of the Rockmart is a thrust fault in many places on which the Rockmart has been detached from its site of deposition and thrust or glided upon the unconformity upon which it was deposited.

Regardless of how it arrived, the position of the Rockmart Slate on top of the Lenoir Limestone indicates that slope reversal was taking place in the Georgia Appalachians during the Middle Ordovician. The Rockmart and the overlying Tellico Formation, which contains clasts of Rockmart Slate, were folded and metamorphosed under lowermost greenschist facies conditions that produced a 2M muscovite and chlorite assemblage (Renner, 1987). This deformation and metamorphism occurred before deposition of the unconformably overlying Lower and Middle Devonian Frog Mountain Sandstone, which is consolidated but apparently unmetamorphosed (Cressler, 1970; Sibley, 1983).

Middle Ordovician Tellico Formation

In western Georgia the Middle Ordovician Rockmart Slate (Or) is overlain (conformably?, paraconformably?) by the Middle Ordovician Tellico Formation, exposed a few kilometers north of the Atlanta quadrangle in the southern part of the Cartersville 30′ x 60′ quadrangle (fig. 2). The Tellico is a relatively thin (~90 m thick) unit composed of low-grade metamorphosed siltstone, feldspathic sandstone, and slate with lenses of polymictic conglomerate. The lenses of conglomerate are composed of angular to subrounded fragments, chips, pebbles, and cobbles of limestone, dolomite, slate, sandstone, chert, and quartzite in a matrix of feldspathic sandstone, sandy slate, graywacke, clay slate, or, rarely, dolomite or limestone. Some of the quartzite clasts in the conglomerates were metamorphosed before deposition, and some of the slate clasts lithologically match the underlying Rockmart Slate (Cressler, 1970; Chowns and McKinney, 1980; Sibley, 1983; Higgins and others, 1988). Cressler (1970) suggested that the slate clasts are reworked Rockmart. Carbonate clasts lithologically match rocks of the carbonate shelf sequence below the Rockmart (Cressler, 1970, p. 25). Cressler (1970, p. 30) and Higgins and others (1988, p. 81) interpreted the Tellico in western Georgia to represent depositional equivalents of the Tellico Formation and overlying Chota Formation (Neuman, 1955) in southeastern Tennessee.

Higgins and others (1988, p. 81–82) summarized evidence that the Tellico Formation was derived from a source to the east or southeast rather than from the craton or the carbonate shelf. An eastern or southeastern source is indicated (1) by the size and angularity of some of the noncarbonate clasts in the conglomerates, (2) by the presence of clasts that were metamorphosed before deposition, (3) by the fact that grain size in sandstone beds increases from west to east and bedding thickens toward the east, and (4) by the fact that the conglomerate lenses in southeasternmost outcrops are thickest, have the widest lateral extent, and contain the coarsest and least rounded pebbles and cobbles. Cressler (1970, p. 30) described the Tellico as "an eastward thickening wedge of clastics."

The age and structural and (or) stratigraphic position of the Rockmart Slate (Or) and Tellico conglomerate are interpreted to indicate that orogeny was taking place oceanward (present eastward-southeastward) from the Cambrian and Ordovician carbonate shelf during the Middle Ordovician.

Devonian Frog Mountain Sandstone

Not far northwest of the northwestern corner of the Atlanta quadrangle, the rocks of the carbonate shelf and the Rockmart Slate (Or) and Tellico Formation are overlain unconformably by the Devonian Frog Mountain Sandstone (Neunan and Lipps, 1968; Cressler, 1970; Sibley, 1983), a coarse-grained, proximal facies of the Armuchee Chert (Cressler, 1970). The Armuchee has a warm, shallow-water shelly fauna that suggests it was deposited in quiet conditions and this was probably also the depositional environment of the Frog Mountain Sandstone although it is less fossiliferous than the Armuchee. This quiet depositional environment suggests that either the event that was responsible for placing the Rockmart Slate upon the shelf rocks had ended by the Early Devonian or, more likely, that the event took place farther east-southeast of where the Frog Mountain was deposited.

Lower Mississippian Fort Payne Chert

In the western part of the recess at Cartersville, including the northwestern corner of the Atlanta quadrangle, the Middle Ordovician Rockmart Slate (Or) is unconformably overlain by the Lower Mississippian Fort Payne Chert (Mf). Near the Emerson fault, the Fort Payne is a breccia composed of hard, angular fragments of light- to medium-gray recrystallized chert and siltstone mixed with softer, generally smaller and more rounded, red, white, and tan fragments of similar material, all cemented by silica and iron oxide to locally form boxwork (Cressler, 1970, p. 41–42). A warm, shallow-water fauna composed of crinoid stem plates, horn corals, brachiopods, pelecypods, and bryozoan indicate that the chert is Osagean (Cressler, 1970, p. 42–44). Its age sets the time of brecciation of the chert by movement along the Emerson fault at this point as younger than Early Mississippian.

PIEDMONT-BLUE RIDGE PROVINCE

Two units in the Piedmont-Blue Ridge province in northern Georgia have a direct bearing on age assignments of units in the Atlanta quadrangle. These units are the Middle(?) to Late Proterozoic Corbin Metagranite (ZYc) (Higgins and others, 1996a; Crawford and others, 1999) of the Allatoona Complex of basement rocks and the Early Silurian Austell Gneiss (Sa) (Higgins and others, 1997). In addition, five Carboniferous plutons can be used to infer minimum ages of stratigraphic units, folds, foliation, and faults that they intrude. However, none of the five plutons is sufficiently well dated to be used to definitively set age limits.

Middle(?) to Late Proterozoic Corbin Metagranite

In the western part of the Piedmont-Blue Ridge in northern Georgia, and at least as far west as the Mulberry Rock structure in the northwestern corner of the Atlanta quadrangle in western Georgia, basement is represented by the Allatoona Complex. This complex is composed of the Middle(?) to Late Proterozoic Corbin Metagranite (ZYc) and two units intruded by the Corbin, the Red Top Mountain and Rowland Spring Formations. The Red Top Mountain and the Rowland Spring occur as large xenoliths and roof pendants in the Corbin around Lake Allatoona in the Cartersville 30' x 60' quadrangle, but are not mapped in the Atlanta quadrangle.

The Corbin Metagranite (ZYc) has been dated by two methods. Dallmeyer (1975, p. 1740) reported preliminary Middle Proterozoic U-Pb zircon ages obtained from Odom and others (1973) and Rb-Sr whole-rock isochron ages in excess of 1 Ga. Dallmeyer (1975, p. 1740–1743) also reported undisturbed $^{40}Ar/^{39}Ar$ release spectra with total-gas ages of 735 Ma and 732 Ma, both ±15 Ma, for the Corbin and suggested that "the biotite ages date the time of cooling below temperatures required for argon retention following Grenville metamorphism" (p. 1740). A zircon sample from the Corbin exposed along the southern shore of Lake Allatoona in Red Top Mountain State Park yielded a U-Pb age of 1.1 Ga (Crawford and others, 1999). However, the Corbin Metagranite (ZYc) is a complex rock, the dated zircons may be inherited detrital zircons, and previous interpretations that it has been metamorphosed to pyroxene-granulite facies are probably incorrect (Higgins and others, 1996b; Kath and others, 1996). Nevertheless, the Corbin must be either Late or Middle Proterozoic, and its age can therefore be used to place some limits on the age of rocks it has intruded, rocks it has supplied sediment to, and rocks it has been faulted upon or against. We have used the Middle(?) to Late Proterozoic age of the Corbin Metagranite to assign ages of Late Proterozoic as the probable older age for most of the non-plutonic rocks in the Atlanta, Athens, and Cartersville quadrangles.

Early Silurian Austell Gneiss

Many of the chronologic assignments in the Piedmont-Blue Ridge in Georgia depend upon the age of the Austell Gneiss (Sa), a gray, medium- to coarse-grained, strongly foliated, biotite-(±muscovite)-oligoclase-quartz-microcline (quartz monzonite) orthogneiss that crops out in the northeastern end of the Austell-Frolona anticlinorium on the northwestern side of the Brevard fault zone in the Atlanta quadrangle. In many outcrops the Austell is a mylonite, with textures ranging from protomylonite to mylonite gneiss. Locally, the Austell Gneiss contains microcline megacrysts, as long as 4 cm, but more commonly 1 to 2 mm (Coleman and others, 1973; Crawford and Medlin, 1974) that make up 20 to 50 percent, but commonly 25 to 30 percent, of the rock. Accessory minerals include euhedral to subhedral grains of sphene and allanite as well as garnet, zircon, and opaques. Minerals of probable secondary origin include epidote, chlorite, and sericite. The chemical composition of the Austell Gneiss (Sa) (Higgins and others, 1997) is close to that of a minimum-melt (Tuttle and Bowen, 1958).

Zircons from three localities in the Austell Gneiss (Sa) have been dated by the U-Pb-Th method and yield data interpreted using a concordia plot to indicate an age of about 430 Ma (Higgins and others, 1997). In addition, six samples gave a Rb-Sr isochron age of about 430 Ma (Higgins and others, 1997). We interpret the age of the Austell Gneiss to be about 430 Ma and to be the time of crystallization of the Austell from a granitic magma. The agreement between the age of the Austell Gneiss as determined by the two methods and the fact that isotope ratios indicate little contamination are considered to indicate that the age has not been reset during metamorphism.

The Austell Gneiss (Sa) has intruded the Bill Arp Formation (O€b) and the Gothards Creek Gneiss (SYg) (Higgins and others, 1997, 1998). Austell Gneiss (Sa) can be seen to have intruded schist and metagraywacke of the Bill Arp Formation (O€b) in *lit-par-lit* fashion at their contact along the northern fork of Little Bear Creek in the Campbellton quadrangle. Xenoliths of Bill Arp Formation schist (O€b) in Austell Gneiss (Sa) can be seen in the roadcut along the left side of the east-bound lanes of Interstate 20 approximately 3.5 km west of the juncture of Interstate 20 with Georgia Highway 5. The contact between the Austell Gneiss (Sa) and Gothards Creek Gneiss (SYg) west and northwest of Austell, Ga., is a mixed zone of layered Gothards Creek Gneiss intruded in a *lit-par-lit* fashion by Austell Gneiss; this *lit-par-lit* intrusion can be seen in a pavement outcrop on the south bank of Sweetwater Creek about 60 m west of U.S. Highway 278 (Camp Creek Parkway) in the Austell quadrangle. So the Bill Arp (O€b) and Gothards Creek (SYg) must be older than Early Silurian. Moreover, if the Austell Gneiss (Sa) intruded the fault(s) that carried the allochthonous assemblage and placed it upon the parautochthonous assemblage, as appears to be the case, then the allochthonous assemblage and the fault must be older than Early Silurian. Because the Gothards Creek Gneiss (SYg) is completely bounded by faults it is unknown whether it belongs to the allochthonous or parautochthonous assemblage.

The Austell Gneiss (Sa) has been truncated along its southeastern side by the Chattahoochee fault (Crawford and Medlin, 1973; Hurst, 1973), along its northeastern side by the Olley Creek fault, and along its northern side by faults of the Oak Mountain fault zone. The Chattahoochee fault bounds the southeastern side (German, 1985, p. 15) of the Olley Creek fault zone (proposed here), which is bounded on the northwest by the Olley Creek fault, named for Olley Creek which it follows for several kilometers. Kinematic indicators, although sparse, indicate that the Olley Creek fault zone is a dextral strike-slip fault zone. Because the strike-slip faults cut the Early Silurian Austell Gneiss (Sa), some of the strike-slip faulting must be younger than Early Silurian, but earlier strike-slip faulting is not precluded.

The major metamorphic event that changed the Austell (Sa) from a granite into a gneiss must have taken place during and (or) after the Early Silurian. The foliation in the Austell Gneiss (Sa) is the same foliation as that in its country rocks. The isoclinal folds in the foliation of the country rocks and the folding that produced the second early-fold set were probably established during the thrusting that emplaced the allochthonous assemblage upon the parautochthonous assemblage (see section on Folding). The second early-fold set was modified by folds of the en echelon set during strike-slip faulting. Therefore the foliation and second set of folds must be as young or younger than Early Silurian and the third set of folds and the wrench faulting that produced the third set of folds must be younger than Early Silurian.

Carboniferous Ben Hill and Palmetto Granites

The Ben Hill and Palmetto Granites (Cb and Cp, respectively), which have been tentatively dated as Carboniferous (about 325 Ma, but with large possibility of error), lack foliation, except near the Rivertown fault at the southeastern edge of the Brevard fault zone. The granites are interpreted to have been intruded during strike-slip faulting because they occur as retort-shaped plutons having tails that extend to the northeast along the Rivertown fault (Higgins and Atkins, 1981). Their shapes are interpreted to be the result of en echelon folding during dextral movement along the Brevard fault zone (Higgins and Atkins, 1981; Vauchez, 1987). En echelon folding is a type of folding that is commonly associated with strike-slip or wrench faulting (Wilcox and others, 1973; Dibblee, 1977; Little, 1992).

STRATIGRAPHIC SEQUENCE

The western part of the Atlanta quadrangle is underlain by a series of fault zones where nearly every unit is in contact with nearly every other unit at some place. Because of the lack of fossils or much reliable radiometric age dating in the Piedmont-Blue Ridge of Georgia, the age of most units can only be established by bracketing from radiometric age dates. Some metasedimentary units have enough facing criteria to establish, for example, that antiforms are anticlines and not antiformal synclines (Higgins and others, 1988, p. 7). For the most part, however, the stratigraphic sequence of the parautochthonous and allochthonous assemblages must be empirically deduced based on (1) the repetition, in many places, of the same sequence of units; (2) the relation of a given unit to a datum, such as a dated pluton, and the relation of other units to that datum by their relation to the original given unit; (3) the relation of units to an event, whether an active event or a passive event, that leaves its mark upon the rocks; and (4) structural sequence such as emplacement of one unit over another by thrust faulting, in which the overthrust (upper plate) unit must be older than the unit it is thrust upon (lower plate).

The stratigraphic sequence of the parautochthonous assemblage has been deduced from relations in the Corbin massif, the Crawfish Creek structure, and the Mulberry Rock structure. In the Atlanta quadrangle the stratigraphically lowest unit is the Corbin Metagranite (ZYc). In the Cartersville quadrangle to the north, the Red Top Mountain and Rowland Spring Formations occupy the lowest stratigraphic position and were intruded by the Corbin. The Corbin is followed by a cover sequence of metasedimentary rocks that contain debris from the Corbin. The cover sequence consists, in ascending stratigraphic order, of six units. (1) The Chilhowee Group, which is represented in the Atlanta quadrangle by the Crawfish Creek Formation (€cf) and the overlying Nantahala Formation (€n) and its Laffingal Member (€nl). The Crawfish Creek and Nantahala Formations are part of the unit that Crawford and Medlin (1973) called the Frolona Formation, which Higgins and others (1996a) recognized is the Crawfish Creek, Nantahala, Sweetwater Creek, and Illinois Creek Formations. Crawford and others (1999) abandoned the name Frolona because the name Nantahala, which is the unit present at the type locality of the Frolona Formation, had precedence (Keith, 1907). (2) The Sweetwater Creek and the Illinois Creek Formations (€sw and €i, or €swi where they cannot be divided) (McConnell and Costello, 1980; McConnell and Abrams, 1984; Crawford and others, 1999), which are the nongraphitic parts of the abandoned Frolona Formation of Crawford and Medlin (1973), that crop out in the Austell-Frolona anticlinorium in the southwestern corner of the Atlanta quadrangle. (3) The Bill Arp Formation (O€b) and its informal schist of Hulett facies (O€bh), which directly overlie the Nantahala Formation where the Sweetwater Creek and Illinois Creek Formations are not present. (4) The informal northern facies of the Bill Arp Formation, which is only found north and east of Canton, Ga., in the Cartersville 30′ x 60′ quadrangle, consists of metapelite and metagraywacke like the Bill Arp Formation (O€b), but also contains amphibolite and pods of ultramafic rocks. (5) The Sandy Springs Group, as modified by Crawford and others (1999), which consists of the aluminous schist unit (€as) and the Chattahoochee Palisades Quartzite (€cp).

The stratigraphy of the allochthonous assemblage is more difficult to decipher than that of the parautochthonous assemblage because there is no firm datum unit like the Corbin Metagranite (ZYc) upon which to base a top or bottom. Nevertheless, a probable bottom to top sequence can be deduced based on repetitive sections and structure. The deduced sequence consists of (1) the mixed unit (OZm); (2) the Ropes Creek Metabasalt (OZr) and the Crider Gneiss (OZcr), which is interpreted to have intruded the Ropes Creek; (3) the Stonewall Gneiss (OZs); (4) the Clairmont Formation (OZcm) only present southeast of the Brevard fault zone; and (5) the Paulding Volcanic-Plutonic Complex (OZp). On the eastern side of the Narroway fault zone on the eastern side of the Mulberry Rock structure the mixed unit (OZm) is the structurally lowest unit in the sequence. It is structurally overlain by the Ropes Creek Metabasalt (OZr), followed by the Stonewall Gneiss (OZs), followed by the Paulding Volcanic-Plutonic Complex (OZp). On the western side of the Mulberry Rock structure, adjacent to the Yorkville fault, the mixed unit (OZm) is followed by the Ropes Creek Metabasalt (OZr), which is followed by an extremely mylonitized gneissic unit that may be mylonitized Stonewall Gneiss (OZs). The mylonitized gneissic unit overlies and is faulted against the Bill Arp Formation (O€b), and, locally, Corbin Metagranite basement (ZYc) as well. The same section, but without the mixed unit (OZm), is repeated (1) immediately to the southeast in the fold-fault structure southwest of Dallas, Ga., (2) in the Crawfish Creek structure, and (3) in the Oak Mountain fault zone, where the mixed unit (OZm) lies structurally upon the Crawfish Creek Formation (€cf) of the parautochthonous assemblage and is succeeded by Ropes Creek Metabasalt (OZr).

Either the mixed unit (OZm) or the Ropes Creek Metabasalt (OZr) are typically the first units of the allochthonous assemblage to lie upon the cover sequence or directly upon the basement. The Ropes Creek is commonly succeeded by the Stonewall Gneiss (OZs). Where present, but generally only in major synforms(?), such as the large fold-fault structure southwest of Dallas and the Soapstone Ridge structure in south Atlanta, the Paulding Volcanic-Plutonic Complex (OZp) succeeds the Stonewall Gneiss (OZs). The contact between the two is thought to be a fault but has not been observed except at Soapstone Ridge (see section on Paulding Volcanic-Plutonic Complex). The Paulding also crops out over a vast area in eastern Georgia and in south-central Georgia near the Fall Line (Higgins and others, 1988). The Paulding has a few widely scattered outcrop areas northwest of the Pine Mountain window, south of the Atlanta quadrangle, in the Griffin quadrangle (fig. 2).

PARAUTOCHTHONOUS LAURENTIAN CONTINENTAL MARGIN ASSEMBLAGE

The structurally and stratigraphically lowest assemblage of rocks in the Piedmont-Blue Ridge of Georgia is the parautochthonous assemblage, which includes the Allatoona Complex of Appalachian basement, composed of Middle Proterozoic and (or) older metasedimentary and metavolcanic rocks, that have been intruded by Middle(?) to Late Proterozoic orthogneisses, and Late Proterozoic to Early Ordovician(?) metasedimentary cover sequence rocks derived from and deposited unconformably upon the basement rocks. The unconformity is seldom preserved, generally being the site of thrust faulting as the cover rocks detached from the basement, so that different cover units are in contact with basement in different places. Included in the cover sequence in the Atlanta quadrangle are the Crawfish Creek Formation (€cf), the Nantahala Formation (€n) and its Laffingal Member (€nl), the Sweetwater Creek Formation (€sw), the Illinois Creek Formation (€i), and the Bill Arp Formation (O€b) and its informal schist of Hulett facies (O€bh) (Crawford and others, 1999). The Sandy Springs Group, as revised by Crawford and others (1999), is interpreted to be cover sequence rocks that have been metamorphosed to kyanite-staurolite grade.

Crawfish Creek Formation

In the Atlanta quadrangle, where it is at high metamorphic grade, the Crawfish Creek Formation (€cf) is a garnetiferous to very garnetiferous schist that contains staurolite, kyanite, or sillimanite, and numerous quartzite stringers and lenses as thick as several meters, but more commonly less than 2 m thick and, locally, mappable "clean" quartzites. Garnets in the Crawfish Creek are commonly medium size (~0.5 mm to ~1 cm), but locally larger, and in many outcrops some of the garnets are elongated. Locally, garnets are so abundant in the Crawfish Creek that they cover the ground along unpaved roads and trails. In many places the Crawfish Creek schists contain small crystals of staurolite or kyanite, and locally these are abundant, and, less commonly, large. Garnetites are also locally common in the Crawfish Creek. The high-grade Crawfish Creek Formation is generally resistant to weathering and erosion because of the high quartz and garnet content, and commonly holds up high, steep ridges. The type locality of the Crawfish Creek Formation is along Crawfish Creek, in the Crawfish Creek structure south of Villa Rica (Crawford and others, 1999).

Where the Crawfish Creek Formation is at lower metamorphic grade, as in the outcrop belt northwest of the Dahlonega fault zone and southeast of the Emerson fault (Higgins and others, 1996a), in the Cartersville 30′ x 60′ quadrangle and in places along the Murphy marble belt duplex window (fig. 2), it is a pale-green and green-flecked silvery phyllite that is commonly slightly to moderately calcareous and generally has many lumps, stringers, and veins of clear to milky quartz, and locally, mappable clean quartzites. The phyllite is intensely folded in most outcrops and roadcuts. Despite its calcareous nature, the low-grade Crawfish Creek contains a fair percentage of quartz, is generally resistant to erosion, and commonly holds up fairly high, irregularly shaped hills, with steep stream valleys between the hills.

Higgins and others (1996a) summarized evidence that the stratigraphic placement of the Crawfish Creek Formation is beneath the Nantahala Formation, and that the Crawfish Creek is part of the Chilhowee Group. La Forge and Phalen (1913, p. 6) included "... a considerable thickness of banded garnetiferous and staurolitic quartz schists" in the basal part of the Nantahala Formation, but stated that the "basal beds" are best developed northeast of the Ellijay 15-min quadrangle in the Dalton 30′ x 60′ quadrangle (fig. 2) and are inconspicuous southeast of Cherrylog in that quadrangle. They considered the Crawfish Creek Formation to be at the base of the Nantahala Formation. High-grade garnetiferous kyanite-bearing schist of the Crawfish Creek Formation underlies the graphitic Laffingal Member of the Nantahala Formation in the Crawfish Creek structure, where no basement has been found. In the Mulberry Rock structure the Crawfish Creek Formation directly overlies the Corbin Metagranite in nearly as many places as the Laffingal Member of the Nantahala Formation. Higgins and others (1996a, p. 25) suggested that the Crawfish Creek Formation may be a facies of the Pinelog Formation, perhaps equivalent to the tidal flat deposits of the Wilson Ridge Formation (Mack, 1980, p. 512–513).

Nantahala Formation

The Laffingal Member (Ꞓnl) of the Nantahala Formation, which structurally overlies the pods of Corbin Metagranite (ZYc) in the Mulberry Rock structure in the Atlanta quadrangle, locally contains lenses of blue-quartz- and angular microcline-granule or pebble metaconglomerate that link it to the Corbin Metagranite basement. The Nantahala also is linked to the basement geochemically (Higgins and others, 1988, p. 137, 140–149), because it has high titanium and high barium contents much like the Corbin Metagranite. The graphitic rocks and associated metaconglomerates of the Nantahala Formation have been mapped through the Cartersville and Dalton, Ga., 30′ x 60′ quadrangles and the Fontana Lake, N.C., 30′ x 60′ quadrangle to the type Nantahala (Keith, 1907) along the Nantahala River. Therefore Crawford and others (1999) have assigned all of the conglomerate-bearing, geochemically similar graphitic metapelites to the Nantahala Formation (Ꞓn). The Laffingal Member (Ꞓnl), named by Crawford and others (1999), is a more graphitic, more schistose facies of the Nantahala that also contains fairly clean quartzites, rarer metaconglomerates, and rarely metaconglomerates that contain pebbles of Corbin Metagranite.

Sweetwater Creek and Illinois Creek Formations

Overlying the Nantahala Formation in the core of the Austell-Frolona anticlinorium, southwest of the Atlanta quadrangle (fig. 2), is a unit composed of slightly graphitic, quartzose, biotite-muscovite schist and biotite-plagioclase-quartz metagraywacke that contains metaconglomerates with blue-quartz and microcline granules and chips of graphitic schist probably derived from the underlying Nantahala Formation. Farther to the northeast, in the Cartersville 30′ x 60′ quadrangle (fig. 2), this assemblage of rocks is divisible into the Sweetwater Creek Formation (Ꞓsw) and the overlying Illinois Creek Formation (Ꞓi) (McConnell and Costello, 1980; Crawford and others, 1999), but the division has not been made in the Austell-Frolona anticlinorium, Crawfish Creek, or Mulberry Rock structures, so the unit overlying the Nantahala is mapped as the undivided Sweetwater Creek and Illinois Creek Formations (Ꞓswi). In the Austell-Frolona anticlinorium, the undivided Sweetwater Creek and Illinois Creek Formations is overlain by the informally named (Crawford and others, 1999) schist of Hulett facies of the Bill Arp Formation (OꞒbh), consisting of garnetiferous and ungarnetiferous phyllite/schist without metagraywacke.

Southeast of the Corbin massif in the Cartersville 30′ x 60′ quadrangle, the Sweetwater Creek Formation (McConnell and Costello, 1980; McConnell and Abrams, 1984; Crawford and others, 1999) is composed of interlayered tan, slightly graphitic metapelite (phyllite/schist); tan to cream-colored, nongraphitic sericite phyllite; and scattered lenses of metagraywacke, arkosic metagraywacke, and metaconglomerate. The metaconglomerate contains blue-quartz granules that link its provenance to the Corbin Metagranite and flattened clasts of graphitic slate/phyllite that link its provenance to the underlying Nantahala Formation; it is locally very feldspathic. Locally, metagraywacke in the Sweetwater Creek contains calc-silicate nodules/lenses similar to those found locally in metagraywacke of the Bill Arp Formation.

McConnell and Costello (1980), McConnell and Abrams (1984), and Costello (1988) equated the Nantahala Formation on the flanks of the Corbin massif (fig. 2) with the Wilhite Formation, and considered it to be a different unit from the Nantahala Formation west of Jasper, Ga., that was considered to be a part of the Murphy marble belt. Therefore, they interpreted the Sweetwater Creek Formation to lie above the Bill Arp Formation (their Etowah Formation) and below the Illinois Creek Formation, which they equated with the Dean Formation of Hurst (1955). We consider the Nantahala Formation to be repeated by thrust faulting and therefore consider it to underlie the Sweetwater Creek Formation. We consider the Illinois Creek Formation to overlie the Sweetwater Creek Formation and the Bill Arp Formation to overlie the Illinois Creek (Higgins and others, 1996a; Crawford and others, 1999). We interpret the graphitic slate chips in metaconglomerates in the Sweetwater Creek to have been derived from the underlying Nantahala. That the graphitic slate chips become less common in metaconglomerates as one proceeds away from the Sweetwater Creek-Nantahala contact (in the part of the Sweetwater Creek that McConnell and Costello (1980) called the Illinois Creek Formation) supports our interpretation that the Sweetwater Creek stratigraphically overlies the Nantahala Formation.

Schist of Hulett facies, Bill Arp Formation

Immediately overlying the Illinois Creek Formation in the axial area of the Austell-Frolona anticlinorium (fig. 2) is a biotite-muscovite schist that contains small (~1–3 mm) red garnets in many outcrops and lacks garnets in nearly as many outcrops. The garnetiferous and ungarnetiferous schists were not separately mapped in the Hulett, Ga., 7.5-min quadrangle. A persistent secondary characteristic of the schist is the presence of closely spaced schistosity planes that gives it a finely cleaved "pin-striped" appearance in many outcrops; the "pin-striped" appearance may be a transposition feature. The schist of Hulett facies underlies the metapelite and metagraywacke facies of the undivided Bill Arp Formation in the axial area of the Austell-Frolona anticlinorium and in the Crawfish Creek structure (fig. 2), but the nature of the contact between them is unknown. It is likely that the schist may be part of the Bill Arp Formation and may be partly equivalent to garnetiferous Bill Arp Formation mapped to the northeast in the northeastern part of the Austell-Frolona anticlinorium in the Atlanta quadrangle. Northeast of the Atlanta quadrangle, on the flanks of the Corbin massif and the Murphy marble belt (fig. 2), the schist of Hulett facies is probably the unit mapped as "sericite schist, with small garnets (staurolite)" (Higgins and others, 1996a, table 1).

Frolona Formation of Crawford and Medlin (1974), Abandoned

The Frolona Formation of Crawford and Medlin (1974) consists of four units, the Nantahala, Sweetwater Creek, and Illinois Creek Formations, and the informal schist of Hulett facies of the Bill Arp Formation. The lowermost unit is the Laffingal Member of the Nantahala Formation and is the unit present in the type locality and type section at Frolona, Ga. (fig. 2). The Nantahala at the type section of the Frolona Formation is composed of graphitic and very graphitic schist with lenses and layers of relatively clean quartzite and lesser amounts of quartz-pebble metaconglomerate; some of the quartz in the metaconglomerate is blue and the feldspar granules are mostly the same composition as those in the Corbin Metagranite. It is identical to the Laffingal

Member of the Nantahala Formation we have mapped to the northeast in the Atlanta, Cartersville, and Dalton 30′ x 60′ quadrangles (fig. 2), except that it is at kyanite rather than staurolite grade or garnet. Because the rocks at the type locality (Crawford and Medlin, 1974, p. 9) and in the type section (Higgins and others, 1988, p. 126–127) of the Frolona Formation are Nantahala Formation and because the Nantahala was named in 1907 (Keith, 1907, p. 4), Crawford and others (1999) abandoned the name Frolona Formation.

Bill Arp Formation

The Bill Arp Formation (O€b) is interpreted to belong to the cover sequence because it is titaniferous and generally contains ilmenite, and its metagraywacke beds locally contain blue-quartz and microcline granules like the blue quartz and microcline in the Corbin Metagranite (ZYc). In western Georgia (Anniston and Atlanta quadrangles and the southwestern part of the Cartersville quadrangle, see fig. 2), the Bill Arp Formation (Crawford and Medlin, 1973; Higgins and others, 1988) is a clastic metapelite-metagraywacke unit that lacks amphibolite or other metavolcanic rocks and lies structurally and probably stratigraphically above the Illinois Creek Formation in the Corbin massif, and above the undivided Sweetwater Creek and Illinois Creek Formations in the Mulberry Rock structure, the Crawfish Creek structure, and the Austell-Frolona anticlinorium. Like the Nantahala Formation, the Bill Arp Formation undergoes a facies change in northern Georgia. North and east of the vicinity of Canton, Ga. (fig. 2), the Bill Arp Formation contains lenses, pods, and layers of amphibolite, and the percentage of amphibolite increases to the east and northeast, so that it is sparse in the Bill Arp near Canton, and accounts for a small percentage of rock in the formation 16 to 24 km northeast of Canton. Across strike, amphibolite constitutes a small percentage of the Bill Arp only a few miles east of Canton where the formation has been telescoped and repeated by thrust faulting and probably offset along the Dahlonega fault zone. In addition, at about the same place the Bill Arp Formation starts to contain amphibolite, it also starts to contain pods and small lenses of metamorphosed ultramafic rocks, chiefly metapyroxenite. Also like the amphibolite, the metamorphosed ultramafic rocks become more prevalent to the northeast along the regional strike and across regional strike to the southeast. This northern facies of the Bill Arp Formation is not present in the Atlanta quadrangle.

The age of the Bill Arp can only be established by bracketing. It is younger than the Middle(?) to Late Proterozoic Corbin Metagranite because its metaconglomerates contain blue-quartz and microcline granules and pebbles probably derived from the Corbin. It overlies the Chilhowee Group rocks in Georgia. Therefore, Crawford and others (1999) assigned it an age of Early Ordovician(?) to Cambrian.

Sandy Springs Group

The Sandy Springs Group, as redefined by Crawford and others (1999), consists of the Chattahoochee Palisades Quartzite (€cp) and the aluminous schist unit (€as) and its quartzite (€aq). It is not known if the quartzites in the aluminous schist unit are fault slices of Chattahoochee Palisades Quartzite (€cp); they are lithologically the same. The stratigraphy of the Sandy Springs Group is not well understood. The units in the informal Sandy Springs sequence recognized by Higgins (1966, 1968) in the Brevard fault zone were mapped to the southwest along strike by Crawford and Medlin (1973, 1974; Medlin and Crawford, 1973) and to the northeast by Murray (1973). The units were given formal stratigraphic names by Higgins and McConnell (1978) on the basis of the pseudostratigraphy in the Brevard fault zone. More detailed mapping now requires modification of the stratigraphy of the Sandy Springs Group. Rather than being a stratigraphic sequence preserved in a fault zone as originally thought (Higgins, 1966, 1968; Crawford and Medlin, 1973, 1974; Medlin and Crawford, 1973; Higgins and McConnell, 1978; McConnell and Abrams, 1984), the Sandy Springs is a sequence of fault slices that mimics a true stratigraphy. A major unit of the Sandy Springs Group, the Powers Ferry Formation (Higgins and McConnell, 1978; gneiss-schist-amphibolite unit of Higgins, 1966, 1968), is now considered to be Stonewall Gneiss (OZs) and to belong to the allochthonous assemblage, whereas the other major units, the Chattahoochee Palisades Quartzite and aluminous schist unit, belong to the parautochthonous assemblage. The probable stratigraphy is given in the Correlation of Map Units. The same units also are present to the east, in the eastern part of the Atlanta quadrangle and western part of the Athens quadrangle (fig. 2), where the Chattahoochee Palisades Quartzite (€cp) and underlying aluminous schist unit (€as) crop out as roof pendants in the Lithonia Gneiss (Dl). Higgins and Atkins (1981) interpreted the Sandy Springs Group to rest either unconformably or in thrust contact upon the Lithonia Gneiss because where streams cut across the Sandy Springs ridges they appear to have cut through the Sandy Springs Group rocks exposing the Lithonia Gneiss. New deep roadcuts in the southwestern part of the Athens 30′ x 60′ quadrangle show that the Sandy Springs Group rocks are mostly in the Lithonia Gneiss, not on it. Therefore the courses of the streams were probably determined by the absence of Sandy Springs Group xenoliths/roof pendants rather than cutting through and removing the xenoliths/roof pendants.

Sandy Springs Group rocks are at high metamorphic grade and are partly granitized/migmatized. Although these features are secondary, they are ubiquitous and characteristic. Dikes and sills of "sweat-out" pegmatite pervade the schists and gneisses, and small bodies of granitoid are common. The quartzites are granular, thoroughly recrystallized, and commonly contain garnet and aluminosilicate minerals.

The continuity of the quartzites in the Sandy Springs Group in the Brevard fault zone west and southwest of Atlanta is an enigma. Mappable quartzite units a few meters thick, mostly assigned to the Chattahoochee Palisades Quartzite (€cp) or to mylonitized Chattahoochee Palisades Quartzite (P0cm), are continuous for as much as 100 km along strike. West and southwest of Atlanta two quartzite units less than 10 m thick run parallel with a separation of less than 0.5 km for about 70 km. A reasonable conclusion is that the thinness and continuity of the quartzites is due to attenuation during faulting and folding in the Brevard fault zone.

Zircon from the Chattahoochee Palisades Quartzite (€cp) north of Lithonia, Ga., yielded U-Pb ages of about 1.1 Ga (Crawford and others, 1999). The ages are interpreted to indicate that detrital zircons were derived from the Grenvillian basement and that the Chattahoochee Palisades Quartzite and probably also the rest of the Sandy Springs Group (as revised by

Crawford and others, 1999) were derived from the basement and are part of the parautochthonous assemblage. Chattahoochee Palisades Quartzite is found as far south as the northern side of the Towaliga fault zone east of La Grange, Ga., in the La Grange, Ga.-Ala. and Thomaston, Ga., 30′ x 60′ quadrangles (fig. 2).

The Sandy Springs is assigned to the cover sequence because (1) the group (as revised) consists of the Chattahoochee Palisades Quartzite and the aluminous schist unit containing quartzite lenses, 0.5 m or less to as much as 300 or 400 m thick, that may be part of the Chilhowee Group that has been greatly attenuated; (2) the Sandy Springs quartzites are locally in contact with graphitic schist that is probably part of the Nantahala Formation (Ꞓn); (3) zircons from the Chattahoochee Palisades Quartzite southeast of Atlanta have yielded ages interpreted to be about 1 Ga (Crawford and others, 1999), supporting a basement source; (4) amphibolites formerly thought to belong with the quartzite and aluminous schist are now known to be either Ropes Creek Metabasalt (such as the abandoned Mableton Amphibolite Member of the Powers Ferry Formation) or to belong to the mixed unit that is interpreted to be a mixture of Sandy Springs Group rocks and the mixed unit of the allochthonous assemblage; (5) although it has not been observed overlying basement, the Sandy Springs Group overlies granitic gneisses that may have been derived from anatexis of basement rocks. East and southwest of Atlanta the Sandy Springs Group overlies Lithonia Gneiss and in western Georgia it structurally overlies Austell Gneiss. The units of the Sandy Springs Group (Ꞓcp and Ꞓas) may be correlative with the Crawfish Creek Formation (Ꞓcf) (Higgins and others, 1996a).

ALLOCHTHONOUS OCEANIC ASSEMBLAGE

The allochthonous assemblage consists of the informal mixed unit (OZm), the informal mixed unit of Goldmine Branch (OZgb), the Clarkston Formation (OZcl), the Wahoo Creek Formation (OZw), the Ropes Creek Metabasalt (OZr), the Crider Gneiss (OZcr), the Villa Rica Gneiss (OZv), the Stonewall Gneiss (OZs) and its Kalves Creek (OZsk) and Powers Ferry Members (OZsp), the Clairmont Formation (OZcm), the unnamed metatrondhjemite gneisses (OZmt), and the Paulding Volcanic-Plutonic Complex (OZp).

Informal mixed unit, informal mixed unit of Goldmine Branch, and Clarkston Formation

Rocks mapped as the informal mixed unit of the allochthonous assemblage vary from place to place but always contain schist, amphibolite, and manganiferous rocks. Most mixed unit outcrop areas have been mapped as OZm (undivided mixed unit), but in the northwestern corner of the Atlanta quadrangle, southeast of Yorkville, is a unit of mixed rock that contains considerable amounts of feldspathic gneiss that has been mapped separately and informally named the mixed unit of Goldmine Branch (OZgb of Crawford and others, 1999).

Underlying the mixed unit in the large synform that underlies Atlanta (Atkins and Higgins, 1980) is a unit composed of sillimanite-rich schist and hornblende-plagioclase amphibolite that Higgins and Atkins (1981) named the Clarkston Formation (OZcl). The Clarkston also is found in the southwestern part of the Atlanta quadrangle and underlies large areas in the adjoining Griffin, Ga., 30′ x 60′ quadrangle to the south (fig. 2).

Ropes Creek Metabasalt

The Ropes Creek Metabasalt (OZr) consists of locally pillowed and generally garnet-bearing amphibolite and metalliferous quartzites. Closely associated with the Ropes Creek, which contains almost no metasedimentary components, are metatrondhjemites (OZv, OZmt) that have intruded the metabasaltic rocks. Amphibolite- and ultramafic-bearing pelitic units and the Stonewall Gneiss and Clarkston Formation are the pelitic parts of the allochthonous oceanic assemblage. The metabasaltic rocks also are intruded by tonalitic orthogneisses of the Crider Gneiss that are chemically similar to the metatrondhjemites (Sanders, 1983, 1990). Amphibolite chemical compositions in the Ropes Creek Metabasalt indicate an oceanic origin (Stow and others, 1984; Higgins and others, 1988; Spell and Norrell, 1990; Sanders, 1990), as do its rare earth elements and other trace elements (Higgins and others, 1988; Spell and Norrell, 1990) and its isotopic compositions (Shaw and Wasserburg, 1984).

Crider Gneiss

Crider Gneiss (OZcr) (Crawford and others, 1999) is a widespread unit in the Georgia Piedmont-Blue Ridge. On the basis of geologic map relations it has apparently intruded the Ropes Creek Metabasalt (OZr), but intrusive relations in outcrop have not been observed. Because of its high feldspar content the Crider Gneiss weathers deeply so that saprolite is the most common exposure of the gneiss.

Stonewall Gneiss

Stonewall Gneiss (OZs) (Higgins and Atkins, 1981) is a unit of pegmatitic biotite-muscovite-quartz-potassium feldspar gneiss that commonly contains amphibolite and pods of metamorphosed ultramafic rocks. The Stonewall Gneiss is one of the most widespread units in the Georgia Piedmont-Blue Ridge. Five other formally named gneiss units in the Georgia Piedmont-Blue Ridge were recognized as belonging to the Stonewall Gneiss and were abandoned by Crawford and others (1999). Moreover, it is likely that the Richard Russell Formation of Gillon (1989) and Nelson and Gillon (1985) is correlative with the Stonewall Gneiss (Higgins and others, 1996a).

Clairmont Formation

The Clairmont Formation (OZcm) is a tectonic mélange in which a variety of clasts float in a sheared and granitized matrix. The Clairmont is similar to a broken formation, but the variety of exotic clasts it contains indicates a much more complex history that involved more than one unit. The paleosome of the matrix is a schistose biotite gneiss, with variable amounts of biotite, that resembles biotite gneisses in the Stonewall Gneiss. The most prevalent exotic clasts in the mélange are thinly layered amphibolite that was folded before being incorporated into the matrix, but the Clairmont contains clasts (exotic blocks) of many different kinds of rock, including amphibolite; amphibolite and light-gray granofels; light- to medium-gray, equigranular biotite granitic gneiss; epidosite; light-gray granofels; metagranite; clean quartzite; and rare ultramafic rocks. Autoclastic chips, blocks, and slabs (native blocks of Hsü, 1968) are common (Higgins and others, 1988).

We interpret the Clairmont to be granitized tectonic mélange deformed at high metamorphic grade. It has autoclasts and exotic clasts that preserve structural features not found in the matrix.

The Clairmont is locally a mixture of ductile and brittle features (Higgins and others, 1988, p. 33–35, figs. 13–15) and may have formed in or near the brittle-ductile transition (Sibson, 1977, 1983). The deformation of the Clairmont supports an early, probably Middle Ordovician to Early Silurian, phase of deformation. The Clairmont was further deformed during Middle Silurian to Permian or younger strike-slip faulting along the Brevard fault zone.

Paulding Volcanic-Plutonic Complex

The Paulding Volcanic-Plutonic Complex (OZp) (Higgins and others, 1988) is a chaotic mixture of mafic and felsic rocks marked by an overall meta-igneous, veined, faulted, disrupted, gray to epidote-green appearance (see Description of Map Units for a complete lithologic description). The contact of the Paulding Volcanic-Plutonic Complex at Soapstone Ridge with structurally underlying granitic gneiss is locally marked by about 1 m of light-green to emerald-green, fine- to medium-grained, highly sheared and strongly schistose talc-actinolite-chlorite, talc-tremolite-chlorite, and actinolite-chlorite-talc schists, locally with epidosite clots and veins and veinlets of asbestos that weather to an apple-green saprolite and soil.

DEVONIAN GNEISSES

In the Atlanta quadrangle there are large bodies of coarse-grained, partly migmatitic gneisses, including the Lithonia Gneiss (Dl) (Herrmann, 1954; Grant and others, 1980); its migmatitic phase, the Mount Arabia Migmatite of Grant and others (1980) and Size and Khairallah (1989); and its informal amphibolite-rich facies (formerly called the Promised Land Formation, but abandoned by Crawford and others, 1999). All contain xenoliths and roof pendants of amphibolite and the Lithonia contains xenoliths and roof pendants of Sandy Springs Group rocks.

FOLDING

Six sets of folds have been documented in the Atlanta area (Atkins and Higgins, 1980). In this map we separate the major folds into (1) a set of early minor isoclinal folds within the foliation that may have formed during Middle Ordovician to Early Silurian thrusting and (2) a second set of minor and major folds (f_e) that folded the early isoclinal folds. These first two fold sets are folded by (3) a set of en echelon folds (f_{en}) formed in the dextral strike-slip fault system that includes the Brevard and Dahlonega fault zones. The en echelon folds formed in response to strike-slip faulting that probably started in the Late Silurian and probably continued at least through the Permian. En echelon folds occur along strike-slip faults and have an angle of 30° to 45° to the principal deformation zone of the strike-slip fault. Wilcox and others (1973) called these folds en echelon folds and illustrated their development along many major wrench fault systems. They have been well documented along the San Andreas fault system in California by Dibblee (1977).

In the Atlanta quadrangle the axial traces of en echelon folds (f_{en}) trend south-southeast from the Rivertown fault at the southeastern edge of the Brevard fault zone at the correct angle to the Rivertown fault for folds formed during dextral movement on that fault (for example, Moody and Hill, 1956; Wilcox and others, 1973; Harding, 1976; Sylvester and Smith, 1976; Dibblee, 1977). Northwest of the Brevard fault zone axial traces of en echelon folds in the Austell-Frolona anticlinorium trend northeastward from the Chattahoochee fault and turn northward to cross the structure. En echelon folds with north- to northeast-trending axial traces are thought to be largely responsible for the Mulberry Rock structure in the northwestern corner of the Atlanta quadrangle, although the structure may have originally formed due to northeastward displacement along the Dahlonega fault zone (fig. 2). Southeast of the Brevard fault zone the three sets of early and en echelon folds have been folded by two more sets of gentle open folds (Tara and Scott Creek folds of Atkins and Higgins, 1980).

MAJOR STRUCTURES

AUSTELL-FROLONA ANTICLINORIUM

By the mid 1970s Crawford and Medlin (1973, 1974; Medlin and Crawford, 1973) had shown that a major feature of the northwestern side of the Brevard fault zone in western Georgia and eastern Alabama is a structure they named the Austell-Frolona anticlinorium (fig. 2). The northeastern end of the structure is occupied by Austell Gneiss (Sa) in which antiformal foliation is defined by preferred orientation of biotite and megacrysts of microcline. Crawford and Medlin (1974) interpreted the Austell Gneiss to be a paragneiss that overlies the Bill Arp Formation (O€b) in the antiform. They mapped a narrow belt of schist and metagraywacke, which they showed as the same lithology as the Bill Arp, dividing the Austell Gneiss in the antiformal end of the anticlinorium and showed the allochthonous assemblage of this paper, extending along the axis of the Crawfish Creek structure of this paper. The southeastern side of the Austell Gneiss (Sa) and the antiform are truncated by the Chattahoochee fault (Medlin and Crawford, 1973; Hurst, 1973) that has placed rocks of the allochthonous assemblage against the Austell Gneiss (Sa) and the Bill Arp Formation (O€b). The northwestern side of the antiform is truncated by high-angle faults of the Oak Mountain fault zone.

McConnell and Abrams (1984, p. 39) also interpreted the antiformal structure to extend southwestward into the Frolona (Nantahala, Sweetwater Creek and Illinois Creek Formations, and the schist of Hulett facies of the Bill Arp Formation) outcrop belt near Whitesburg, Ga., at the southwestern corner of the Atlanta quadrangle, and the Austell-Frolona structure to be an upright F_2 antiform with the Bill Arp in the axial area of a northwest-vergent F_1 recumbent isoclinal fold that had been folded by the F_2 antiform. Their map compilation (McConnell and Abrams, 1984, Plate 1W) does not have structure symbols and they did not present cross sections. However, in their text (1984, p. 39) they show a cross section (fig. 3b) that crosses the anticlinorium from east of Villa Rica southeast to the Chattahoochee fault, in which they depict part of the Frolona Formation, which they propose renaming the Andy Mountain Formation, stratigraphically below the Bill Arp but structurally above and below it in the F_1 fold; they show the Austell Gneiss to be in the closure of the F_1 fold with the gneiss stratigraphically above the Bill Arp and partially under it around the F_1 closure. McConnell and Abrams' (1984) section does not explain the repetition of the Bill Arp Formation in the Austell Gneiss at the northeastern end of the anticlinorium.

Our detailed mapping shows that the narrow belt of Bill Arp Formation (O€b) that divides the Austell Gneiss (Sa) in the northeastern end of the Austell-Frolona anticlinorium is juxtaposed against the main body of Bill Arp (O€b) to the southwest by the Bear Creek fault. On the northwestern side of the Austell Gneiss in the northeastern end of the anticlinorium the narrow belt of Bill Arp Formation (O€b) either truncates against the southernmost fault in the Oak Mountain fault zone or wedges out along the continuation of the fault that has placed the Crawfish Creek Formation (€cf) within the Austell a few kilometers to the southwest. The Bill Arp Formation schists and metagraywackes (O€b) in the narrow belt within the Austell Gneiss (Sa) are locally sheared to button schist and phyllonite indicating, along with geologic map evidence, the presence of faulting. Faulting along the narrow belt of Bill Arp also is indicated by the presence of mylonitized Austell Gneiss exposed in several places along the northwestern margin of the belt; one of the better exposures of this mylonite gneiss is in the pavement outcrops southeast of Vulcan road where it curves westward a few hundred meters north of Interstate 20 to parallel that highway near Lithia Springs, in the Austell 7.5-min quadrangle. We interpret the repetition of the gneiss to be a result of Early Silurian to Permian thrust faulting that accompanied dextral wrench faulting, and the northeastern end of the Austell-Frolona structure to be an antiformal stack in the sense of Boyer and Elliott (1982, p. 1211–1215). The Bill Arp Formation (O€b) and the Austell Gneiss (Sa) are interpreted to be exposed in a window through the allochthonous assemblage.

There are garnet-rich zones (O€bc, O€bb, O€ba) in the Bill Arp Formation that trend north-northeast from the southeastern margin of the window nearly to the Austell Gneiss along the northwestern margin. These garnet-rich zones may correlate with the schist of Hulett facies (O€bh), but more work must be done to determine that correlation. One set of lineations, including mineral elongations, rodding, and minor folds, in rocks of the Bill Arp Formation in the Austell-Frolona window also trend northward (Higgins and others, 1998). The trend of the lineations and the garnet-rich zones are interpreted to be the result of Middle Silurian to Permian dextral movement along the Brevard fault zone.

MULBERRY ROCK STRUCTURE

The Mulberry Rock structure, in the northwestern corner of the Atlanta quadrangle, is bounded on the west by the Raccoon Creek fault of this map and on the east by the Narroway fault or fault zone of this map. Along the eastern and western sides of the structure are pods of Middle(?) to Late Proterozoic Corbin Metagranite (ZYc) with disrupted remnants of Cambrian and Cambrian(?) Crawfish Creek Formation (€cf) and of the Laffingal Member of the Nantahala Formation (€nl), and Bill Arp (O€b) Formation of the cover sequence. The axial area of the structure is underlain by Bill Arp Formation with lenses of graphitic phyllite/schist (O€g), that may be graphitic horizons in the Bill Arp or thin slices of the Laffingal Member of the Nantahala Formation (€nl). At the southern end of the structure is a body of Corbin Metagranite (ZYc) and an entrainment of fault-bounded slices of Corbin Metagranite and cover sequence units. Lineations, including axes of minor folds, crenulations, alignment of elongate minerals, and rodding, fall into three groups in and around the Mulberry Rock structure (Higgins and others, 1998). The majority trend southward toward the Mulberry Rock body and plunge increasingly steeper from north to south toward the body reaching 45° or 50° a few hundred meters north of the body. The second largest group of lineations trend southeastward across the main north-northeast trend of the Mulberry Rock structure. The third set of lineations occurs in the rocks in the maze of fault slices that surround the Mulberry Rock body. The lineations of this group are vertical to subvertical and, where they include shear criteria, indicate dextral sense of shear. The cross section that crosses the Mulberry Rock structure (*B–B′*) shows the structure as a faulted antiform that has brought up basement and cover in a complex structural window. We speculate that the window formed during northeastward displacement of the rocks lying northwest of the Dahlonega strike-slip fault zone (Higgins and others, 1996a).

SOAPSTONE RIDGE STRUCTURE

The Paulding Volcanic-Plutonic Complex (OZp) rocks at Soapstone Ridge occupy the axial region of a recumbent structure that is a tubular sheath fold (terminology of Skjernaa, 1989) plunging 20° to 30° to the east and also an interference structure resulting from superimposition of younger, nearly east-trending en echelon folds upon northeast-trending early folds. At the western end of the Paulding outcrop area, Stonewall Gneiss (OZs) dips eastward beneath the Paulding rocks (OZp), and at the eastern end of the Paulding outcrop area, Paulding rocks dip eastward beneath eastward-dipping Stonewall Gneiss. The fold terminates against a high-angle fault that is interpreted to have had oblique dextral displacement with the eastern-southeastern side displaced downward relative to the west-northwestern side. To the northeast of the structure at Soapstone Ridge the rocks that form the lower part of the structure are folded into a southwestward plunging synform; the closures of the synform are what caused Higgins and Atkins (1981) to interpret the entire structure to be a simple large synform extending from Tucker on the northeast to Newnan in the adjacent Griffin 30′ x 60′ quadrangle to the south, which they called the Newnan-Tucker synform.

BREVARD-DAHLONEGA FAULT SYSTEM

In the southern Appalachians dextral strike-slip faulting has been documented along the Brevard fault zone (Reed and Bryant, 1964; Higgins, 1966, 1968; Bobyarchick, 1983, 1988; Evans and Mosher, 1986; Vauchez, 1987; Bobyarchick and others, 1988). Gates and others (1986) proposed that a dextral strike-slip fault system dominated the Appalachian orogen from Newfoundland through Alabama during the Carboniferous. However, major strike-slip faulting has not been previously documented northwest of the Brevard fault zone. Although most of the high-angle faults within the system probably had oblique displacements rather than strictly strike-slip displacements, kinematic indicators along the faults and in rocks in the fault zones generally indicate dextral strike-slip displacements; lineations are horizontal or subhorizontal with low plunges. These high-angle faults belonged to a complex fault system dominated by the Brevard and Dahlonega strike-slip/wrench fault zones (fig. 2).

BREVARD FAULT ZONE

Low to moderate dips to the southeast have been reported as a characteristic of the Brevard fault zone by nearly everyone who has worked along it (see review and references in Bobyarchick and others, 1988). Seismic reflection surveys have been interpreted by many authors as indicating that the Brevard is a single

"Brevard fault," a thrust fault that dips 40° to 55° to the southeast, in line with the prevailing thrust interpretation. However, the straight trend of the faults that bound the Brevard fault zone (Chattahoochee, Morgan Falls, and Rivertown faults) in the Atlanta quadrangle and the overall straight trend of the fault zone throughout its length not only indicate that strike-slip (or wrench) faulting was the latest and probably most important faulting in the history of the zone, but that the dip of the zone must be steep regardless of the dip of planar features within the zone and regardless of misinterpreted seismic reflection data. Interpretations of the seismic reflection data are not tied to known reflectivity values from the rocks and can be maneuvered into indicating almost anything the interpreter wants.

DAHLONEGA FAULT ZONE

The Dahlonega fault zone, recognized as a major shear zone since the turn of the century (Yeates and others, 1896; Jones, 1909), is a northeast-trending, 1- to 2-km-wide zone of steeply dipping, highly sheared, mylonitized, and altered, partly retrograded, kyanite- and staurolite-grade, metavolcanic and metasedimentary rocks (Jones, 1909; Crickmay, 1933, 1952; Hurst, 1970, p. 388; Rodgers, 1970, p. 180–182; Albino and Gillon, 1987; Albino, 1987, 1989) that extends across Georgia parallel to the Brevard fault zone (fig. 2).

Kinematic indicators, including minor folds, porphyroclasts, and microstructures, indicate dextral shear along the fault zone (Higgins and others, 1996a; Albino, 1987, 1989). In addition to the kinematic indicators, the presence of en echelon folds, the acute angles at which units are truncated against the fault zone, horizontal or subhorizontal lineations, and the straight trend of the Dahlonega fault zone are also strong evidence that this is a strike-slip fault zone.

CHRONOLOGY OF DEFORMATION

There have been at least two separate periods of deformation in the Appalachians in Georgia. The ages of these deformations are based on the Early Silurian age of the Austell Gneiss (Sa) (Higgins and others, 1997), on the interpretation that the unconformity on top of the Upper Cambrian to Middle(?) Ordovician Knox Group is the result of outward migration of a peripheral orogenic bulge (Dewey and others, 1986), and on the interpretation that the deposition of the Tellico Formation was molassic and caused by orogeny to the east-southeast (present directions). On the basis of these data and interpretations, the earlier period of deformation is interpreted to have been from Middle Ordovician to Early Silurian, and it was during this period that the allochthonous oceanic assemblage was thrust upon the parautochthonous continental-margin assemblage. This was also the period when the early isoclinal folds in the foliation and possibly also the early second set of folds originated. During the Early Silurian the granitic magma which later became the Austell Gneiss intruded the Bill Arp Formation and the thrust fault which had brought (obducted) the oceanic assemblage over the continental-margin assemblage.

The later period of deformation, dated as Early Silurian to Permian or younger, occurred when the dextral wrench fault system, accompanied by thrust faulting, caused en echelon folding that modified the second set of early folds, caused formation of a thrust stack in the Austell fold, deformed the Ben Hill and Palmetto Granites by dextral movement along the Rivertown fault at the southeastern edge of the Brevard fault zone, and formed thrust duplexes in the Paleozoic sedimentary rocks of the Valley and Ridge province.

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