Geology of the Inner Piedmont, Carolina Terrane, and Modoc Zone in Northeast Georgia

Gilles O. Allard
James A. Whitney

GEORGIA DEPARTMENT OF NATURAL RESOURCES
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PROJECT REPORT 20

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James A. Whitney

GEORGIA DEPARTMENT OF NATURAL RESOURCES
Joe D. Tanner, Commissioner
ENVIRONMENTAL PROTECTION DIVISION
Harold F. Reheis, Director
GEORGIA GEOLOGIC SURVEY
William H. McLemore, State Geologist

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ABSTRACT

The report area covers twenty one 7 1/2' quadrangles in northeast Georgia located in Elbert, Greene, Lincoln, Madison, McDuffie, Oglethorpe, and Wilkes counties. This area of the Southern Appalachians straddles the Inner Piedmont, Charlotte belt, Slate belt, and Modoc belts.

The Inner Piedmont consists of refolded nappes of migmatized biotite gneisses, sillimanite-quartz-muscovite schists, amphibolites, and orthogneisses. The Inner Piedmont belt is separated from the Carolina terrane (formerly called Charlotte belt and Slate belt) by the Middleton-Lowndesville fault zone. This major regional ductile deformation zone strikes N40°E and dips to the southeast. A narrow brittle fault zone consisting of a silicified breccia zone marks the western limit of the deformation zone.

The Slate belt (Cambrian age), predominantly volcanic in origin, varies from felsic to mafic, and from greenschist to amphibolite grade of metamorphism. The metavolcanic rocks of the Slate belt have been intruded by a series of large composite zoned plutons of the Charlotte belt. A marked increase in the metamorphic grade of the rocks of the Slate belt takes place in the vicinity of the plutons. We see no reason to separate the Charlotte belt from the Slate belt and we have grouped the two belts into the Carolina terrane.

The Modoc fault zone is a wide zone of mylonites separating the Carolina terrane from the Kiokee belt to the south. The Modoc fault zone juxtaposes low grade chloritic phyllites and argillites of the Carolina terrane with migmatized mylonitized biotite gneisses, amphibolites, sillimanite mica schists, and orthogneiss lenses.

The rocks of the Piedmont and Carolina terrane have been metamorphosed and deformed in the Taconic orogeny (425-500 Ma). The post kinematic Elberton and Danburg granite plutons were intruded around 300 Ma.

The Russell Lake allochthon is an ultramafic-mafic thrust sheet which initially covered most of the Southern Appalachians within Georgia and the Carolinas. It is undeformed except for localized narrow shears which may be associated with the Alleghenian deformation of the Modoc fault zone. The allochthon is deeply eroded and only small klippen are left throughout the map area.

The map area lies a short distance south of four producing gold mines in South Carolina. The Lincolnton dacitic volcanic center is surrounded by many former mines and showings of base metals and/or gold. The area offers excellent potential for exploration geologists searching for gold or base metals.

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INTRODUCTION

Our understanding of the geology of the Southern Appalachians has made unbelievable strides in the last twenty five years. This area of "undifferentiated basement complex" has changed into a collage of thrust sheets, nappes, suspect terranes, each with fairly well established lithostratigraphic assemblages.

The advent of plate tectonics and the use of plate tectonic-inspired models, which succeed so well in younger orogenic belts and oceanic basins throughout the world, has contributed much in helping geologists unravel a very complex geological picture.

The current map compilation is designed to present a cross section of tectonic units within the Eastern Piedmont of Georgia. This work is the product of 20 years of mapping by University of Georgia students and faculty, along with recent field work and compilation supported by a grant from the Georgia Department of Natural Resources, Environmental Protection Division, Geologic Survey Branch.

General Geologic Background

The Southern Appalachians were first subdivided on a geomorphological basis (LaForge et al., 1925). Later, Crickmay (1952) subdivided the Southern Appalachians into belts based on lithologies, structure, tectonostratigraphic assemblages, and metamorphic grades. King (1955) and Overstreet and Bell (1965) expanded on this scheme and formalized the names of these belts and their boundaries. From northwest to southeast these are the Cumberland Plateau, Valley and Ridge, Blue Ridge, Brevard fault zone, Inner Piedmont, Kings Mountain Belt, Charlotte Belt, Carolina Slate Belt, Kiokee Belt, and Uchee Belt (Fig. 1).

Griffin (1969) mapped recumbent folds and concluded, before plate tectonics had been proposed, that thrust faulting was involved in the deformation of the rocks of northwest South Carolina. Hatcher (1972) integrated the data available at the time and used the recently-suggested plate tectonic concept to model the evolution of the Southern Appalachians.

The Piedmont (King, 1955; Hatcher, 1972, 1978) is a wide lithotectonic belt subdivided into smaller units. It consists of paragneisses and orthogneisses, amphibolites, calcsilicate granofels, minor schists, quartzites, and iron formations. The Brevard fault zone and the Middleton-Lowndesville fault zone mark the northwest and southeast boundary of the Inner Piedmont. Griffin (1971a, b) subdivided the Inner Piedmont belt into a lower grade non-migmatitic northern belt, a high grade mobilized Inner Piedmont core, and a lower grade southeast flank. Griffin (1971b, 1978b) mapped a series of nappes in South Carolina and proposed a model of "stockwork tectonics" suggested earlier by Wegman (1935) and Haller (1962) in the Caledonides of Greenland. Griffin suggests that the Middleton- Lowndesville cataclastic zone (which becomes the western boundary of the Kings Mountain Belt to the north according to some authors) is the detachment zone separating the Piedmont infrastructure from the superstructure consisting of the Charlotte belt and Carolina Slate belt.

The Charlotte belt has also been called the Uchee belt in Georgia (Crickmay, 1952). The Carolina Slate belt has been referred to as the Little River Series or belt. For reasons that will become obvious later in this report, we will use the term Carolina Terrane for both the Charlotte and Carolina Slate belts in Georgia as was done by Secor et al. (1986a,b).

The Charlotte belt is composed of gneisses, schists, amphibolites, and minor quartzites and aluminosilicate schists. These units are intruded by a variety of pre- and post-kinematic plutons (Overstreet and Bell, 1965; Butler 1966; Butler and Ragland, 1969).

The Carolina Slate belt is predominantly of metavolcanic origin and is distinguished by the lower grade of metamorphism which has affected the belt. The main lithologies are dacites, dacitic pyroclastics, basaltic tuffs, pillowed basalts, tuffaceous argillites, pumice lapilli tuffs, argillites, minor quartzite and iron formation. Fossils have been reported from a few localities (St. Jean, 1965, 1973; Maher et al. 1981; Bourland and Rigby, 1982; Samson, 1984; Samson et al. 1990). The metadacites have been dated at 568 Ma (Carpenter et al., 1982).

The relationships between the Charlotte belt and the Carolina Slate belt remain one of the major problems of Piedmont geology. Some authors favor an unconformity with the Slate belt as the younger unit (Overstreet and Bell, 1965); others favor a thrust of the Carolina Slate belt on top of the Charlotte belt. Tobish and Glover (1969) working on the North Carolina-Virginia border, traced formations from one belt to the other and proposed a gradational metamorphic gradient. Precise geochronological data would help resolve this problem. Work by Secor et al. (1986a) also suggests stratigraphic equivalence between the belts; they used the term Carolina terrane for both (Secor et al., 1986b).

Structural Setting and Tectonic Models

The southeast has been neglected for a long time because of the deep saprolite cover, the lack of fresh outcrops, and the lack of relief which would permit direct observations of the major structures (as is possible in the Alps, Rockies, and other orogens). However, detailed quadrangle mapping has shown that much can be done with saprolite where structures are preserved. The abundances of outcroppings along the innumerable small streams is much better than one would have anticipated from the exposures along the major roads.

The advent of plate tectonics and the seismic profiling of COCORP (Cook et al., 1979) have contributed to a better understanding of the structural evolution of the Southern Appalachians. As mentioned earlier, Griffin (1971b, 1978a, b, 1979) following quadrangle mapping along the South

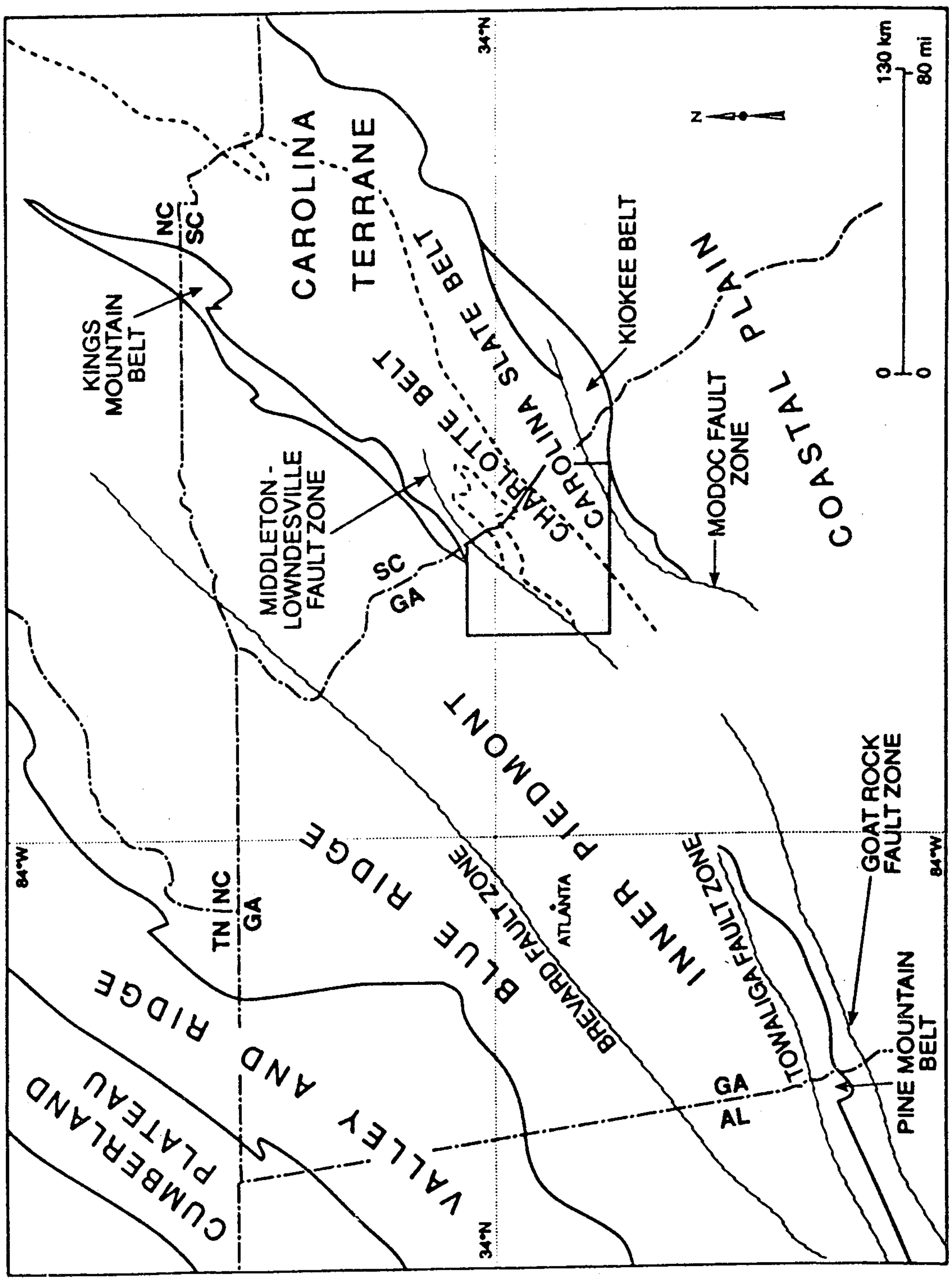


Figure 1. Index map of the Southern Appalachian orogen showing the location of the main belts. Modified from Hatcher and Odom, 1980.

Carolina-Georgia border, presented a "stockwork tectonic" model in which the Inner Piedmont acts as the infrastructure separated from the supracrustal Charlotte Belt and Carolina Slate belt by the detachment zone which he called the Lowndesville cataclastic zone (the Middleton modifier was added later by Rozen, 1978). Hatcher (1972) first proposed a plate tectonic model based on the Bird and Dewey views (1970). Zen (1981) and Williams and Hatcher (1982) proposed different structural models for the Southern Appalachians, as did Higgins et al. (1988). The reader is referred to these papers for a review of the proposed theories.

The Inner Piedmont core consists of a series of nappes with northwest vergences, supporting the concept of major westward Paleozoic thrusting accompanying the closing of the Atlantic Ocean. COCORP seismic sections confirmed the allochthonous nature of the Inner Piedmont. Griffin (1972) extended the Kings Mountain belt southward as far as the South Carolina-Georgia border. Griffin (1978) found a series of cataclastic rocks forming an envelope around an infolded zone of phyllonites, quartzites, amphibolites, manganiferous mica schists and minor talc schists. Rozen (1978) and Davidson (1981) in the Elberton East, Lexington, and Rayle quadrangles mapped a cataclastic zone separating the Inner Piedmont and the volcanic belts to the southeast and called it the Middleton- Lowndesville cataclastic zone. We use the term Middleton-Lowndesville Zone for the broader ductile cataclastic zone as described by Griffin (1978) and the term Middleton-Lowndesville fault zone for the more brittle silicified fault which is located within the ductile zone. We favor Kesler's model (1972) which dissociates the Middleton-Lowndesville zone from the Kings Mountain belt.

Recent work by Legato (1986) in Heardmont quadrangle led to the identification of a late structure which may affect the whole Southern Appalachian province. On the shores of the Savannah River, Legato identified ultramafic rocks in sharp discordance with metavolcanics and metaplutonic rocks of the Carolina Slate belt. The contact is a flat shear zone and Whitney et al. (1987) postulated a large flat thrust of Alleghenian age which they called the Russell Lake allochthon. Previous workers (Davidson, 1981; Young, 1985; Rogero, 1986; Rozen, 1978; Turner, 1987; Conway, 1986) had identified a number of gabbroic and ultramafic bodies throughout the Southern Appalachians Piedmont, including the Inner Piedmont, the Charlotte belt and the Carolina Slate belt. Some of these bodies produce strong aeromagnetic anomalies and sizable hornfels halos suggesting a steep cylindrical geometry and intrusive relationship with the enclosing rocks. Other bodies, generally more ultramafic than gabbroic, lack metamorphic halos of hornfels and do not have an aeromagnetic signature, in spite of the omnipresent fine-grained magnetite accompanying the serpentinization process. These bodies, as documented by Legato and our recent mapping, are flat lying klippen and erosional vestiges of the Russell Lake allochthon. Irregularities in the pre-thrust surface or post-thrust faulting and folding explain some of the gently dipping internal primary structures reported within some of these ultramafic bodies.

Geochronological Constraints and Geological History

A complete geochronological compilation of the work done in the Southern Appalachians would require more space than warranted in this report. See the recent papers by Dallmeyer (1988) and Dallmeyer et al. (1986) for a review of available dates within South Carolina rocks which are essentially the strike extension of the rocks in Georgia. The following dates are important in establishing the sequence of events within the map area.

Rocks deformed by the Grenville Orogeny are relatively rare in the southern Appalachians. Grenville-age windows have been identified in the Blue Ridge and Pine Mountain block. These are the oldest rocks in the orogen.

Slate belt rocks have been dated at 568 Ma using U-Pb in zircons (Carpenter et al., 1982; Dallmeyer et al., 1986). Butler (1972) and Butler and Fullagar (1975) reported an age of 554 ±20 using Rb/Sr in whole rocks. Middle to Lower Cambrian trilobites have been found in at least two localities (St. Jean, 1965, 1973; Maher et al., 1981; Samson, 1984; Samson et al., 1990). Sponge spicules (Bourland and Rigby, 1982) have also been reported of Middle Cambrian age. Whitney et al. (1977), suggested a primitive island arc tholeiite association to explain the Slate belt volcanic rocks. They could not establish the position and dip direction of the related subduction zone at the time of formation of these volcanics.

Metamorphism and deformation of the Inner Piedmont rocks has been dated between 480 and 380 Ma (Dallmeyer et al., 1986; Kish et al., 1979; Glover et al., 1983). The Elberton granite (Whitney et al., 1980b) was intruded about 320 ±20 Ma ago following a period of ductile deformation (Ross and Bickford, 1980; Whitney et al., 1980a).

In neighboring South Carolina, Alleghenian (Hercynian) deformation and metamorphism (D_2 or Lake Murray deformation of Secor et al., 1986) took place between 295 and 315 Ma. The D_3 or Clarks Hill deformation of Secor et al. (1986) took place contemporaneously with a period of rapid uplift and erosion between 285 and 295 Ma (Dallmeyer et al. 1986). The D_4 or Irmo deformation took place between 268 and 290 Ma (Dallmeyer et al., 1986).

Problems to be Resolved

To date, there have been few detailed kinematic studies of the deformed belts within the Southern Appalachians. The lack of detailed geologic maps is partly responsible for this deficiency.

A few studies of major fault zones consistently indicate dextral horizontal movement and yet all the models mentioned above are based on northwestward thrusting of the belts presently located within the Southern Appalachians. Secor et al. (1986) refer to a 175-km apparent decollement during the Alleghenian orogeny. Vauchez

(1987) demonstrates that the Brevard fault zone experienced right lateral strike-slip movement. Bobyarchick et al. (1988) came to the same conclusion. Vauchez and Brunel (1988) also concluded that the Henderson mylonitic gneiss had suffered (or enjoyed) two successive steps of mylonitization but both deformations pointed to a motion parallel to the orogen. More recently, Steltenpohl (1988) in Alabama, working on the Towaliga, Bartlett Ferry, and Goat Rock faults, came to the same conclusions, that is that the Alleghenian orogeny produced right-lateral strike-slip faults and not northwest-directed thrusts. Dennis et al. (1987) came to the same conclusion in their study of the Irmo shear zone and the Modoc fault zone. One solution is that the westward stacking of nappes was associated with the Taconic orogenic event (470-440 Ma) and the strike-slip movement on all the major faults was related to an Alleghenian (Hercynian) orogeny. The lack of age determinations does not allow us to accurately determine the effects of the Acadian orogeny.

Location and Geography

The map area is composed of approximately 21 quadrangles (1:24,000) located in the eastern Georgia Piedmont province between 33°37'30" and 34°07'30" north latitude, bounded on the west by 83°07'30" west longitude and on the east by the Savannah River and 82°22'30" west longitude (Fig. 2). This area forms a transect of the Piedmont province from the eastern part of the Inner Piedmont, across the Middleton-Lowndesville ductile deformation zone (southwestern extension of the Kings Mountain belt), across belts formally termed the Charlotte and Carolina slate belts (herein referred to as the Carolina terrane), and terminating in the Modoc ductile deformation zone.

Topography and Drainage

The area is dominantly in the Washington Plateau physiographic province (LaForge et al., 1925; Clark and Zisa, 1976). Average elevations decrease from approximately 700 feet (210 m) in the northwest to 300 feet (90 m) in the southeast. The topography is in an early stage of topographic maturity, as it is dominated by broadly rolling hills with the majority of the area in sloping surfaces. Average relief is approximately 100 feet. The rivers are rather deeply incised with narrow to nonexisting flood plains. The incised nature of the major drainages is demonstrated by the shapes of the three reservoirs along the Savannah River. The dissection of the old Piedmont surface suggests renewed downcutting by drainages, probably associated with continued uplift of the area over the last 10 to 15 million years.

The dominant drainage patterns are dendritic to trellis with minor streams following structural control. Curiously, the major drainages of much of the Piedmont province do not appear to follow structural control, but cut across most major structures as if they are an inherited drainage system.

Culture

The area is crisscrossed by a good network of paved roads. This system is augmented by gravel and dirt roads whose quality varies between counties. In addition, there are numerous trails and haulage roads developed for the timber industry and used extensively by hunters and fishermen. A major active rail line extends east and west from Elberton.

The major land use is for timber and farming. A great deal of land is managed by the timber companies with routine clear cutting and replanting of pine for pulp and construction materials. Farming includes pasture for beef and dairy cattle and some row crops. Much of the topsoil, however, was lost following cotton farming during the last century. Therefore, the quality of the soil is generally low, with the B horizon being prevalent.

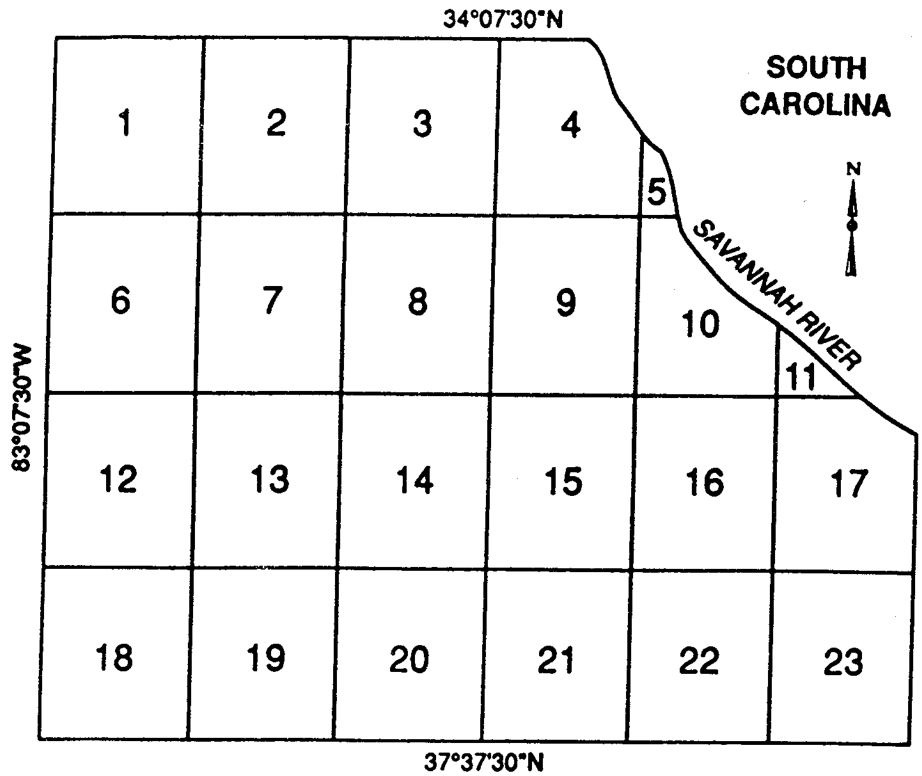
Industry is mainly concentrated near the major towns. Elberton in the northwest is an international center of the granite monument industry. Extensive quarrying, cutting, and polishing operations form a major part of the local economy ($126,000,000 for 1990).

Previous Geologic Investigations

Early geologic investigations were concentrated on the stone and mineral resources including granite (Watson, 1902), gold (Jones, 1909), soapstone (Hopkins, 1914), and aluminosilicates (Furcron and Teague, 1945). The first Georgia State Geologic Map (1939) characterized the bedrock geology in broad lithologic terms such as Carolina Gneiss, an all encompassing term including a variety of unrelated units. The younger postkinematic granites such as the Elberton, Siloam, and Danburg were recognized, but their outlines contained a great deal of older foliated granite and gneiss.

The first modern regional compilation was by Crickmay (1952) who defined a generalized series of geologic belts based on lithologic associations and metamorphic grade. Hurst et al. (1966) compiled mapping of the eastern part of the area for mineral resource evaluation of the Central Savannah River region. Hatcher (1972, 1978) has published important regional tectonic interpretations of the southern Appalachians that form the basis for recent tectonic syntheses. The most recent Geologic Map of Georgia (1976) shows varying degrees of detail depending on the mapping available at the time of compilation. Most units are described in lithologic terms with little interpretation of protolith for metamorphic units.

Detailed geologic mapping was delayed in this region by the lack of large-scale topographic maps. The first quadrangle maps began to appear in the 1960's. It was the early 1970's before 1:24,000 quadrangle maps began to be available for much of the area. Over the last 20 years, M.S. students at the University of Georgia have mapped numerous areas based on these topographic maps under the direction of various faculty members (Fig. 2 and Appendix). The



U.S.G.S. 7 1/2" QUADRANGLES
INDEX TO DATA SOURCES
(see Bibliography of report)

1.	Carlton	Potter (1981) + Allard
2.	Elberton West	Hess (1979) + Allard
3.	Elberton East	Allard + Rozen (1978)
4.	Heardmont	Allard + Legato (1986)
5.	Calhoun Falls	Allard
6.	Sandy Cross	Allard
7.	Vesta	Turner (1987) + Allard
8.	Jacksons Crossroads	Young (1985) + Allard
9.	Broad	Allard + Parker
10.	Chennault	Thurmond (1979)
11.	Willington	Delia (1982)
12.	Lexington	Allard + Davidson (1981)
13.	Rayle	Davidson (1981) + Hutto (1986) + Cook (1967)
14.	Celeste	Hall (1991) + Allard
15.	Tignall	Allard + Rogero (1986)
16.	Metasville	Allard + Murphy (1984) + Reusing (1979) + Sibley (1982) + Goldstein (1980)
17.	Lincolnton	Paris (1976) + Fay (1980) + Biggs (1982) +Allard
18.	Woodville	Allard + Davis (1980)
19.	Philomath	Conway (1986) + Lovingood (1983)
20.	Washington West	Dunnagan (1986)
21.	Washington East	Von der Heyde (1990)
22.	Aonia	Allard + Reusing (1979)
23.	Woodlawn	Allard

Figure 2. Index map of 7 1/2 minute quadrangles covered in the map area of Plate 1 and source of data.

current compilation (Plate 1) is an attempt to integrate and reinterpret these diverse studies in order to develop a consistent lithotectonic geologic map of the bed-rock relationships within the eastern Georgia Piedmont. Where no mapping had been done by students, the senior author conducted detailed mapping at a scale of 1:24,000. It is hoped that this map will form the basis for additional scientific investigations into the tectonic history and natural resources of the area.

Field Conditions and Techniques

The Piedmont is characterized by deep chemical weathering. Where the rock is thoroughly decomposed, but the original rock structure and texture is preserved, the term saprolite is used. Saprolite grades downward into unweathered bedrock and upward into the zone of illuviation, commonly termed the B Horizon. Both saprolite and the B Horizon can be extremely useful for geologic mapping as the weathering residues of original minerals are preserved, and in many cases structures can be recognized and measured. The higher soil horizon (A horizon), however, can be misleading as deep chemical weathering has caused extensive desilicification and leaching. The color of such higher soil horizons may also be very sensitive to topographic setting and agricultural history. Those of the lower horizons are more sensitive to lithology.

Exposures of bedrock are found along streams and in rare roadcuts. Within the Elberton district, more than 50 quarries are available as well as numerous pavement areas. Certain lithologies such as the sillimanite-quartz-sericite schist, and the ultramafic rocks of the Russell Lake allochthon form resistant bouldery outcrops. Other units, such as some of the synkinematic granites, are rarely seen as fresh exposures. The susceptibility to deep weathering seems to depend both on the mineralogy and the ease of infiltration of water which is controlled by the development of a metamorphic foliation and microfracturing during metamorphism and deformation. The Elberton Granite, for example, appears to be almost impermeable to surface water infiltration and therefore is rarely weathered to a depth of more than a few feet. However, some of the synkinematic granites having the same mineralogy are apparently much more permeable and form deeply weathered saprolite to depths of more than 50 feet.

LITHOLOGIES OF THE INNER PIEDMONT TERRANE

The Inner Piedmont has been subdivided into the Inner Piedmont core and flank by Griffin (1971a). Within the map area, most of the exposures are of the core. Much of the eastern flank has been intruded by the Elberton granite. Griffin (1971a) suggests that the core and flank are separated by an early tectonic slide. Wells (1982) and Potter (1981) attempted to follow this structure into the current map area. Within this area, the boundary between core and flank is partially obscured by the Elberton granite. The flank is characterized by steeper dips to the southeast than exhibited by most of the core. Unique lithologies such as a megacrystic microcline gneiss with varying degrees of ductile deformation are encountered, as well as an increase in the amount of mica schist and amphibolite. However, the tectonic significance of the boundary between core and flank cannot be well evaluated in this map area.

Inner Piedmont Core

The Inner Piedmont core is composed dominantly of migmatized biotite gneiss and granitic gneiss, with lesser amounts of mica schists and gneisses, quartz- muscovite-sillimanite schists, and metagranite. Minor interlayered lithologies include calc-silicate granofels and amphibolites.

Migmatized Biotite Gneiss

Migmatized biotite gneiss forms the majority of the Inner Piedmont core terrane. It consists of microcline, quartz and biotite with varying amounts of plagioclase (oligoclase). Accessory and minor minerals include muscovite, sillimanite, garnet, zircon, apatite, and sphene. This unit is very heterogeneous in mineralogy. It is usually well foliated with concentrations of pegmatitic leucosome cross cutting early fabric elements. Mafic horizons, containing more biotite and plagioclase with little microcline, are found within it. As the amount of biotite decreases, the rock becomes a migmatized granitic gneiss. An excellent exposure of this lithology can be seen at Watson Mill State Park (Carlton quadrangle). In this location, sillimanite is rare, but muscovite and garnet are present as minor phases.

Several minor lithologies are found within the migmatitic gneiss. One is a fine grained biotite gneiss, composed of quartz, plagioclase (oligoclase), and biotite with accessory muscovite, hornblende, garnet, zircon, and opaque minerals. This lithology is well foliated, but seldom shows gneissic layering or migmatization. Incipient migmatization is generally associated with the presence of potassium feldspar.

Amphibolite layers show a variety of textures and mineralogy. They usually form thin (up to several meters thick) continuous horizons. Most are composed of hornblende (40- 70%), plagioclase (20-40% labradorite), minor quartz and accessory epidote, garnet, sphene, and apatite. Some layers are relatively coarse grained and contain relic pyroxene suggesting they are probably metadiabase dikes. Others contain no relic original minerals and are generally finer grained. These may have been derived from mafic dikes, volcanic or volcaniclastic lithologies.

Calc-silicate granofels are found as layers and pods in most Inner Piedmont lithologies. These units typically form fine grained massive granofels with no internal layering. Most are composed of quartz, plagioclase (labradorite), hornblende, and epidote. The epidote content is highly variable in abundance (0 to 40% of the rock). Accessories include sphene, calcite, pyrrhotite, apatite, zircon, and garnet.

The migmatitic biotite gneiss assemblage has experienced several periods of deformation. The predominant foliation is associated with extensive recrystallization in a high temperature ductile environment. This foliation is more flat lying in the middle of the Inner Piedmont, and dips more steeply to the southeast as the flank is approached. This change appears to be caused by refolding by northeast trending F_2 folds. A map scale F_2 fold is recognized in the Carlton quadrangle (Potter, 1981). Outcrop scale folds can be seen at the southern end of the exposure at Watson Mill State Park. In this location these are somewhat anomalous for the Inner Piedmont in that they are rather planar structures in a chevron pattern, with a shallow westerly plunge. The peak of migmatization appears to have postdated the F_1 event, but its relationship with F_2 is less certain. These units have subsequently been cut by leucocratic granitic dikes which themselves show a faint foliation, and finally by the Elberton granite which does not have a tectonic fabric.

The protolith of the migmatitic biotite gneiss association is uncertain. The chemical and mineralogic composition is suggestive of an igneous protolith. The absence of clearly sedimentary compositions, such as high grade pelitic rocks, quartzites, or other sandstones, suggests that the protolith had to be either igneous or not strongly weathered in a sedimentary environment (e.g. volcanic graywackes, etc.). At this time, we favor a differentiated pluton containing a variety of cross-cutting lithologies and abundant xenoliths of biotite schist. This association would then have been strongly deformed and metamorphosed to the onset of anatexis. The amphibolites could have been mafic dikes which have now been metamorphosed. If this model is correct, the migmatitic biotite gneiss association would be similar to some of the syn-volcanic igneous complexes observed to the southeast in the Carolina terrane.

Quartz-Muscovite-Sillimanite Schist

The Quartz-Muscovite-Sillimanite Schist is a very distinctive lithology and can be easily traced along the strike. It continues into Hart County, Georgia, where it was mapped by Furcron and Teague (1945) and Grant (1958).

This unit forms many northeast trending bands within the Carlton quadrangle. These are interpreted to be the same unit repeated by an F_2 fold. Each band is composed of two to three very sillimanite-rich horizons separated by mica schists and gneisses containing less sillimanite.

These schists are composed of varying proportions of quartz (20-80%), muscovite (40-80%), and sillimanite (10-40%). They are typically fine grained, with a very strong foliation defined by alignment of muscovite and fibrolitic masses of sillimanite. This foliation is generally undulatory and kinked. Pyrite is an extremely common minor mineral in this lithology, staining the rock a distinctive purple color. As with the other minerals, the abundance of pyrite seems to vary from layer to layer. Other accessory minerals include biotite, graphite, and hematite. The strongly crenulated foliation causes this rock to break into elongate fragments. Some of the muscovite throughout this unit is present as large subhedral grains which are disoriented with respect to the dominant foliation. These are interpreted to be formed under retrograde conditions.

These aluminous schists are nearly identical to those found in the high metamorphic grade sections of the Carolina terrane to the southeast. Their high alumina content and relatively low content of alkali elements suggests they came from a very clay-rich protolith which must have been chemically leached. The strong similarity to lithologies in the Carolina terrane suggests that these areas must have similar geologic histories, even if they are not statigraphically related.

Mica Schists

The mica schists are generally coarse grained consisting of biotite (10-40%), muscovite (30-70%), and quartz (0-55%). Sillimanite is commonly present as fibrolite masses aligned in the schistosity. The relative proportion of these minerals varies from layer to layer in an outcrop. With a decrease in biotite content and an increase in sillimanite, the mica schists grade into the quartz-muscovite-sillimanite schists Most of muscovite lies parallel to the foliation, but some coarse grains are randomly oriented indicating a postkinematic crystallization. Muscovite and quartz are observed in contact with sharp, nonreactive boundaries indicating that the second sillimanite isograd has not been surpassed.

Other minor units associated with the micas schists include amphibolites and calc-silicate granofels which are similar to those previously described within the migmatized biotite gneiss assemblage.

The protolith for these lithologies is uncertain. They resemble high grade pyroclastic or volcanic sedimentary units in the Carolina terrane. The association with similar aluminous schists makes us favor such a volcanic or volcanic-sedimentary protolith. The presence of easily identifiable pumice lapilli confirms that some of these rocks are volcanic in origin.

Inner Piedmont Flank

The Inner Piedmont flank is composed dominantly of megacrystic microcline gneiss interlayered with biotite schists and gneisses. Minor lithologies include amphibolite and calcsilicate granofels and gneisses.

Biotite Schists and Gneisses

Biotite is the predominant phase in the biotite schists, with minor amounts of plagioclase (An 23-28%), muscovite, and quartz. Accessory minerals include sphene, magnetite, allanite, apatite, and zircon. Potassium feldspar (microcline) is absent in the schists but forms a major component of the gneissic bands. Hornblende is sporadically present and where abundant the rock becomes a hornblende gneiss. Epidote is an alteration product from both plagioclase and allanite, while chlorite forms by alteration from biotite. These units are invariably strongly foliated, and in places appear to be interlayered with the megacrystic microcline gneiss.

Minor lithologies associated with this assemblage include amphibolite and calcsilicate granofels. The amphibolites within the Inner Piedmont flank occur as concordant, compositionally distinct layers up to a few meters thick. They are composed of hornblende and plagioclase (An 25-35%) with minor amounts of epidote, sphene, biotite, magnetite, pyrite, and quartz. In a few occurrences relic pyroxene has been observed. The mineralogical composition and the occurrence of pyroxene suggest an igneous protolith. These amphibolites are thought to be either mafic dikes or flows within the biotite schist and gneiss sequence.

The calc-silicate granofels are similar to those described in the Inner Piedmont core. They are composed of quartz, epidote, plagioclase, and garnet in varying proportions.

As in the Inner Piedmont core, the protolith for these schists is uncertain. We favor a volcaniclastic and/or volcanic-sedimentary protolith since no classic metapelites, quartzites, or other sedimentary protoliths have been encountered. The interlayered amphibolites could be mafic dikes, volcanics, or volcaniclastic units.

Megacrystic Microcline Gneiss

The megacrystic microcline gneiss is a relatively unique lithology which becomes predominant within the Inner Piedmont flank of the Elberton East quadrangle. It is composed of slightly perthitic megacrysts of microcline set in a matrix of plagioclase (An 23-27%), biotite, hornblende and quartz. The relative proportions of hornblende and quartz are highly variable. Some samples are poor in quartz, while in others it is abundant. Myrmekitic intergrowths are also observed. Muscovite and sillimanite are rarely found in some horizons, and are not predominant minerals. Accessories include sphene, magnetite, zircon, and apatite.

The foliation is well developed in the biotite-rich matrix, but the microcline megacrysts are only crudely aligned. As this unit approaches the Middleton-Lowndesville zone it takes on a strong ductile fabric. Deformation is concentrated in certain horizons in which the megacrysts are rotated and deformed with a well developed fluxion structure producing an augen gneiss. Quartz also becomes increasingly strained and then polygonized as the gneiss is deformed into a protomylonite. With increased deformation, the grain size is extensively reduced until the rock becomes a blastomylonite. Xenoliths of the protomylonite and blastomylonite are found within the undeformed Elberton granite. Therefore, the development of the mylonitic fabric along the Middleton-Lowndesville zone predates 325 Ma, the age of intrusion of the Elberton body (Ross and Bickford, 1980). Also, since the megacrysts are deformed by the ductile deformation prior to incorporation into the granite they are not formed by metasomatism related to the Elberton intrusion.

Chemically, the megacrystic microcline gneiss is intermediate to granitic in composition. When not sheared, it appears as if it could have been a porphyritic intrusion. Currently, we favor a plutonic origin for this lithology as its composition and fabric do not seem to fit any sedimentary or volcanic protolith.

LITHOLOGIES OF THE CAROLINA TERRANE

The oldest tectonostratigraphic units recognized within the Carolina Terrane are metavolcanic, metavolcaniclastic, and metavolcanic sediments. When at low metamorphic grade, these units have been described as the Little River Series of the Carolina Slate belt. However, mapping in the eastern Georgia Piedmont has demonstrated that these units can be mapped into higher grade lithologies previously referred to as portions of the Charlotte belt. Many of the mica schists, quartz- sericite-sillimanite schists, and amphibolites formerly described as Charlotte belt can now be recognized as the high grade equivalents of metapyroclastic and volcanic lithologies of the Slate belt. These have been intruded by a variety of plutonic lithologies varying from subvolcanic, premetamorphic to postkinematic in age. Therefore, in this report we have chosen to combine the Charlotte Belt and the Carolina Slate Belt into the "Carolina terrane". This correlation of tectono-stratigraphic units between the two belts is similar to what Secor et al. (1986a,b) have proposed in neighboring South Carolina. To the north, this Carolina terrane has been further combined with the Raleigh and Kiokee belts and termed the Avalon terrane by Hatcher and Williams (1983).

Metavolcanic Lithologies

Lincolnton Metadacite

The Lincolnton metadacite forms an elliptical body of felsic quartz porphyry in central Lincoln County (Paris, 1976; Whitney et al., 1978). The presence of interbedded sediments and pyroclastic units, combined with relic volcanic textures and lithologic heterogeneity, suggests a volcanic origin for much of this unit. There are, however, stocks and dikes of intrusive quartz porphyry which cut the intrusive lithologies but are of similar composition. Therefore, the area mapped as Lincolnton metadacite includes extrusive dacite and related intrusive lithologies.

The porphyritic units are white to light pink containing phenocrysts of elliptical blue-gray quartz and saussuritized euhedral plagioclase in a fine to medium-grained matrix of quartz and feldspar. Chlorite, biotite, or hornblende are common mafic accessories. A few possible pseudomorphs of pyroxene have been reported. Small amounts of white mica and iron-titanium oxides are also present. Other minor textural varieties include fine-grained, granophyric, and gneissic metadacite (Paris, 1976).

As metamorphic grade increases, the metadacite becomes increasingly gneissic. Minor amounts of biotite and/or amphibole become the dominant mafic minerals. The plagioclase composition changes from albite to oligoclase. Quartz and plagioclase phenocrysts may become elongated and sheared. The mafic minerals begin to form streaks in the plane of foliation. Perthitic microcline has also been reported in the gneissic dacites, but has not been recognized at lower grade. One of the best exposures of the transitional lower amphibolite grade metadacite is near Curry Creek (Stop 7 of Whitney and Allard, 1990).

The metadacite is cut by numerous metamafic dikes, both fine-grained and porphyritic varieties. These demonstrate that the metadacite is part of a larger volcanic association including basaltic lithologies (see Paulson, 1980, for extensive chemical data on the metadacite and related mafic units). These contain altered plagioclase phenocrysts in a matrix of dark-green amphibole, chlorite, and epidote. Most show chilled margins and an increase in size of phenocrysts toward the center of the dike when metamorphism has not destroyed the original textures. The composition of the amphibole changes with increasing metamorphic grade from actinolite to magnesiohornblende using the classification of Leake (1978). The composition of the plagioclase also changes from albite to oligoclase or andesine as metamorphic grade increases.

Several felsic metatuffs and metasediments are also found interbedded with the metadacite. The tuffs vary from dacitic to mafic in composition and are quite variable in texture. The dacitic ones are composed of quartz and plagioclase phenocrysts in a matrix of sericite, quartz, chlorite, epidote, plagioclase, and magnetite. The more mafic ones are mainly composed of chlorite, amphibole, epidote, and plagioclase. As metamorphic grade increases, the mineralogy changes in the same way it does in the dacites and mafic dikes, except that the tuffs are richer in white mica. A distinctive lithology which forms a quartz-sericite schist is also found. It is composed of rounded quartz grains in a quartz-sericite matrix.

The environment of deposition is somewhat problematic. The interbedded sediments suggest that at least part of the metadacite was deposited subaqueously. No distinctive subaerial lithologies such as welded tuffs have been identified. Therefore, the metadacite preserved in the rock record is thought to have been deposited mostly subaqueously.

Mafic Metavolcanic Sequence

A number of mafic units have preserved volcanic structures and textures which indicate a volcanic origin. Excellent examples are found in the northern half of the Metasville quadrangle (Murphy, 1984) and northern half of the Philomath quadrangle (Conway, 1986). These include pillow structures, amygdules, and hyaloclastic textures. Mineralogically, the amphibolites are composed of amphibole and plagioclase with varying amounts of chlorite, epidote, sphene, biotite, and iron- titanium oxides. With increasing grade chlorite disappears, the amphibole goes from actinolite to magnesiohornblende while the plagioclase increase from albite to andesine. Foliations, and especially lineations, are well developed in the pillow basalts, but compositional layering is nearly absent. Compositionally, most samples of pillow lavas yield silica contents close to 50% and are therefore classified as basalt. From the few analyses currently available, most resemble low potassium tholeiites in composition.

A variety of other amphibolites which do not preserve diagnostic volcanic structures have been encountered. Those which are homogeneous in composition and similar in mineralogy to the pillow lavas are thought to also be mafic flows. Others are more problematical. At high grades, some hornblende rich units become hornblende gneisses. Interpretation of protolith becomes increasingly difficult in this case.

Numerous amphibolite horizons are found within felsic pyroclastic sequences at low metamorphic grades, and within the biotite gneiss association at higher grades. Many of these are also thought to be either mafic flows or mafic pyroclastic deposits. However, some may be mafic sills or transposed mafic dikes.

Quartz-Epidote Granofels

Quartz-epidote granofel is a massive lithology found throughout the Carolina terrane within all lithologies. However, it is most commonly associated with mafic volcanic lithologies. It is granular in texture and composed of varying proportions of quartz and epidote. At higher grades, garnet and/or calcium rich plagioclase may occur. Since this unit is highly resistant to weathering, it forms resistant float in much greater abundance than in outcrop. On the State Geologic Map one unit is mapped as "epidote quartzite". It is believed that this occurrence is simply float of granofels veins and boudins within other lithologies. Where it is observed in outcrop, the quartz-epidote granofels appears to be either vein fillings, especially in granitic host rocks, or an alteration of mafic lithologies. We have not encountered this unit as a mappable lithology within the map area.

Metapyroclastic Lithologies

Metapyroclastic lithologies of various composition form one of the more voluminous sequences in the Carolina terrane. By their very nature, pyroclastic deposits are fragmental and when deposited in a marine environment commonly become mixed with volcanic debris from several sources. In addition, alteration by the interaction with sea water and superimposed hydrothermal systems causes extensive exchange, especially of mobile components such as the alkali elements. Such processes have been documented for the Lincolnton volcanic center by Whitney et al. (1978). Therefore, the chemistry of such units is highly variable.

At low grades of metamorphism, metapyroclastic units easy to identify as fragmental textures are still recognizable. As metamorphic grade increases, many primary features are destroyed and identification of protolith becomes more difficult. As low grade units of the Little River series are mapped to the west and north in the Metasville and Chennault quadrangles, they become mica schists and gneisses. The proportions of muscovite and biotite are highly variable depending on the chemistry of the protolith. One unit forms an important marker horizon for mapping purposes. This is the highly leached quartz-sericite schists which are formed by intense hydrothermal leaching of pumiceous layers. At higher metamorphic grade, these becomes aluminous quartz-muscovite-sillimanite schists. Von Der Heyde (1990) documents this relationship with increasing metamorphic grade in the northern part of the Washington East quadrangle.

Felsic Metapyroclastic Sequence

The most extensive low grade deposits of the felsic metapyroclastic sequence are surrounding the Lincolnton metadacite volcanic center. Here, it is composed of acid to intermediate metapyroclastic units including crystal, crystal-vitric, crystal-lithic, and lapilli tuffs with minor amounts of intercalated metasedimentary material. Within the Lincolnton area, the metapyroclastic sequence is divided into two units. The lower unit is dominantly sericitic tuffs composed of altered vitric and crystal-vitric tuffs. These are composed of fragmental quartz phenocrysts in an aphanitic groundmass of quartz and sericite. Moving away from the Lincolnton volcanic center, chlorite becomes more abundant in some horizons as contributions from more mafic sources increases.

The upper unit in the Lincolnton area is dominantly formed of dacitic crystal vitric tuffs. This unit grades into chloritic tuffs moving northeast and west from Lincolnton as more mafic components are encountered. The dacitic units are composed of varying amounts of fragmental quartz and plagioclase phenocrysts in an aphanitic matrix of quartz and plagioclase.

To the south in the Woodlawn quadrangle horizons of intermediate composition tuffs are encountered. It is thought that the changes in composition from dacitic to chloritic to intermediate tuffs reflects differences in volcanic source material. Near a felsic center deposition is dominated by dacitic material. Moving away from the felsic center toward more mafic sources the metapyroclastic debris becomes more intermediate to mafic in composition. Since we are dealing with a mixing of volcanic products, little can be said about the chemistry of the source areas from the metapyroclastic debris, except that we are mixing felsic and mafic sources (Whitney et al., 1978).

A number of features including graded bedding, interbedded quartzites (metacherts), meta-argillites, and volcanic metagraywackes, suggest that the metapyroclastic sequence was deposited subaqueously. Many of the more massive horizons lack recognizable bedding, but no evidence of welded tuffs which would suggest subaerial deposition have been found.

Within the felsic metapyroclastic sequence there are also a number of amphibolite horizons which are not extensive enough to be separated on the geologic map. Some of these are laterally continuous over a significant distance, while others are only locally present. The mineralogy is similar to that of the metabasalts, with actinolite, epidote, chlorite, and albite at low grades, changing to magnesiohornblende, intermediate plagioclase, with less epidote and traces of biotite at higher grades. Some of these amphibolites appear to be dikes and sills of intermediate to basaltic compositions. At low metamorphic grades, chilled margins and original phenocryst morphologies can be seen. Others may be mafic flows or mafic pyroclastic deposits as they are more laterally continuous. Some of the massive amphibolites are resistant to weathering due to their low permeability. These units may yield copious float far in excess of their abundance in the lithologic record and may mislead the casual observer as to their significance.

Quartz-Sericite-Schists and Quartz-Kyanite Granofels

Layers of pumice lapilli metatuff form important horizons within the metapyroclastic sequence. Several horizons have been identified within the Lincolnton region, both at the top of the lower unit and near the base of the metapyroclastic sequence. Although all bedding in volcaniclastic sequences is discontinuous, several of these pumiceous lapilli horizons can be followed for many miles. Being highly porous, they act as a reservoir for hydrothermal fluids. The migration of these, driven by heat from the volcanic center, causes extensive leaching and hydrothermal alteration. These horizons become highly aluminous due to such leaching, yielding quartz-sericite schists at low grades of metamorphism. With increasing conditions of metamorphism, the most heavily leached areas become quartz-kyanite schists, and eventually quartz-sillimanite schists. At amphibolite grade, most horizons are composed of quartz-muscovite-sillimanite in highly varying proportions. In addition, pyrite is present at many locations. Presumably, pyrite was deposited along with the hydrothermal alteration. Upon weathering, the pyrite imparts a characteristic reddish purple coloration even after all of the pyrite has weathered out.

It is thought that the Graves Mountain kyanite occurrence (Furcron and Teague, 1945; Crickmay, 1952; Hurst, 1959; Espenshade and Potter, 1960; Hartley, 1976), located within the lower unit of the metapyroclastic sequence, is an area of unusually intense hydrothermal alteration associated with such a fossil hydrothermal reservoir (Allard and Carpenter, 1988).

Graves Mountain itself has an average N70°E strike and consists of interbedded and somewhat lensoidal kyanite granofels (called quartzite by most authors because of the high quartz content) and sericite schist (with or without kyanite). The individual granofels units vary in thickness from 6 to 50 feet.

The principal lithology exposed at the mine is pyritiferous kyanite granofels. Relic quartz phenocrysts suggest that the rock formed by replacement of pre-existing crystal (quartz, feldspar) vitric (quartz, sericite, feldspar) tuffs. Prior to regional metamorphism, the protolith of the kyanite granofels probably was an assemblage of quartz, kaolinite, and pyrite. Chemically, the replacement involved depletion of Ca, Mg, Na, and to a lesser extent, K. Numerous pods of massive silica suggest that an extensive network of cavities existed at an early stage of alteration when silica was mobile. At a later stage, probably during cooling, silica precipitated in the cavities. Locally, filling was incomplete, which accounts for vugs lined with large quartz crystals. Sulfur, phosphate, fluorine, barium and titanium probably were introduced because pyrite, lazulite (hydrous iron-magnesium aluminum phosphate), topaz, barite, and rutile are notably more abundant in the kyanite granofels than in surrounding metapyroclastics (for more details on this process of alteration and the resultant metamorphic assemblages, please see Carpenter and Allard, 1980a, b; and Allard and Carpenter 1982, 1983, 1988). We interpret the alteration to have been synvolcanic. Constituents leached during alteration were transported to the sea floor via fumarolic vents; hence, kyanite granofels may be linked genetically to exhalative lithologies.

Pyrophyllite has replaced the kyanite granofels locally. It is particularly noticeable along postmetamorphic faults and fractures. Beautiful gem-quality rutile crystals, up to 50 mm in size, occur locally on the mountain. Very fine, disseminated rutile crystals are ubiquitous in the kyanite granofel, even though the average TiO_2 content is less than 1 percent. It is thought that the disseminated rutile originally came from the sulfidization of ilmenite, but the gem quality rutile has obviously been mobilized and deposited by much later hydrothermal solutions in open fractures.

The quartz-sericite schist horizons are also associated with banded iron formations composed of fine grained quartz and magnetite, and manganese deposits. Small amounts of massive sulfide have also been reported associated with such horizons. Therefore, these altered and leached deposits appear to be related to exhalative hydrothermal systems similar to those described at Otake (Hayashi and Yamasaka, 1976).

Mafic and Intermediate Metapyroclastic Lithologies

The rocks of the Lincolnton volcanic center are very metadacitic in composition. Proceeding outward from the center, especially to the south in Woodlawn and Aonia quadrangles, the metapyroclastic units change gradually from dacitic to basaltic in composition. This change is especially noticeable in the tuff breccias, volcanic breccias, and lapilli tuffs where the metapyroclasts are white vitric metadacites, porphyritic metadacites, and metadacitic pumice in a green chlorite-rich matrix. Closer to the Lincolnton dacite dome, these rock types are totally white consisting of a matrix of quartz and feldspar (devitrified glass and phenocrysts) which is difficult to distinguish from the clasts. This change suggests contemporaneous eruptions from different sources, dacitic around the Lincolnton center and more basaltic further south and east.

To the northeast of Lincolnton, Biggs' (1982) map depicts an interfingering relationship between the Lincolnton dacitic sequence and what he termed the Winterseat metavolcanic complex. His description corresponds very well with our observations in the Woodlawn and Aonia quadrangles. Our mapping and Biggs' work point to simultaneous overlapping eruptive centers producing dacitic pyroclastics around Lincolnton and basaltic metapyroclastics to the east and south.

Metasedimentary Sequence

The metasedimentary sequence which overlies the metavolcanic and metapyro-clastic sequence is composed principally of meta-argillites and tuffaceous metagraywackes formed from volcaniclastic material. The argillites occur as both banded and massive varieties. Sedimentary structures include laminated bedding, cross-bedding, graded bedding, scour-and-fill, and bedding slump. Grains are fairly well rounded and roughly equigranular indicating sedimentary transport and sorting. Clasts of quartz, epidote, albite, and lithic fragments are commonly found in a weakly foliated matrix of chlorite and sericite. The fragments are of widely differing compositions depending on the source. The argillites appear to have formed by extensive transport and reworking of volcanic debris.

Tuffaceous metagraywackes occur as layers several centimeters to a meter thick interbedded with meta-argillites. They are composed of lithic fragments, quartz, and albite grains embedded in a groundmass of sericite and chlorite. The diversity of material suggests several source materials, but all of volcanic origin.

Mafic horizons are also found within the metasedimentary sequence. Their mineralogy is similar to those found within the metapyroclastic sequence. Again, those that are laterally continuous may have been flows or mafic pyroclastic material, while others are dikes and sills. The prevalence of mafic dikes within both the pyroclastic and sedimentary sequence confirms that the area was in an active volcanic environment.

Mica Schists, Gneisses, and Related Lithologies

As the volcanic and volcaniclastic lithologies increase in metamorphic grade it becomes increasingly difficult to determine the exact nature of the protolith. This is especially true since volcanic associations are known for rapid and dramatic facies changes as the nature of volcanic centers and supply of pyroclastic material feeding a site of deposition changes. In some cases, low grade lithologies can be mapped continuously into higher grade equivalents. In other cases the correlation can only be made on similarities in composition and gross physical characteristics. Where the protolith is in doubt, we have chosen to use metamorphic lithologic terminology.

These higher grade rocks, combined with a large proportion of intrusive lithologies, are what has previously been termed Charlotte belt in Georgia. Mapping to the north and west from the Lincolnton center has demonstrated stratigraphic continuity between the low grade Little River series and the higher grade biotite gneisses, amphibolites, and aluminous schists. These units have then been cut by prekinematic, synkinematic, and postkinematic plutons which yield a variety of orthogneisses and recognizable metaplutonic and plutonic units. Given the apparent continuity of tectonostratigraphic units across metamorphic grade, and the lack of evidence for major transport or structures along the belt boundary, we see no justification for defining a major tectonic boundary along this metamorphic gradient. As will be discussed later, we agree with Secor et al. (1986a, b) that the so-called Charlotte belt is a higher grade plutonic/volcanic infrastructure formed from the so-called Slate belt. The Charlotte belt metavolcanics are Slate belt rocks which have suffered contact metamorphism on a regional scale. The complex of plutons of the Charlotte belt have intruded the volcanic assemblages of the Slate belt producing the gradual increase in metamorphism as one approaches the plutons.

Biotite Gneiss Association

The biotite gneiss association consists mostly of biotite gneiss interlayered with mica schists and amphibolites. Most of the gneissic layers consist of biotite, plagioclase and quartz in widely varying proportions with minor amounts of muscovite, sillimanite, magnetite, ilmenite, hornblende, and/or sphene. Textures vary with degree of recrystallization. Some are completely granoblastic, while others retain some primary megascopic features. Biotite defines the foliation and gneissosity. Muscovite, when present, is usually secondary in abundance to biotite. Sillimanite, when present, forms acicular crystals and fibrolite.

Amphibolites form an important secondary lithology. Their abundance is highly variable. Mineralogically they are composed of magnesiohornblende to hornblende, intermediate plagioclase (An20-50%), and epidote, with minor amounts of quartz. Accessories include ilmenite, sphene, and magnetite.

The biotite gneiss association has been interpreted as forming from various protoliths. The most common interpretation is that it formed from volcanic metagraywackes (Conway, 1986; Delia, 1982; Murphy, 1984). These authors based their interpretation on the whole rock chemistry compared to compilations of graywackes (e.g. Pettijohn, 1975). However, mapping in the Washington East, Tignall, and surrounding quadrangles suggests that portions of the biotite gneiss association is stratigraphically equivalent to the pyroclastic lithologies. In addition, all chemical analyses currently available appear to fall within the envelope of the pyroclastic samples reported by Whitney et al. (1978). The abundance of biotite led several investigators to assume the biotite gneiss association was more potassic than the pyroclastic units of the Little River Series. However, biotite contains only about 10% K_2O and modal abundance rarely exceeds 30%. Therefore, most samples contain between 1 and 3 % K_2O which is within the envelope observed for the lower grade pyroclastic lithologies. In addition, the variation in abundance of amphibolites and more mafic lithologies is similar to that observed within the metapyroclastic sequence. As the association approaches more mafic source areas, the composition becomes richer in these components. The interlayered amphibolites are also similar to what is observed in the lower grade metapyroclastic association. These are interpreted as mafic dikes, flows, and mafic metapyroclastic material.

It is possible that some horizons within the biotite gneiss association are higher grade equivalents of tuffaceous volcanic metagraywackes or meta-argillites, since these are found interbedded with the metapyroclastic lithologies. However, it is believed that the majority of the biotite gneiss association represents high grade metapyroclastic lithologies with varying contributions from felsic and mafic volcanic centers. The identification of pumice lapilli at many localities supports the choice of a metapyroclastic protolith.

Quartz-Muscovite-Sillimanite Schists

The quartz-muscovite-sillimanite schist is a highly aluminous unit which forms an important marker horizon as it is resistant to weathering and forms prominent hills and outcrops. It is composed of varying proportions of quartz (40-70%), muscovite (0-55%), and sillimanite (0-25%), with accessory pyrite, magnetite, rutile, biotite, and zircon. The weathering of pyrite, when present, gives a characteristic reddish purple color to the rock, as previously described for similar rocks in the Inner Piedmont. Remnants of kyanite partially replaced by muscovite and sillimanite have been reported in several localities (Conway, 1986). In one location within the Chennault quadrangle the quartz content went to zero and corundum was observed. Within the Philomath and Washington West quadrangles a band of these schists appears to define the nose of a fold and extends eastward through the Stoney Ridge gold mine. Numerous exploration pits and abandoned gold mines follow this horizon. In addition, in the Washington West quadrangle manganese deposits, spessartine garnetite, and banded iron formations are associated with this horizon (Lovingood, 1983; Whitney and Allard, 1990). These lithologies suggest exhalative hydrothermal deposits associated with this horizon. Other banded iron formations are associated with this zone in the Metasville quadrangle.

Texturally, rounded quartz crystals similar to those found as volcanic phenocrysts have been observed within the schist. Sericite-rich lenticular bodies which may have been pumice lapilli have also been found. The foliation is well defined by the sillimanite. Extensive crenulation development is also common. Some of the muscovite and sillimanite is oriented across the primary foliation and some sillimanite has been deformed by the crenulation suggesting a complex relationship between fabric elements and mineral growth (see later sections for detailed structural analysis).

The origin of these units have been discussed by numerous authors. Compositionally, they are highly aluminous and even some of the muscovite appears to be a late forming phase. Mapping in the Washington East quadrangle suggests that these units can be mapped continuously into the quartz-sericite schists of the lower grade Little River Series (Von Der Heyde, 1990). These rocks are thought to be porous pumice lapilli tuffs which acted as reservoirs and conduits for hydrothermal fluids. The aluminous composition is the result of intensive hydrothermal alteration. These are therefore the leached reservoir rocks associated with hydrothermal exhalative systems.

These horizons are nearly identical to those described in the Inner Piedmont. These similarities suggest that rocks of the Inner Piedmont and the high grade portions of the Carolina terrane may be closely related at least by process. Combined with the stratigraphic correlation with low grade pumice lapilli tuff, this similarity suggests that lithologies of the Inner Piedmont should also be examined for evidence of volcaniclastic origin.

Amphibolite and Hornblende Gneisses

Amphibolite is present not only within the biotite gneiss associations but also in concentrations extensive enough to form a mappable unit. The overall mineralogy is similar to those seen within the biotite gneiss association. At amphibolite grade, they are composed of magnesiohornblende to hornblende and intermediate plagioclase (An30-50%), with lesser amounts of epidote, clinopyroxene, magnetite, sphene, and quartz. Some are highly foliated while others are more massive. Nearly all have a strong lineation defined by the amphibole.

Most of the amphibolites are thought to be amphibolite grade equivalents of the mafic volcanic sequence. Some retain structures suggestive of pillows, interpillow hyaloclastites, and vesicles. Others do not have such definitive structures remaining, but have similar mineralogy and chemistry. Most of the amphibolites that are extensive enough to be shown as a map unit are thought to be volcanic, although less extensive horizons within other units may also be dikes and sills. Chemically, most amphibolites are around 50 to 55 wt. % SiO_2 with 0.1 to 0.2 wt. % K_2O. They would, therefore, be classified as low potassium tholeiites.

In some occurrences, mafic lithologies become much more gneissic and form hornblende gneiss. Mineralogically, these are composed of magnesiohornblende to hornblende, intermediate to calcic plagioclase (An 40-60%), quartz, magnetite, with minor sphene and pyroxene. Some units also have significant biotite and become a hornblende-biotite gneiss. Most of these gneisses are thought to form from mafic volcanic material which has undergone various degrees of hydrothermal alteration and/or mixing with other more felsic material in the sedimentary environment.

One other unusual assemblage is calcsilicate gneiss which has been reported in several places associated with mafic lithologies, but never as a mappable unit. This lithology is composed of extremely calcic plagioclase (An 80-90%), garnet, amphibole and/or pyroxene, and quartz. These units are thought to be the high grade equivalent of the quartz-epidote granofels observed as vein and hydrothermal alteration deposits at greenschist grade. With increasing grade, the epidote has reacted to calcic plagioclase plus magnetite and garnet, with any magnesium available combining with the iron to form amphibole and/or pyroxene. Epidote is observed in these lithologies as rims on garnet, suggesting a retrograde reaction.

INTRUSIVE IGNEOUS LITHOLOGIES

The map area has experienced numerous igneous intrusions during its long tectonic history. Since igneous intrusions tend to cross terrane boundaries, we have chosen to describe them separately from the tectonostratigraphic lithologies, even though some may be restricted to a single terrane. In general, the intrusive episodes can be roughly divided into three groups based on their relationship to tectonic fabric development: prekinematic or synvolcanic, synkinematic, and postkinematic.

Prekinematic, Synvolcanic Plutons

Within the Inner Piedmont, deformation has so erased primary textures that it is hard to identify uniquely prekinematic plutons. As previously discussed, we believe that the migmatic biotite gneiss association of the Inner Piedmont core may be a zoned, differentiated prekinematic pluton. The variation in lithologies is thought to be caused by cross-cutting phases of a complex pluton as well as the occurrence of xenoliths and mafic dikes. In addition, we feel that the megacrystic microcline gneiss of the Inner Piedmont flank originated as a porphyritic intrusion. Since these interpretations cannot be proven due to the intensity of deformation and metamorphism, we have chosen to describe these units along with tectonostratigraphic units of the Inner Piedmont. We feel, however, that these units may be petrogenetically similar to those described within the Carolina terrane.

Within the Carolina terrane, there are several igneous complexes which appear to be closely related with the volcanic centers. These are commonly cut by numerous dikes suggesting proximity to an active volcanic center. These synvolcanic complexes are thought to be related to the magmatic arc now represented by the volcanic and volcaniclastic lithologies. Chemically, most are calc-alkaline and range from diorite to granodiorite in composition.

Heardmont Complex

The Heardmont complex extends from east of the Middleton-Lowndesville ductile deformation zone within the Elberton East quadrangle across the Heardmont quadrangle. It is composed of a differentiated hornblende-biotite metadiorite and quartz diorite, which grades into hornblende-biotite granodiorite and granite to the north, and gabbro to the south. Early mapping by Legato included much of this unit within the Russell Lake allochthon.

Subsequent remapping of the quadrangle revealed that the ultramafic and mafic rocks of the allochthon are much more magnesium rich and lie above the diorites and quartz-diorites of the Heardmont complex being separated by a distinct, horizontal fault surface. In addition, the Heardmont complex is cut by metadacite dikes in the southern part of Heardmont and northern part of the Broad quadrangle, demonstrating that the Heardmont complex is older than part of the Little River volcanic complex. The Heardmont complex is a compound zoned pluton composed of many cross cutting phases. The most common lithology is a hornblende quartz-diorite composed of plagioclase (An 30-40%), hornblende, biotite, and quartz. Accessory minerals include ilmenite, sphene, magnetite, and apatite. Actinolite and epidote are found as alteration products from plagioclase and hornblende.

Foliation development is variable. In areas of ductile deformation strong foliation is observed, but in other areas portions of the complex have escaped extensive penetrative foliation. To the south, the complex becomes more gabbroic, being composed dominantly of plagioclase and hornblende with accessory magnetite and epidote. To the north, the complex becomes more granitic, but still contains abundant hornblende as well as biotite. In any given location, several cross-cutting phases are commonly observed.

The complex is in turn cut by a number of felsic dikes. To the south, approaching the Lincolnton volcanic center, it appears to be cut by dacitic dikes which closely resemble the quartz porphyry dikes observed in the Lincolnton metadacite itself. Throughout much of the complex, dikes of an extremely leucocratic granitoid are found. These are usually linear dikes with sharp boundaries. It is not known at this time whether these leucocratic dikes are differentiates of the Heardmont complex, or are offshoots of the younger synkinematic Jacksons Crossroads granite to the southwest. Similarities in appearance to the leucocratic phases of this latter intrusion make this second interpretation probable.

The Heardmont complex is deformed by numerous ductile shear zones. Near the Middleton-Lowndesville zone it is deformed by north-east trending shear zones which parallel those observed within the Middleton-Lowndesville zone. The frequency and intensity of the northeast trending shear zones is greatest near the Middleton-Lowndesville fault zone. In addition, the Heardmont complex is cut by two other sets of shears oriented east-northeast and northwest. Because of relationships between these sets and the overlying Russell Lake Allochthon (see later section), these sets are thought to be younger.

At this time, there is no radiometric dating available for the Heardmont complex. Since it is apparently cut by volcanic dikes correlated with the Lincolnton volcanic center (about 570 Ma, Carpenter et al., 1982), it is thought to be late Precambrian to early Cambrian in age. It is likely that it forms part of a plutonic infrastructure underlying the developing volcanic arc, as is commonly observed for such terranes.

Tonalite Complex of Russell Dam

A series of epizonal tonalites and related mafic units are found at the site of the Russell Lake Dam and extending to near Calhoun Falls in South Carolina. These have been previously described by Weisenfluh and Snoke (1978) in South Carolina. In Georgia, portions of these intrusions extend into the northern part of the Chennault and Broad quadrangles (Thurmond, 1979).

The dominant lithology is a medium grained tonalite (or trondhjemite) composed of plagioclase, quartz, and varying proportions of biotite and amphibole. Microcline when present is minor in abundance. Metamorphic minerals include epidote and chlorite. The tonalite is cut by a large number of mafic dikes. These tend to take on a stronger foliation than the tonalite itself. The original igneous texture of the tonalite is still visible in hand samples.

Chemically, the tonalite is very similar to portions of the Lincolnton metadacite, but tends to be slightly more mafic. Since these tonalites are so intensively cut by mafic dikes, which is indicative of a volcanic center, and are similar to the metadacite in chemistry, they are thought to be epizonal plutons related to the latest Precambrian to Cambrian volcanic arc. The Little Mountain Pluton in South Carolina is chemically similar and has been dated at 550 ma (Dallmeyer et al., 1986). A similar age is hypothesized for these plutons.

Quartzofeldspathic Gneiss of War Hill

The area extending east from War Hill in eastern Philomath quadrangle is underlain by a series of silica rich, sodic gneisses of varying texture. Modal mineralogy includes sodic plagioclase (An 20%), quartz, and minor biotite. The foliation is weakly defined by the biotite. Near the outside edge of the center the layering becomes more distinct. This unit is also cut by a number of metamorphosed mafic dikes. To the east, it becomes coarser grained and more uniform in texture. Evidence of at least two phases of fabric development have been observed. Compositionally, this unit is similar to portions of the Lincolnton metadacite.

The protolith for this assemblage is uncertain. At the moment, it is most likely an intrusive center similar in composition to the Lincolnton metadacite, but much smaller in size. Some of the more layered rocks may be volcanic rather than plutonic, but limited outcrops and the metamorphic grade make it difficult to subdivide the unit. The presence of a mafic dike swarm is suggestive of such an intrusive center.

Synkinematic Plutons

Within the map area, there are numerous differentiated granitic plutons which have been deformed by periods of ductile fabric development but appear to be substantially younger than the volcanic arc development. Many of these contain disoriented, foliated xenoliths suggesting that they intruded after the first period of deformation but before the development of various ductile shear zones. Within the map area, the most voluminous are meta-aluminous intermediate granites composed of subequal amounts of plagioclase and microcline and abundant quartz. Many are compound plutons with numerous cross-cutting phases. Although no radiometric age dates are currently available, most of these are thought to correlate with the Siluro-Devonian granites of the Charlotte belt further northeast (Sinha et al., 1989; Secor et al., 1986a, b; Dallmeyer et al., 1986).

Numerous specific bodies of these synkinematic granites have been identified and described in theses on specific quadrangles. However, in Plate 1 all synkinematic granites have been labelled the same (gr) and contacts between adjacent bodies removed. The reader is referred to the original theses (Appendix I) for more detailed mapping of individual plutons.

In addition to the granites, there are several gabbros and syenites which may belong to this age group. These have gravity and magnetic signatures which appear to indicate that they are rooted structures, but do not have the pristine diabasic fabric of the postkinematic stocks and dikes. Many show signs of alteration and zones of deformation even though the original magmatic textures can still be recognized. A similar association of gabbros and syenites is also reported from the Carolinas within the Siluro-Devonian association (Sinha et al., 1989).

Jacksons Crossroads Granite

The Jackson Crossroads Granite is a compound differentiated pluton that covers a significant percentage of several quadrangles including Jacksons Crossroads, Rayle, and Celeste (Young, 1985; Hutto, 1986; Hall, 1991). The majority of the pluton is an intermediate granite composed of subequal amounts of quartz, plagioclase (albite), and microcline with up to 10% biotite as the dominant mafic mineral. Most of the plagioclase has been altered to epidote/zoisite so the primary zoning and composition is lost. However, some traces of oscillatory zoning are still visible with plagioclase compositions up to An19% being reported. Normative analysis suggests that the plagioclase was originally sodic oligoclase. Chlorite and sericite are also observed as alteration products after biotite and feldspar respectively. The quartz is commonly polygonized and the plagioclase has bent twin planes further demonstrating post-magmatic deformation.

Numerous cross-cutting phases of the Jacksons Crossroads granite are observed. Portions of the body become exceedingly leucocratic with color index approaching 1%. Porphyritic phases are also encountered with microcline phenocrysts up to several centimeters in size. Even in these cases, however, the microcline is now nearly pure potassium feldspar indicating that its composition has reequilibrated at submagmatic temperatures with the albite component leaving the body of the crystal.

A weak foliation is visible in most samples and is defined by deformation and ribboning of the quartz, deformation of feldspars, and orientation of the biotite. In addition, the Jacksons Crossroads granite is deformed by numerous ductile deformation zones. In these areas, the quartz forms ribbons defining the foliation and the feldspars are reduced in size. Epidote, biotite, and chlorite are observed as mafic phases recrystallized into the foliation. The boundaries of these ductile zones are commonly rather sharp. The width of such zones is highly variable from a meter to many tens of meters.

Within the Rayle and Philomath quadrangles, a separate porphyritic granite termed the Dry Fork Creek granite has been recognized (Hutto, 1986; Conway, 1986). This phase appears to cross cut the rest of the Jacksons Crossroads complex, but is not distinct enough to define it as a separate intrusive event. Several lines of evidence suggest that this phase may be somewhat younger than the rest of the complex. Some ductile deformation zones which affect the neighboring Jacksons Crossroads granite do not appear to deform the Dry Fork Creek member. The phenocrysts are still perthitic and have not homogenized. The Dry Fork Creek member is somewhat richer in mafic minerals with up to 10% biotite and has accessory allanite with epidote overgrowths. The plagioclase does show evidence of albitization through alteration to epidote and sericite, plagioclase and quartz show signs of deformation including polygonization of quartz, and the body is deformed by some ductile deformation zones. Therefore, without radiometric age dating, it is not possible to determine whether this unit is significantly younger than the rest of the Jacksons Crossroads complex, or just another member. The map (Plate 1) groups all these granitoid bodies under one symbol (gr).

Woodville Granite Complex

The Woodville granite is generally similar to the Jacksons Crossroads complex, but it crosses the boundary between the Inner Piedmont and the Carolina terrane in Woodville and Lexington quadrangles. It is a compound zoned differentiated pluton exhibiting many cross-cutting relationships between members. It is again composed of subequal amounts of quartz, plagioclase, and microcline with up to 10% biotite. Accessories include magnetite with alteration products of chlorite, muscovite, sericite, and epidote.

The quartz is commonly polygonized, while the plagioclase shows alteration to sericite and is fractured and bent. The microcline is nonperthitic and less altered than the plagioclase. Thus, there is evidence of some degree of deformation within the granite. A weak foliation is developed in some areas, but is often difficult to see. Xenoliths of the Woodville are found throughout the southern portion of the Elberton batholith. The cross-cutting relationships demonstrate that the Woodville was deformed and developed a foliation before being incorporated into the Elberton. In addition, xenoliths of biotite schists within the Woodville demonstrate a strong foliation in a different orientation to the host. The Woodville complex is also cut by several ductile deformation zones ranging in size from 1 meter to tens of meters. In these zones the rock is strongly deformed to mylonite or ultramylonite.

Our mapping has expanded the area of the Woodville granite at the expense of the Elberton granite. More detailed mapping would further reduce the extent of the Elberton granite. The two granites are very similar, producing similar soils and saprolite. The major difference comes from the metamorphism and deformation of the Woodville granite giving a faint foliation and a textural change, allowing easier water penetration and much deeper weathering. The Elberton granite commonly resists weathering giving "pavements" with minimal saprolite and soil development. The Woodville granite, on the other hand, is weathered to a depth of 30-50 feet and can easily be identified in the field and on topographic maps by the steep-walled deep ravines that are so common between Lexington and Union Point.

Smaller Synkinematic Granites

A variety of other smaller synkinematic granites are found throughout the higher grade portions of the Carolina Terrane within nearly every quadrangle. Most of these are similar to the Jacksons Crossroads and Woodville complexes, except that they are smaller and have less lithologic variation within their borders. Examples include the King Branch granodiorite in the Philomath quadrangle (Conway, 1986), the granite of Graball in the center of the Chennault quadrangle (Thurmond, 1979), as well as many other bodies.

Most of these granites are intermediate granite to granodiorite in composition, composed of plagioclase, quartz, microcline, and biotite. The original plagioclase composition is oligoclase, but varying degrees of albitization during alteration/metamorphism are observed. Biotite is by far the dominant mafic mineral, but traces of hornblende are reported as well as retrograde chlorite alteration.

Most of the occurrences have been deformed by localized ductile deformation zones with foliation developed to varying degrees. Although most retain granitic textures throughout much of the body, varying degrees of recrystallization which may be attributed to metamorphism and deformation are observed. It is possible that some of the plutons mapped as synkinematic granites could be older, but without radiometric dating it is difficult to tell. Similarly, a few could be younger but deformed by Alleghenian ductile deformation associated with the Modoc zone.

Our mapping in Woodlawn and Aonia quadrangles has discovered an important small granitic pluton in the southwest corner of the Woodlawn quadrangle extending southwest into the Aonia quadrangle and out of our map area into Wrightsboro and Cadley quadrangles. Mapping was done when the lake level (Clark Hill Lake, now called Thurmond Lake in South Carolina) was very low. Very few outcrops are available but excellent saprolite was located in a number of shoreline cuts. This body of granite, called here the South Aonia pluton, is easily identified at low water level by the enormous quantity of quartz vein float which completely covers the ground. The pluton is crisscrossed by an inordinate number of shear zones and quartz veins. Its importance lies in the fact that it is closely associated with the "McDuffie Gold Belt" (Hurst et al. 1966; Jones, 1909). This relationship will be discussed in the chapter on exploration potential. The proximity of this pluton to the Modoc fault zone explains the greater abundance of shear zones and quartz veins when compared to other similar plutons further north.

A number of granite bodies (mylonitized orthogneiss) have been mapped within the Modoc fault zone in the southeast corner of the map area. Excellent exposures were available when the lake level dropped to 17 feet below the full level (330 feet). The axis of Clark Hill Lake is underlain by highly foliated chlorite schists and phyllites of volcaniclastic origin. Proceeding southward, small tabular lenses of mylonitized granite are found; the size and proportion of granite increases rapidly southward. This change accompanies a change from low grade phyllitic rocks to amphibolite grade migmatic gneisses and amphibolites. All the rocks involved show a pronounced mylonitic fabric. Locally, the sill-like bodies of granite are cross cutting the gneissic layering and the foliation of the host rocks.

The origin of the granite appears to be linked with the deformation. The process of "melt enhanced deformation" described by Hollister and Crawford (1986) fits the field evidence gathered in mapping the southeast corner of the Woodlawn quadrangle. The presence of higher grade gneisses and amphibolites in sharp contact with low grade greenschists of the Slate belt suggest a major amount of tectonic transport. The fact that all the granites within the Modoc zone are mylonitized and sill-like in geometry supports the model of Hollister and Crawford. Whether the shearing caused the melting or the melt caused and/or enhanced the ductility is not clear from the limited exposures mapped.

Synkinematic Gabbros

Several gabbros which post-date regional fabric development, but with varying degrees of recrystallization and alteration of their magmatic assemblages have been mapped. Although no radiometric dates are available for these, they are thought to roughly correlate with similar gabbros to the northeast. Most of these gabbros have large positive magnetic anomalies associated with them which suggests that they are deep, rooted structures.

Two such gabbros are in western Rayle and eastern Lexington quadrangles (Davidson, 1981) and have been termed the Chafin and Georgia Farm gabbros. These are composed of plagioclase, hornblende, and pyroxene with secondary actinolite, epidote, and chlorite. The Georgia Farm gabbro has cumulate plagioclase which has retained a calcic composition (An45-55%), while the Chafin gabbro appears to have been more thoroughly metamorphosed to albite. Both appear to cross cut regional foliation, although the Georgia Farm gabbro appears to be less altered and overprints the surrounding rocks with a contact aureole.

Another gabbro occurs at Rose Hill between the Elberton East and Heardmont quadrangles. This one also has an associated pronounced magnetitic anomaly. Some samples of these gabbros are so fresh looking that they could be considerably younger and be correlative with Mesozoic diabase dikes. Without radiometric age dating it is hard to evaluate this possibility.

Delhi Syenite

The Delhi Syenite is a rather unique lithology which is thought to be related to the synkinematic gabbros as is the case further north in the Carolinas. Although the outcrop pattern of the syenite appears to crosscut the Danburg granite, careful petrographic observations indicate that the syenite has been recrystallized and hydrothermally altered near the granite, indicating that the syenite is older.

The syenite is dominantly composed of fine to medium grained perthitic alkali feldspar, iron-titanium oxides, and an alkali rich hornblende, ferrohastingsite. In many samples, much of the mafic mineral has been altered to oxides. Traces of a calcium-rich clinopyroxene and fayalitic olivine have been observed. Near the Danburg granite, biotite is found in some samples altering from the mafic phases. The coarse grained syenite is also found next to the granite where there is a small abandoned quarry for feldspar concentrate.

The feldspar in the syenite contains numerous micron-sized inclusions of iron-titanium oxides. When a fresh sample is broken it looks gray, but oxidation of the micron-size inclusions turns it a greenish yellow in a few hours. Weathered samples become white as these inclusions are weathered away.

Chemically, the syenite appears to be the product of fractional crystallization of a gabbroic source, as it shows extreme iron enrichment. It probably overlies a differentiated gabbro.

Post-Kinematic Plutons

The post-kinematic plutons are composed of the Elberton granite, Danburg granite, and diabase dikes within the study area. Since these have long been recognized as intrusive igneous rocks, they have been previously studied in more detail by many researchers.

Elberton Granite

The Elberton granite is a fine-grained, equigranular, extremely homogeneous unit composed of approximately equal proportions of quartz, microcline, and plagioclase, and as minor components, biotite, muscovite, allanite, and occasional sphene. It contains only small amounts of opaque minerals; these, in decreasing order of abundance, are hemano-ilmenite, ilmeno-hematite, and magnetite. A very fine-grained opaque phase (magnetite?) is scattered throughout the feldspar and is responsible for its gray color. Where the granite is pink, this phase is replaced with hematite.

Feldspars are fairly homogeneous; minor amounts of oscillatory and normal zoning are visible in plagioclase. Microcline is nearly pure, although occasional perthitic cores remain, testifying to the more sodic original composition. Most feldspars probably homogenized at lower temperatures during slow cooling of the body.

Muscovite is mostly deuteric or secondary, but in the southern parts of the body, a small percentage may be primary. Biotite is well formed, but in some areas, small amounts of chlorite replace biotite. Allanite, commonly metamict with anastomosing cracks radiating into the surrounding minerals, is common. Sphene is much more rare and is present only locally in northwestern parts of the pluton (Hess, 1979).

Crude estimates of ilmenite composition, based on visual methods, and its coexistence with ilmeno-hematite and magnetite, suggest high oxygen fugacities, one to two log units below the hematite-magnetite buffer, and temperatures of crystallization around 650 to 700°C (Baldasari, 1981). Water contents of the magma are not known, but, based on crystallization history and probable temperatures, values around 4 percent seem reasonable.

A distinctive feature of the body is its extreme homogeneity and fine grain size throughout its outcrop area, several hundred square kilometers. Locally the granite develops some foliation near its contacts, due dominantly to igneous flowage. In one or two places, this foliation is complex, apparently because of late-stage movements. The current erosion surface seems to be near the top of the body, particularly along its northwestern boundary. The body possibly stopped rising when it passed through its solidus and, therefore, quenched to a homogeneous fine-grained fabric. From observations in more than 50 quarries, no internal contacts within the Elberton proper can be discerned.

The Elberton granite is the most important monument stone locality in the southern Appalachians, and its exploitation dominates the economy of the area. Of highest value is the "Elberton Blue," found only near the contact in the northern part of the body. It is highly prized as a monument stone, and much of it currently is being shipped in bulk to Japan. The "Blue" is a slightly finer grained phase that occurs near the outer part of the body, giving the stone a bluish cast when polished. Downward, this phase passes continuously into the more common gray phase.

"Elberton Gray" is less valuable, but much more extensive. Recently, large volumes of "Gray" have been quarried from the center of the body, near Vesta, Georgia. This rock contains fewer xenoliths, aplites, and pegmatites, which results in a decrease of waste material. "Elberton Pink" is the least common variety. Only about four quarries cut pink stone. Currently, only one is active, the Hedquist Pink quarry of the Keystone Granite Co. The pink grades continuously into the gray, as can be seen in an exposed ledge between the "Dawn Gray" and "Sunset Pink" quarries in the southeastern part of the Elberton West quadrangle.

The age of crystallization of the Elberton currently is thought to be 320±20 Ma based on U/Pb zircon dating (Ross and Bickford, 1980). An earlier U/Pb zircon age (Gruenfelder and Silver, 1958) yielded an older age but it is believed that this sample has a substantial inherited zircon component. A Rb-Sr whole rock isochron from quarries with low oxygen isotopic values yields an age of 350 ± 11 Ma with an initial intercept of 0.7038; however, several samples from quarries that commonly contain xenoliths are anomalous and define a pseudoisochron with an age of 376 ± 45 Ma that lies nearly parallel, but with a higher initial Sr^{87}/Sr^{86} of 0.7054 (Ellwood et al., 1980). A combined Rb-Sr biotite and whole rock age is distinctly younger, nearly consistent with K-Ar and Ar^{40}/Ar^{39} ages on biotite (~ 250 Ma), and younger than Ar^{39}/Ar^{40} ages on hornblende (Fairbairn et al., 1960; Dallmeyer et al., 1981). This discrepancy suggests that the body cooled slowly, but did not cool below the blocking temperature of biotite (300 to 350°C) for about 100 Ma.

Detailed major, minor, and trace element data obtained from the central part of the pluton (West Elberton quadrangle; Hess, 1979) suggest that the Elberton granite is exceedingly uniform in most major elements: for example, the SiO2 content is 71.5 ± 1.0 wt. % from 30 different localities. However, systematic, broad variations in certain dispersed trace elements, such as Rb/Sr, Ba, Mn, occur in a manner in which isocontours of Rb/Sr ratios commonly display an approximate north-south alignment (Hess and Stormer, 1980). This pattern is most obvious in the center of the body where most data exist. These isocontours are nearly coincident with paleomagnetic foliation, which is interpreted to define the magmatic flow direction (Ellwood et al., 1980).

Detailed whole rock oxygen isotopic data show a relatively broad range of O^{18} values (6.1-9.3; mean = 7.9±0.7) throughout the pluton, which probably represents primary magmatic O^{18}/O^{16} variations (Wenner, 1980). Isocontours based on O^{18} values reveal a pattern remarkably similar to the Rb/Sr contours and paleomagnetic foliations. Furthermore, samples that define the lower intercept Rb/Sr isochron of 0.7038 invariably have lower O^{18}/O^{16} values compared to those that define a pseudoisochron with a higher initial Sr^{87}/Sr^{86} of 0.7054 (Ellwood et al., 1980).

The Rb/Sr and O^{18} contours apparently reflect original dispersed trace element and isotopic (O^{18}/O^{16} and Sr^{87}/Sr^{86}) heterogeneities that are preserved during laminar magmatic flow. These heterogeneities could partly mirror a heterogeneous protolith. Partial fusion of a quartz and feldspar-bearing source material would be expected to generate a magma of nearly uniform major element chemistry, because of compositional control by melting at the granite minimum. However, a granitic melt formed by this process could easily be heterogeneous in certain dispersed trace elements and oxygen and strontium isotopes, if such heterogeneities originally existed in the protolith. Alternatively, these heterogeneities could represent some subtle form of contamination, produced either in-situ as a consequence of exchange with the surrounding country rock or during magmatic ascent.

The Elberton pluton has a range of oxygen isotopic compositions intermediate between the O^{18}-enriched Stone Mountain body and the relatively low O^{18} granites of the Carolina terrane (Danburg, Siloam, Sparta) (Whitney and Wenner, 1980). In fact, detailed petrographic studies reveal that many of the O^{18}-enriched samples from the center of the body contain certain accessory minerals (primary muscovite) characteristic of an S-type granitoid, whereas some of the more O^{18}-depleted sites are characterized by sphene, an accessory mineral commonly associated with I-type granitoids. This pluton thus seems to represent a granite of both I-and S-type characteristics.

Danburg Granite

The Danburg granite body is an elliptical, asymmetric, funnel-shaped pluton with steep flow features on the north and shallower features on the south (Speer et al., 1980). The pluton consists entirely of a coarse-grained, porphyritic granite composed of large (up to 5 cm) phenocrysts of perthitic microcline set in a matrix of quartz, oligoclase, biotite, and sphene. Iron-titanium oxides are common, and the body is free of any deuteric or hydrothermal alteration.

Feldspars are clean, and plagioclase shows strong oscillatory and normal zoning. Microcline phenocrysts are highly perthitic; rapakivi rims composed of oligoclase and perthite lamellae of albite are common. The rapakivi texture, therefore, seems to be a magmatic growth phenomenon (Whitney and Stormer, 1977).

Biotite is clean and unaltered. Hornblende is rare, although it has been found in a few locations. Sphene is euhedral and commonly found in mafic clots with biotite and iron-titanium oxides (Fig. 13B). Small amounts of fluorite exist, together with minor sulfides.

Temperatures of crystallization are estimated to have been between 800 and 690°C (Whitney and Stormer, 1977). Oxygen fugacities are unknown, but probably were intermediate for granitic rocks, based on mineral assemblages. Water content of the magma also has not been determined; but based on crystallization temperatures, it must have been moderate (around 4%).

The metamorphic aureole around the body is not well developed due to the high metamorphic grade of country rocks, but evidence of hydration has been found both east and west of the body. The Delhi syenite, which in map pattern appears to cross-cut the Danburg, shows considerable evidence of recrystallization and potassium enrichment near the body and seems to be altered by the intrusion of the granite.

Within quarries, interesting assemblages of xenoliths may be found. In addition to locally derived angular xenoliths, rounded, resorbed, and altered mafic inclusion are common; single large plagioclase xenocrysts occur occasionally. Many mafic xenoliths are totally recrystallized, but seem to have been amphibolitic in composition, converted to a biotite-plagioclase-sphene assemblage by interaction with the granitic magma.

No published age information exists for this body, although it is similar to many of the other post-kinematic granites of the southern Piedmont. L. B. Jones (1975, personal communication) reported a 290 Ma age based on a poor Rb-Sr isochron, but the data was never published. Thus, we assume that it belongs to the "300 Ma" age group.

Oxygen isotopic compositions have mean values of 7.2 ±0.3. These isotopic data, mineral content, location within the Charlotte-Carolina slate belts in an area of probable mafic-rich subcrust, suggest that this granitoid represents a classic I-type granite derived from an igneous protolith.

Lamprophyre

Lamprophyres are limited to the eastern portion of the Aonia quadrangle. We observed a few outcrops close to the Aonia-Woodlawn boundary about 3.2 miles (5.1 km) south of the northeast corner of Aonia quadrangle (Figure 2). Reusing (1979) described the lamprophyres as dikes but it is not clear whether the outcrops examined belong to a dike, sets of dikes, or a small pluton. The lamprophyre occurs as large, dark boulders in a dark brown soil.

The lamprophyre consists of large euhedral phenocrysts of hornblende in a medium-grained matrix of augite, plagioclase, and minor quantities of chlorite, quartz, epidote, muscovite, magnetite, and apatite. The chemical analysis given by Reusing (1979) shows 0.47% P_2O_5. We have no data on the absolute age of the lamprophyres and their magmatic affiliations.

Diabase Dikes

Diabase dikes are common throughout the southern Appalachians. Most are from less than one meter to several meters in width and are therefore not representable at the scale of 1:100,000. Within the map area nearly all are oriented in a northwesterly direction following the trajectories of the brittle northwest faults. These dikes are thought to be Mesozoic in age related to the opening of the Atlantic Ocean. The general northwesterly direction suggests that they are parallel to the third arm of a triple junction from a spreading center somewhere off the Georgia-South Carolina coast.

These dikes have a strong diabasic texture formed of laths of labradorite surrounded by sub-calcic augite. Forsteritic olivine is found in some dikes but is absent in others. Orthopyroxene (enstatite to bronzite) has also been reported. The borders of these dikes are usually chilled, with some rims being so fine grained they appear glassy. These quench textures suggest that the surrounding country rock was essentially cold at the time of intrusion.

RUSSELL LAKE ALLOCHTHON

Isolated occurrences of ultramafic lithologies have long been known in the Carolina terrane (Larrabee, 1966). Local outcrops have been described from numerous quadrangles for many years. Mapping in the Heardmont quadrangle by Legato (1986) during the construction and filling of Lake Russell revealed that these lithologies lie upon a subhorizontal shear zone and are apparently klippen of a more extensive thrust sheet (Whitney et al., 1987; Allard and Whitney, 1989, Whitney and Allard, 1990). Many other occurrences have now been investigated and appear to be klippen of a mafic/ultramafic complex. Remapping of the Heardmont quadrangle and surroundings, however, have revealed that the extent of the allochthon is much less continuous than suggested by Legato (1986). The ultramafic lithologies are limited to those areas with copious boulders on the surface. Outside of these areas, trenches into the saprolite reveals different lithologies which correlate with the surrounding terrane. Thus, the allochthon appears to be a series of small klippen which are resistant to weathering and cap the tops of hills. In most areas, the klippen appear to be thin erosional remnants of a once more extensive sheet. Eighty-eight occurrences have been identified within the map area; some limited to a few resistant boulders and others covering areas as large as 15 square kilometers.

All gabbroic and ultramafic occurrences within the map area have been reinvestigated in light of the remapping of the Heardmont quadrangle. Again, the continuous extent of the allochthon has decreased from preliminary compilations due to the realization that the ultramafic allochthon does not extend between bouldery outcrop areas, but is rather a series of isolated klippen. Much of the intervening material assigned by Legato (1986) to the allochthon is actually part of the Heardmont prekinematic intrusive complex.

The lithologies of the allochthon are composed of varying proportions of serpentine, amphiboles (anthophyllite, actinolite, tremolite), talc, chlorite, epidote, magnetite, and ilmenite. Small amounts of albite (up to 10%) are encountered in some of the more gabbroic samples. In the more gabbroic units, round quartz grains have been observed. These could either have formed from granophyric quartz in a differentiated gabbro, or as the product of metamorphism. Relic olivine and pyroxene have been observed in a few cases, with pseudomorphs of olivine and pyroxene common in unsheared portions of the complex. In fact, many of the less deformed samples exhibit excellent relic igneous textures indicating that the protolith was a medium to coarse grained intrusive lithology.

From the limited geochemistry now available, the allochthon appears to have ranged in composition from peridotite and pyroxenite to olivine gabbro and feldspathic gabbro. Magnesia contents as high as 30 wt. % have been reported, with SiO2 contents between 36 and 56% (Legato, 1986; Young, 1985; Turner, 1987; McFarland, 1992). Trace element abundances also indicate an ultramafic parent with up to 1800 ppm Cr and 700 ppm Ni. Alumina contents are highly variable, probably reflecting variability in the initial calcic plagioclase content. The more mafic samples contain 5 to 6% alumina, while the more gabbroic samples may have up to 22%. Most of the alumina now resides in chlorite, epidote, and minor albite. Normative analyses suggest protoliths composed of olivine (5-60%), pyroxene (20-50%), and calcic plagioclase (bytownite to anorthite, 5-

40%). Since a significant amount of the anorthite component could have been originally dissolved in the pyroxene as Ca-Tschermak's molecule, this normative analysis may overestimate the amount of original modal plagioclase. A more thorough study of the petrology and geochemistry has been conducted by McFarland (1992).

The base of the allochthon is characterized by a narrow ductily deformed zone with a subhorizontal orientation. This horizon is commonly rich in talc and serpentine. Above this zone the unit becomes more massive with relic textures being observed within a few feet of the base. The allochthon is in turn cut by at least two sets of ductile shears, one at approximately 120° and one at 55°. Near the Middleton-Lowndesville zone, in the northwest corner of the Heardmont quadrangle along the railroad right-of-way, the relationships between various phases of ductile deformation can be observed. The Middleton-Lowndesville deformation (approximately N40°E) appears to cut the Heardmont complex, but does not deform the allochthon. The allochthon lies above the Heardmont complex with a subhorizontal ductile zone as previously described. The allochthon and the underlying rocks are cut by two sets of near vertical shears oriented approximately N55°E and N120°E. These latter deformations appear to have downdropped sections of the allochthon suggesting some component of vertical movement. Thus, the emplacement of the allochthon appears to have postdated the ductile deformation phase of the Middleton-Lowndesville zone, but is itself deformed by later ductile events. These later events may be related to one phase of movement along the Modoc zone and the formation of northwest-southeast faults within the Carolina terrane. To date, no direct relationship between the allochthon and intrusion of the Elberton granite or the Danburg granite has been observed.

At this time, we have little radiometric control on the date of emplacement of the allochthon. By comparison with the tectonic development in South Carolina, we would suggest that emplacement may correlate with the Alleghenian D_3 (Clarks Hill) deformation of Secor et al. (1986b) which they estimate to have occurred between 285-295 Ma.

The Russell Lake allochthon is not limited to the map area. Similar small hilltop occurrences have been reported in South Carolina (Griffin, 1978a). Soapstone Ridge in Atlanta (Higgins et al., 1980) lies on a thrust fault and may be correlated with the Russell Lake allochthon.

CRETACEOUS (?) SEDIMENTARY ROCKS (Ks)

A small outcrop of unmetamorphosed conglomeratic sandstone was observed at low water level on the shore of Clark Hill Lake within the southwest corner of the Calhoun Falls quadrangle.

Earlier studies in this area interpreted this outcrop to be metalithic conglomerate and metasandstone (Austin, 1965) or crossbedded arkoses interbedded with metavolcanic biotite gneiss (Delia, 1982). This conglomeratic sandstone may be equivalent to the Cretaceous-Tertiary conglomeratic sandstones approximately 30 miles (48 km) to the southeast in the Kiokee belt (Coker, 1991).

All the references mention the fact that this lithology was observed at very low water level. We conclude that Cretaceous (possible Tertiary) sedimentation took place in the ancestral valley of the Savannah River as far west as our map area and possibly further, 40 miles (64 km) northwest of the Fall line (Geological map of Georgia, Georgia Geologic Survey, 1976).

STRUCTURE

The entire Piedmont province has experienced a long structural history with multiple periods of deformation. Correlation of deformational events across terrane boundaries can be hazardous as we do not know whether neighboring terranes were spatially associated in the past or not. For that reason, the Inner Piedmont and Carolina terrane will be dealt with separately, and then a potential correlation in deformational history proposed.

Inner Piedmont

Only a small portion of the Inner Piedmont core is included in the map area. The foliations, or s-surfaces, are defined throughout the Inner Piedmont by schistosity and gneissosity formed by preferred orientation of mica, amphibole, and sillimanite, as well as elongated quartzofeldspathic minerals, accompanied by intense transposition within the migmatized gneisses.

Foliation dips are moderate to gentle within the northwest corner of the Carlton quadrangle and continuing into the Inner Piedmont core. The pattern of foliation pole concentrations (pi-diagram) is similar to that reported by Griffin (1979), defining a small circle thought to represent subhorizontal conical folds (F_1). It is thought that these folds correspond to the Inner Piedmont nappes described by Griffin (1971 a, b) and Nelson et al. (1987).

Moving to the southeast toward the Inner Piedmont flank, the foliations become steeper. The pole positions define a great circle girdle, with most measurements having rather steep dips. This pattern suggests slightly northwest verging, northeast-trending upright folds (Potter, 1981, Fig. 17). Small scale folds in this orientation are described by Potter and observed at Watson Mill State Park. This set of folds appears to be superimposed on the earlier nappe structures and represents a second (F_2) fold set.

Approaching the Middleton-Lowndesville zone, zones of ductile deformation become more common. The megacrystic microcline gneiss is one of the most affected units. The orientation of the ductile zones parallels the main ductile fabric of the Middleton-Lowndesville (N04°E) and is nearly parallel to the axial plane of the F_2 folds. The Inner Piedmont lithologies and the related ductile deformation are terminated against a later brittle fault occupying the western boundary of the Middleton-Lowndesville zone. Dikes of Elberton granite cross cut F1 and F2 structures, and xenoliths of ductile deformed microcline gneiss are found disoriented within the Elberton. Therefore, most of the deformational events of the Inner Piedmont preceded the intrusion of the Elberton at 320 Ma.

Following these major deformational events, a minor event formed isolated northwest trending open folds. No fabric development can be directly related to this minor event. Northwest brittle fracturing and one small northwest trending ductile zone within the Elberton granite may be related to this event.

The first two fold sets seem to correlate well in style and description with F_1 and F_2 structures of McConnell and Abrams (1984) within the greater Atlanta region to the west. The third set of northwest trending folds may correlate with either their F_3 or F_4 structures. Correlation to the southeast with Secor et al. (1986b) is more difficult since they are mainly dealing with Alleghenian deformation. Since F_1, F_2, and ductile deformation related to the Middleton-Lowndesville precedes the intrusion of the Elberton at 320 Ma, all of these events must precede D_2 of Secor et al. (1986b).

The Russell Lake allochthon has not been observed within the Inner Piedmont in this map area. However, it is probable that ultramafic occurrences such as Soapstone Ridge near Atlanta may have been emplaced during the same event (Higgins et al., 1980).

Carolina Terrane

The foliations, or s-surfaces, are defined throughout the Carolina terrane by schistosity and gneissosity formed by preferred orientation of micas, amphibole, and sillimanite, as well as elongated quartzofeldspathic minerals and flattening of primary clasts. The foliations are generally near vertical, striking northeast to east-northeast. Wide variations in strike are found within the higher grade portions of the terrane (formerly Charlotte belt), especially in the vicinity of plutons.

No recumbent nappe structures comparable to the F_1 structures of the Inner Piedmont can be documented at this time, although Turner (1987) suggests that the northern belt of metadacite and related rocks in the Vesta quadrangle may be the core of a refolded nappe. In the nose of this structure, and the nose of the fold forming War Hill in western Philomath quadrangle, there does seem to be evidence of an older subhorizontal foliation being overprinted by one axial plane to the dominant upright northeast trending folds. Whether this foliation represents an earlier folding event or is parallel to original depositional layering is unclear. In addition, the quartz-muscovite-sillimanite schist surrounding War Hill in eastern Philomath quadrangle has a strong S_1 fabric which is being overprinted by a penetrative S_2 schistosity which is axial to the mesoscopic fold. This S_2 schistosity deforms early metamorphic micas, but has sillimanite, a maximum metamorphic grade mineral, growing in the S_2 direction at right angles to S_1. Therefore, although large scale F_1 folds have not been recognized there is evidence that the most pervasive schistosity is not axial planar to the mesoscopic folds, but precedes them. Therefore, the dominant mesoscopic folds such as at War Hill are termed F_2 structures.

The dominant foliation directions are controlled by the orientation of these F_2 structures. The F_2 folds are near vertical, with a very small interlimb angle approaching isoclinal. Within the low grade areas the orientation trends consistently northeast and are highly planar. The dominant S_1 schistosity is nearly parallel to bedding and is folded by the F_2 folds. Thus, changes in the orientation of the foliation can be used, along with lithology, to define F_2 folds. This observation is consistent with the previously described relationships within the higher grade gneisses near War Hill. The planar nature of the foliation, combined with a very restricted hinge zone and small interlimb angle makes these nearly vertical, tight to isoclinal, chevron folds. Within the low grade areas, thickness of strata are also consistent suggesting the folds are concentric or parallel (Ramsay, 1967).

At higher grades, the lithologies tend to deform more plastically and the nature of the folds change. The foliation becomes less planar and interlimb angles decrease. Thickness of layers also becomes much more variable with increased evidence of flowage and boudinage of more competent units. Thus, the folds become isoclinal, similar folds (Ramsay, 1967).

Within the higher grade areas (previously Charlotte belt), the attitude of the folds and the resulting foliation becomes much more complicated, especially around synkinematic plutons. Apparently, the lithologies partially accommodated the intrusion of these plutons by plastic deformation, and were thus still at considerable temperature at the time of intrusion.

Although most foliations are near vertical with little evidence of vergence, statistical analysis suggests a tendency for northwest vergence within the northwest portion of the Carolina terrane, and southeast vergence within the southeast.

The Carolina terrane has subsequently been deformed by numerous ductile deformation zones and brittle faults. Each of these events will be discussed separately.

Middleton-Lowndesville Ductile Deformation Zone

The Middleton-Lowndesville zone is a polydeformational structure involving both an early ductile deformation followed by a much later brittle deformation. The actual boundary between the Inner Piedmont and the Carolina terrane is the brittle fault. The strike is N40°E within the map area.

As with most zones of ductile deformation, the degree of deformation varies strongly within the zone. The most intense development of mylonitic fabric and fluxion structure are within narrow bands which may totally transpose the foliation of the rock. In between these zones the fabric development is much less intense. As the southeastern edge of the Inner Piedmont is approached, the abundance and intensity of the deformation increases.

Within the zone, small scale folds have been observed in the mylonitic fabric within the Elberton East quadrangle (Rozen, 1978). These are northwest verging, gently plunging folds suggesting reverse movement toward the northwest during their formation. Pi diagrams of the foliations also suggest tight folds verging to the northwest.

The age of the ductile deformation along the Middleton-Lowndesville is not well constrained but it must precede the intrusion of the Elberton granite (320 Ma). Disoriented xenoliths of microcline gneiss with well developed fluxion structure have been found in several quarries. Dikes of Elberton also cut ductily deformed gneisses. It is possible that this stage of ductile deformation correlates with ductile deformation along the Brevard, Alatoona, and Cartersville faults to the northwest estimated at 370 Ma. (McConnell and Abrams, 1984). It is distinctly older than ductile deformation along the Modoc zone (Secor et al., 1986b) and the N55°E and N110°E shears which cut the Carolina terrane and also cut the Middleton- Lowndesville fabric.

Russell Lake Allochthon

Much of the Lake Russell Allochthon does not have a pervasive penetrative fabric, although it has been pervasively metamorphosed and recrystallized. Relic igneous textures are therefore commonly preserved. It is, however, locally deformed by several ductile deformation events.

The base of the allochthon is characterized by a narrow sub-horizontal to undulating zone of ductile deformation. In a few places the allochthon and the underlying lithologies have become imbricated within this zone. The foliation is defined by preferred orientation of talc, serpentine and chlorite.

The allochthon and the underlying units have been deformed by two sets of ductile shears oriented approximately N55°E and N110°E. These have deformed the contact as well, downdropping blocks of the allochthon into the surrounding rocks. These shears are near vertical and clearly post-date the emplacement of the allochthon.

The allochthon has not been observed to the northwest of the brittle fault that bounds the Carolina terrane in the western portion of the Middleton-Lowndesville zone, even though it is observed within a few hundred yards cf it. Either the brittle fault post-dates the allochthon and has displaced it, or the allochthon was ramped upward in this region.

Modoc Fault Zone

The Modoc fault zone is located in the southeastern corner of the map area. It is four miles wide within the map area and extends further southwest for unknown distances. All the lithologies within the Modoc fault zone show a pronounced ductile fabric and a few well-defined brittle faults marked by a combination of muscovite schists and quartz lenses forming bold ridges.

The intensity of the deformation and the extremely rapid change from very low grade chlorite schists at the north boundary to migmatites a short distance away suggests that the Modoc is a terrane boundary forming the southern limit of the Carolina terrane and the northern limit of the Kiokee belt. The north boundary of the Modoc fault zone may be stratigraphically controlled by an intermediate metavolcaniclastic horizon composed of a chlorite matrix and abundant felsic and pumice clasts interlayered with argillites. To the south, within a mere three miles, five stratigraphic horizons of muscovite schists and quartzites are clearly mappable on the lake shore. Some of the quartz-muscovite schists horizons have a core of quartz veins forming distinct ridges. The C-S structures indicate a dextral sense of movement on these brittle faults.

At low water level, north of the Modoc zone, within the southern boundary of the Carolina terrane, bedding in the pyroclastics can be observed with difficulty. The strikes of the bedding vary from north-south to east-west and the dips are commonly very shallow. The S_2 cleavage is very well developed and parallel to the main Modoc direction (N70°E).

Within the north edge of the Modoc fault zone, the bedding is strongly transposed parallel to the C-direction of the C-S fabric. Minor folds and crenulations are predominantly plunging at very small angles to the southwest. A strong pencil structure caused by the intersection of a flat cleavage and a steep cleavage is common but not omnipresent. Locally, the flat cleavage crenulates the steeper regional cleavage. We have not done a detailed analysis of the abundant structural elements available. Such an analysis has been done in South Carolina in the Leah and Clarks Hill quadrangles, east of the Woodlawn quadrangle, by Secor (1987), Sacks and Dennis (1987) and Maher (1987). The refolding of bedding north of the Modoc zone, the presence of a number of northeast-trending shear zones within the Carolina terrane, and the abundant northwest-trending brittle faults in the Carolina terrane, are probably all related to the Alleghenian deformation of the Modoc zone.

The literature on this area of the Southern Appalachians often confuses the structural elements which belong to the Middleton-Lowndesville fault zone and the Modoc fault zone. Our mapping clearly shows that the Middleton-Lowndesville is a N40°E tectonic direction and the Modoc is a N70°E direction. More mapping to the southwest is needed to determine the nature of the junction of the two fault systems. This junction would fall within the unmapped area to the southwest of our map area (Figure 1). The lack of mapping in this critical area might explain the difficulties many authors (Davis, 1980; Hatcher et al., 1977; Hooper and Hatcher, 1988; and Steltenpohl, 1988) have had in connecting the well known Alabama faults (Goat Rock, Bartletts Ferry, Towaliga) with the few well known Georgia and Carolina faults (Middleton-Lowndesville, Modoc, Kings

Mountain). The aeromagnetic maps of Georgia and South Carolina (Zietz et al., 1980, 1982) clearly show the Modoc fault zone and the Middleton-Lowndesville fault zone. These difficulties would disappear if additional detailed mapping were done west and southwest of the map area. The economic importance of the Modoc will be discussed in the chapter on exploration potential.

According to Secor (1987), Sacks and Dennis (1987) and Maher (1987), the first deformation within the Modoc zone itself has been termed the Lake Murray deformation (D_2 of Secor et al., 1986a). Structures include overprinting of S_1 fabrics with greenschist or amphibolite grade minerals with local mylonitic fabrics, intrusion of felsic granites oriented parallel to S_2, penetrative deformation to the southeast from the Modoc zone, and the development of a strong metamorphic gradient across the zone. Secor et al. (1986a, b) estimate the age of this deformation at between 315 and 290 Ma based on radiometric dating of deformed and undeformed plutons. They interpret this event to be the development of a subhorizontal boundary between infrastructure and superstructure during the early stages of Alleghenian deformation. This deformation is associated with extensive magmatism within the Modoc zone.

Within the map area to the northwest of the Modoc zone, we cannot document extensive deformation correlated with this D_2 event of Secor et al.. The intrusion of the Elberton granite at 320 Ma, and perhaps the Danburg granite, occur at about this time. Neither is extensively deformed by structures analogous to those found in the Modoc zone.

The second stage of deformation within the Modoc zone is termed the Clarks Hill Deformation (D_3 of Secor et al., 1986a, b). This deformation involved the folding of the Modoc zone into a northwest-vergent antiform. This deformation developed gently plunging F_3 folds trending N50°E to N70°E. The estimated age of this deformation is 285-295 Ma (Secor et al., 1986b). Secor et al. suggest that the sole decollement underlying the Piedmont province also moved at this time.

These folds are similar to those found within the Middleton-Lowndesville zone, but the trend is different and the Middleton-Lowndesville ductile deformation preceded the Elberton granite and must therefore be older. The movement of the Lake Russell allochthon as a thrust from the southeast would be consistent with the sense of vergence of these F_3 folds. Therefore, it is possible that the allochthon was emplaced during this period under similar tectonic forces. This emplacement would correlate with the movement of the entire Piedmont province on a basal sole thrust.

The final stage of ductile deformation in the Modoc zone is termed the Irmo Deformation (D_4 of Secor et al., 1986a, b). This deformation is composed of steeply dipping, northeast-trending shear zones. Movement accompanying this event is thought to be dextral with a strong subhorizontal mineral lineation associated with it. Secor et al. (1986b) estimate the age of this deformation to be 268-290 Ma.

The orientation of these shear zones is parallel or nearly parallel to the N55°E shear zones observed throughout the Carolina terrane and within the Lake Russell allochthon. The orientation appears to splay somewhat northward from the Modoc zone from N70°E to N50°E. It is possible that the other late set of shears at N110°E to N120°E may be a conjugate set formed by the compression of the Carolina terrane between the Modoc zone and the Inner Piedmont.

Brittle Faults

These structures were the loci for hydrothermal deposition of silica and other minerals such as zeolites. Hydrothermal deposition accompanies movement as these zones are characterized by polydeformational silicic breccias sequentially recemented with silica. These lithologies have been termed "flinty crush-rock" by some authors. Two different orientations are encountered, one to the northwest and one to the northeast. The later are much harder to identify unless they are silicified since they parallel regional lithologic trends.

One of the larger northeasterly brittle faults forms the western boundary of the Middleton-Lowndesville zone and defines the actual boundary between the Inner Piedmont and the Carolina terrane. The core is formed of a quartz breccia recemented with quartz. Several periods of movement are indicated by cross-cutting brecciated quartz. The brittle fault appears to post-date the Elberton granite as the granite does not appear to cut the brittle fault. Slickensides suggest some component of normal movement with the Inner Piedmont moving up relative to the Carolina terrane. Hooper and Hatcher (1988) have suggested substantial right lateral movement along the extension of this boundary. Matching up the megacrystic microcline gneiss and Elberton granite across the zone would require 30 to 50 km of right lateral movement, if the outlier of granite near the town of Swords, described by Whitney et al. (1980b), is indeed Elberton. However, a much smaller amount of vertical movement could account for the same distribution if these units underly those of the Carolina terrane to the southeast.

The Modoc zone also contains a number of brittle faults nearly parallel to this structure which also contain polydeformational silicic breccias. Based on cross cutting relations with a diabase dike, Secor et al. (1986b) suggest these faults are between 268 and 195 Ma.

Most of the northwesterly brittle faults appear to have relatively minor offset. Symmetric displacement of contacts suggests that the movement is dominantly vertical rather than lateral. A number of these northwesterly faults have also been silicified, thus making them easier to follow. They also show up dramatically on aeromagnetic surveys as the magnetic stratigraphy is offset along these structures. The direction of these northwesterly sets appears to form a conjugate set of fractures. One of these directions is coincident with the common orientation of diabasic dikes. The borders of these mafic dikes also show slickensides in several cases, suggesting minor movement relative to their surroundings after injection.

Due to the parallel nature of the northwesterly set with Mesozoic diabase dikes and the apparent vertical movement, most of the northwest brittle faults are thought to be related to uplift of the Piedmont in Mesozoic to early Tertiary time after the Alleghenian orogeny. The similarity in appearance of the northeasterly faults makes a similar hypothesis attractive for this set, however, we have less age control on this set. Correlation with the brittle faults of the Modoc zone in South Carolina confirm an age of more than 195 Ma. We believe both sets of brittle faults are associated with Mesozoic rifting and uplift of the Piedmont following initial opening of the Atlantic Ocean.

METAMORPHISM

The metamorphic history of the Piedmont is complicated. The exact chronology of early metamorphism is erased by later higher grades which replace the original mineralogy and reset most radiogenic systems. In many cases, what we now observe is the result of the youngest and highest metamorphic grade.

Inner Piedmont

The Inner Piedmont core has been metamorphosed to sillimanite grade with widespread anatexis. Migmatitic gneisses are a dominant lithology with melting occurring wherever the appropriate mineral assemblage was present. Potter (1981) has estimated the peak metamorphic conditions to be approximately 690 to 725°C based on observed melting reactions and stable mineral assemblages. Potter also estimated the peak pressure at above 6 kb., or depths greater than 21 km. However, critical reactions involving staurolite require low oxygen activity. If the oxygen activity were higher (as it might be in non-graphite-bearing volcanic sediments or metaigneous rocks) the temperature could be as low as 640°C and the pressure as low as 4 kb., or a depth of 14 km. The age of peak metamorphism is also not precisely known. Dallmeyer (1978) and Dallmeyer et al. (1981) have estimated that peak metamorphism occurred between 380 and 420 Ma.

The Inner Piedmont flank as described by Griffin (1979) is lower grade than the core. Within the map area little difference in metamorphic grade can be documented. Although sillimanite is uncommon, the compositions are not sufficiently peraluminous to stabilize sillimanite below the second sillimanite isograd. The flank may indeed be somewhat lower in grade, but the lack of diagnostic lithologies makes this rather minor difference in grade hard to document.

Carolina Terrane

The Carolina terrane varies in metamorphic grade from greenschist to upper amphibolite. Anatexis is not widespread but is encountered in areas of highest grade. Areas of greenschist grade metamorphism form two belts previously termed the southern and northern Little River series. These are the regions classically termed Carolina Slate belt. When the metamorphic grade increases to lower amphibolite, the belt has been classically redefined as Charlotte belt. However, in Metasville, Washington East, Tignall, Chennault and several other quadrangles low grade rocks can be mapped continuously from greenschist to amphibolite grade. Thus, the boundary classically defined as Charlotte versus Carolina Slate belt is at least in part a metamorphic gradient, not a fundamental tectonic or terrane boundary. There are important tectonic structures and boundaries within this terrane, but they do not necessarily correspond to the greenschist to amphibolite metamorphic grade.

As metamorphic grade increases in the metavolcanic and metavolcanic-sedimentary lithologies we do not observe the pelitic index minerals due to bulk composition. The two most universally applicable changes are the appearance of oligoclase instead of albite-epidote and the change in amphibole chemistry from actinolite to magnesiohornblende and eventually true hornblende. The first can be documented optically by oil immersion techniques, while the latter requires microprobe analysis. Biotite also replaces chlorite as the dominant mafic phyllosilicate.

Within the aluminous quartz-sericite schists, sillimanite appears as an amphibolite-grade mineral. In samples that contained kyanite at low grade, the transition is accomplished by the replacement of kyanite by muscovite and the conversion of sericite to fibrolite. Thus, the micas form a reaction pathway to convert the kyanite to sillimanite whereas the kinetics of a direct reaction are not favorable. Paris (1976) suggested that paragonite was also present in some of the sericite schists. The breakdown of paragonite to albite plus sillimanite may also contribute to the appearance of sillimanite in these schists. The final result is a quartz-muscovite-sillimanite schist with varying amounts of plagioclase present. High grade metamorphism of mafic volcanics results in the appearance of increasingly calcic plagioclase and a decrease in the abundance of epidote. The amphiboles change systematically in composition. At greenschist grade the dominant amphibole is actinolite. Within lower amphibolite facies, the amphibole becomes more aluminous and is classified as magnesiohornblende according to Leake (1978). By upper amphibolite grade the sodium content increases and the amphibole becomes true hornblende.

Russell Lake Allochthon

Within the study area the Russell Lake Allochthon appears to have only been metamorphosed to greenschist grade conditions. The pyroxenes have been replaced by actinolite, while the olivine has been largely replaced by serpentine and magnetite. The more magnesium-rich units

TABLE 1. SUMMARY OF THE GEOLOGIC HISTORY OF THE MAP AREA

AGE (Ma)	PERIOD	REGIONAL EVENTS	LOCAL EVENTS (approximate order)
0-200		Opening of Atlantic Ocean	Uplift, brittle faulting, erosion.
200-220	early Jurassic or late Triassic	Rifting of Atlantic margin. Rift valleys. Basalt flows.	Diabase dikes; Brittle NE faults; Brittle NW faults; (both with vertical and normal movement).
250-290	Permian	Alleghenian Orogeny	Folding, metamorphism and faulting in the Modoc zone and vicinity. Thrusting of the Russell Lake (ultramafic) sheet. ?broad open folds? ?NW warps?
270-290	Early Perm. to Penn.		Intrusion of Danburg granite.
325	Mississippian		Intrusion of Elberton granite.
?350 380?	Early Miss. to late Devonian	Acadian Orogeny	Ductile deformation, transport toward the northwest. Greenschist grade metamorphism. Intrusion of metagranite.
?425 500?	Silurian to Ordovician	Taconic Orogeny	F2 folds, upright to NW verging. Thrusting of the Carolina terrane causing terrane amalgamation. Maximum metamorphic grade epidot amphibolite to sillimanite. Different grades in different thrust sheets. F1 recumbent nappes, NW verging.
550-600?	Cambrian to late Precambrian		Eruption of Carolina Slate belt volcanics, deposition of the biotite gneiss terrane.
????			Origin of migmatite gneiss terrane.

contain abundant talc, tremolite, and magnesium-rich chlorites. The highly foliated ductiley deformed samples, either at the base of the allochthon or in later ductile zones, are especially rich in talc, tremolite, chlorite, and magnetite. The calcic plagioclase is largely replaced by clinozoisite-epidote solid solutions. Only in the most gabbroic samples is there any metamorphic plagioclase, and this is albite in composition. Therefore, it appears that the Allochthon has been metamorphosed only to greenschist grade, although at this time without more detailed mineral chemistry the exact conditions cannot be determined.

Contact Metamorphism

Contact metamorphism has been observed around many of the late gabbro plutons (Davidson, 1981; Dunnagan, 1986). The gradual increase in metamorphic grade in the vicinity of the Charlotte belt could be called a type of "regional contact metamorphism". In the vicinity of some individual plutons within the Charlotte belt, contact metamorphism can be observed. Salotti and Fouts (1967) reported an occurrence of cordierite in the Metasville quadrangle. Paris (1976) also reported cordierite in a zone of hornfels which we also identified east of the Goshen granite in the northwest corner of the Lincolnton quadrangle. Fouts (1966) noted that no granite could explain his cordierite but his sample comes from the northern extremity of his map area. Our mapping in the northeast corner of the Metasville quadrangle located the extension of the Goshen granite (Thurmond, 1979; Paris, 1976) within a very short distance of Fouts' samples.

Turner (1987) reported andalusite being retrograded to sericite in altered volcanic rocks within the Vesta quadrangle. This occurrence could be associated with a zone of contact metamorphism, but he suggests that the andalusite may be linked with hydrothermal alteration which preceded the metamorphism. The economic implications will be discussed in the chapter on exploration potential.

GEOLOGIC HISTORY

Within the map area, the oldest lithologies may be the migmatitic biotite schists and gneisses of the Inner Piedmont. These units are thought to have formed from metapyroclastic, metavolcanic, and metavolcanic sediments of unknown age. Since they are grossly similar to high grade units in the Carolina terrane, they may be of similar age (Cambrian), but they may also be an older volcanic terrane (late Precambrian). It is not known where these volcanic units originated. Due to the high metamorphic grade there is little evidence of their original setting or age. They could have originated as an island arc off the North American coast, or on the other side of the proto-Atlantic Ocean.

The oldest units in the Carolina terrane are the felsic and mafic metavolcanics including the Lincolnton Metadacite and related lithologies. These are correlated with rocks containing Cambrian fossils in the Carolinas and dated at 550 to 580 Ma and are therefore mainly Cambrian in age. The eruption of the Lincolnton Metadacite was accompanied by basaltic volcanism as demonstrated by the plethora of mafic dikes near the volcanic centers.

The War Hill complex appears to be an old intrusive and extrusive complex. It is possible that it could be older than the rest of the Carolina terrane, but no radiometric ages are currently available. It may be correlative with the Lincolnton event.

The massive metavolcanic sequence was overlain by a time-transgressive sequence of pyroclastic deposits, interlayered with mafic flows and minor volcanic sedimentary units. During metamorphism, these units were transformed into the biotite schists and gneisses of the higher grade Carolina Terrane. The units mentioned above are overlain by argillite and related volcanic sediments. Although no fossils or other age restrictions are available for this upper stratigraphic sequence they are also thought to be Cambrian or lower Ordovician in age.

The volcanic sequence was intruded by synvolcanic diorites and tonalites very nearly synchronous with volcanism. These intrusions include the Heardmont complex, tonalites, quartz porphyries, and diorites. These are thought to correlate with similar intrusions in South Carolina dated at 525 Ma or older. They are therefore also thought to be latest Precambrian to early Ordovician, although no radiometric dates are currently available from the map area. It is entirely possible that some of these units could be younger than currently believed.

Following the volcanic sequence, both terranes were intensively deformed with F_1 recumbent nappes forming in the Inner Piedmont. Similar recumbent nappes may be present in portions of the Carolina terrane, but the intensity of the refolding during F_2 events make documentation difficult. The peak of metamorphic conditions and associated migmatization appears to have followed F_1 folding, but be synchronous with, or slightly precede F_2. Based on projections by other workers the early F_1 deformation is thought be 425 to 500 Ma or so in age.

The F_2 folding event is responsible for most of the attitudes of foliation in the Carolina Terrane and Piedmont flank. These folds are more upright, NW-verging folds which affect both terranes. This deformation is probably associated with the amalgamation of the Inner Piedmont and Carolina terranes. These folds are quickly followed by the intrusion of some of the metagranites, intrusion of gabbros and syenite, and ductile deformation associated with the Middleton-Lowndesville zone. The extensive occurrence of intrusions over the high grade portions of the Carolina Terrane at this time suggests a great deal of crustal melting related to this event. Most of this deformation, metamorphism, and magmatism is probably associated with amalgamation of the Piedmont Terrane and transport toward the Northwest. The same forces responsible for the F_2

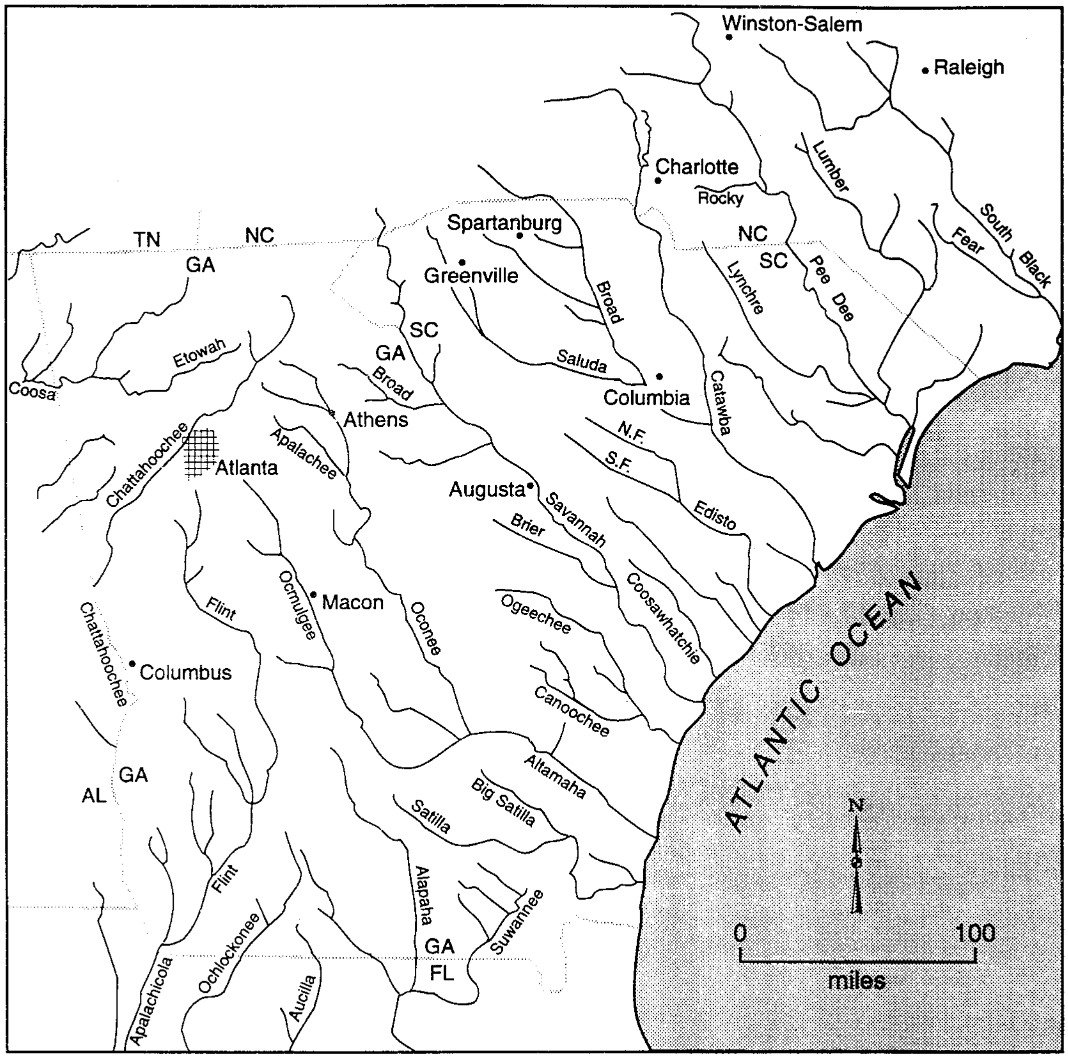


Figure 3. Major drainages of Georgia and the Carolinas.

folds probably caused the ductile deformation along the Middleton-Lowndesville zone. The exact age of these events is not known, however, by correlation with magmatism and deformation further north, it is thought to be between 350 to 425 Ma, or dominantly Siluro-Devonian in age.

The next sequence of events is unclear due to lack of cross-cutting relations or radiometric dates. The Elberton Granite and the Stone Mountain Granite near Atlanta were intruded into the Inner Piedmont approximately 320 Ma. These were followed by the intrusion of coarse grained porphyries at Siloam and Danburg within the Carolina Terrane approximately 270 to 290 Ma.

At a similar time, the Russell Lake Allochthon is thought to have been emplaced. The origin of the allochthon is unknown. It is composed of coarse grained magnesium-rich mafic and ultramafic rocks ranging from peridotite to gabbro. Presumably they were thrust from the southeast during the closing of the Atlantic Ocean. If this event is correlated with the NW-verging folding within the Modoc zone, emplacement would have occurred about 290 Ma. The fact that the thrust sheet is still relatively flat lying suggests that it is relatively young. However, since it is cut by ductile deformation zones which appear to correlate with late stages of movement in the Modoc, it must be at least late Paleozoic in age.

The Modoc zone has a complex history detailed by Secor et al. (1986a, b). We will not repeat their discussions in detail, however, it appears that the Modoc is composed of at least four phases of deformation. North of the Modoc zone, ductile deformation zones are found which correlate with the late stage ductile zones within the Modoc. These clearly cut the Russell Lake Allochthon, the metagranites, and the ductile fabrics of the Middleton-Lowndesville zone.

Subsequent to these events, numerous brittle faults developed in both northwest and northeast orientations. These are steep and at least some have a strong vertical (dominantly normal) component. Others, such as the brittle fault in the western edge of the Middleton-Lowndesville zone, may have a right-lateral component. However, without diagnostic evidence it is hard to quantify the relative motion at this time. It is thought that both sets of brittle faults may date from the uplift associated with the breakup of Pangea during the early Mesozoic.

At a similar time, diabasic dikes were injected throughout the southern Appalachians. Within the map area, most are oriented in a northwesterly direction, paralleling one set of brittle faults. Massive quartz veins are also found following these orientations.

Following the initial rifting of the Atlantic Ocean, continental sediments were laid down in stream channels and flood plains on the developing erosion surface. Some small remnants of these are found and are generally assigned to the Cretaceous, although some could be as old as Triassic or as young as Tertiary.

Subsequent erosion and deep weathering in a subtropical environment has produced the current deeply weathered surface. However, there is evidence in the deeply incised nature of the drainages that recent uplift has rejuvenated most drainage systems. In addition, a number of major rivers do not seem to follow underlying structures but seem to be inherited (Fig. 3). It is likely that these major drainages established their ancient channels in some overlying unstructured material and then cut down into the underlying lithologies in relatively recent geologic time. This overlying material could have either been extensive sedimentary deposits formed before renewed uplift, or it could have been the Russell Lake Allochthon which appears to have overlain much of the Carolina Terrane. If a significant section of ultramafic to mafic allochthon has been removed from this entire section of the Piedmont there should be a record of it in the sediments being transported to the coastal plain during the Tertiary period.

EXPLORATION POTENTIAL

The mapping for this project was done to provide a geological map to potential users of geological information. The exploration geologist searching for gold or/and base metal deposits was much in our mind as we mapped this area. The mapping of the early seventies followed introduction of the volcanogenic theory of ore deposits which was popularized in the Canadian Shield (Hutchinson, 1965; Gilmour, 1965), and which was consistent with the newly proposed theory of plate tectonics. The immense success of these two theories led to numerous spectacular Canadian discoveries. Unfortunately, the same success was not achieved in the Slate belt of Georgia. Carpenter and colleagues working for Conoco did find ample evidence of metaexhalites and mineralized zones within the volcanic lithologies of the Slate belt, especially on the fringes of the Lincolnton metadacite center. Many of these were in areas of old showings rediscovered in the rolling pine-covered forests of Georgia and South Carolina. One has to understand that prospectors and farmers in the late 19th century and early 20th century plowed the ground for cotton farming and thus located innumerable quartz veins, gossanous zones, and silicified breccias which are now completely hidden in the midst of the pine forests of northeast Georgia.

The Slate belt of the Carolina terrane, as described above, is predominantly a volcanic belt centered on the Lincolnton dacite volcanic center. The dacitic complex is surrounded by dacitic pyroclastics, lithic-lapilli tuffs, lithic tuff breccias, andesitic tuff breccias, minor argillites, and thin exhalite horizons. The Charlotte belt is composed of the same volcanic assemblage metamorphosed to a higher grade of metamorphism by the intrusion of a multitude of plutonic complexes described above. The Inner Piedmont contains the same lithologies metamorphosed to the sillimanite grade. Thus the whole map area is underlain by volcanic protoliths and we feel confident that the area deserves as much attention from explorationists as other volcanic belts in the Canadian, African, and Australian shields. The major difference lies in the ubiquitous mantle of soils and deep saprolite which makes the task of geologi-

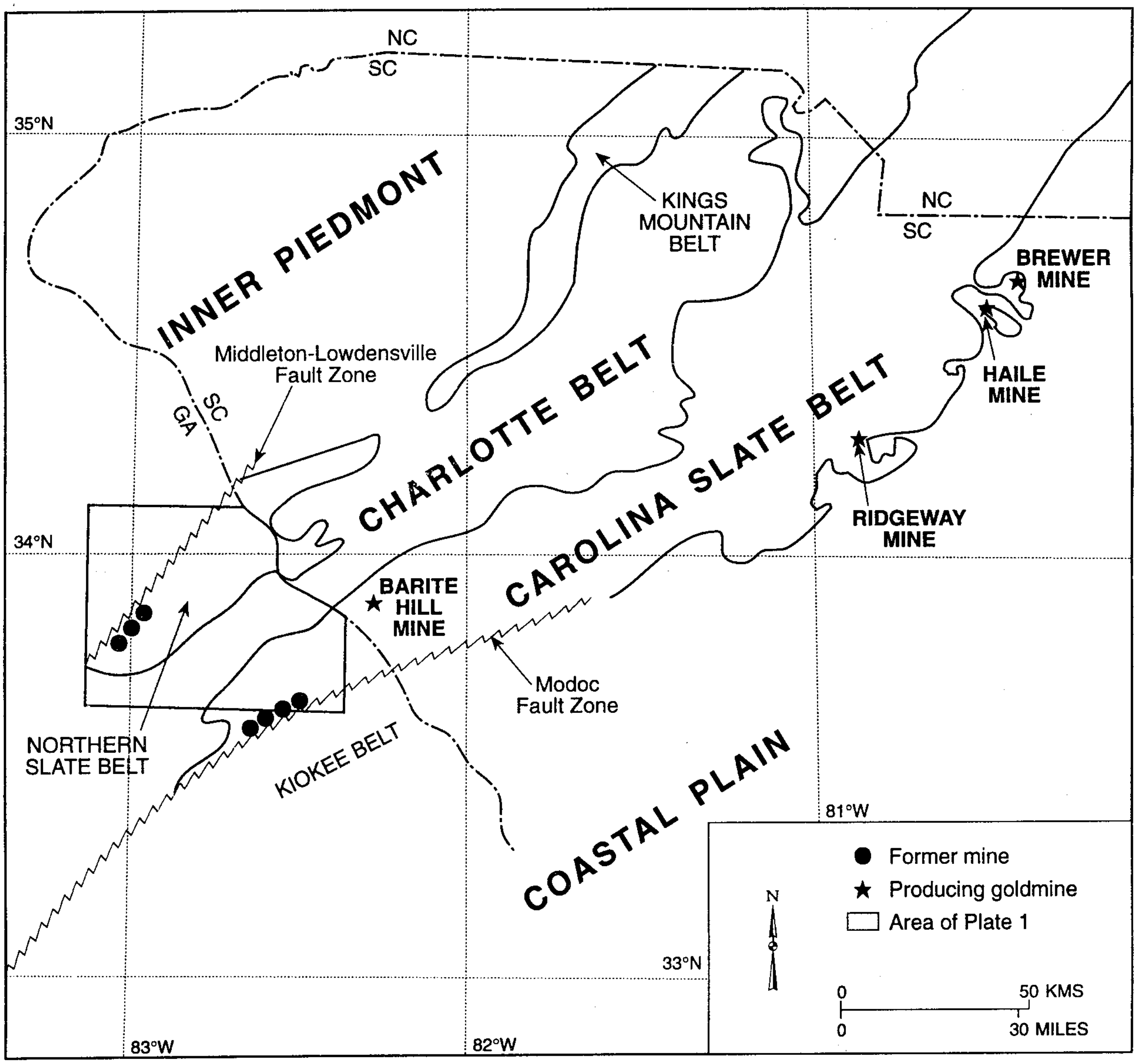


Figure 4. Index map of producing gold mines in South Carolina and old prospects in the area of Plate 1.

cal mapping and geophysical surveys much more difficult. Carpenter (1971) and many others have demonstrated the usefulness of geochemical surveys using stream sediments, soil samples, and manganese coatings commonly found on stream pebbles and stream outcrops.

Geological Units of Special Interest

Numerous academic studies and mineral discoveries of the last twenty years have demonstrated the fact that metamorphism does not affect the bulk chemistry of protoliths, whether they are volcanic rocks, alteration systems, or massive sulfides. Allard and Carpenter (1988) have demonstrated, from the example of Graves Mountain (kyanite deposit) in Lincoln county (northeast corner of Aonia quadrangle), that alteration haloes around ore deposits are zones depleted in Na and Ca, and enriched in Si, Mg, K, and metals. The hydrothermal synvolcanic alteration of glassy (aphyric or porphyritic) rocks depletes the rock in Na and Ca and thus enriches the residual rock in Al_2O_3 and TiO_2. The feldspar phenocrysts and the glassy matrix are completely leached to clays (Hayashi and Yamasaki, 1976) and the metals circulating in the hydrothermal system (Cu, Pb, Zn, Au, Ag, Ba, Mn, Ti) are adsorbed by the spongy clay-rich mixture. The circulation of the hydrothermal solutions can leach the rocks at the focal point of solution egress (a black smoker equivalence) after having picked up quantities of metals on their path through the volcanic pile. This creates a seafloor proximal metal deposit lying on a stockwork of altered rocks. This model has been reproduced in so many textbooks that it is not necessary to reproduce it here.

A modification of this model suggests the formation of a silica cap or a silica barrier within the system which then forces the circulating solutions to pond under the impermeable cap. This produces an intensely altered zone focused under the cap, not necessarily connected to the punctual seafloor smoker. A permeable volcaniclastic horizon of crystal tuff, partly altered by seafloor reactions, would be an ideal porous media for this system to function.

The protolith thus created is a silica-rich rock overlying and surrounded by a clay-rich rock. Metamorphism will convert the silica-rich rock to a quartz granofels (improperly called quartzites by most field geologists) and the clay-rich rocks to an aluminosilicate complex dependent on the grade of metamorphism. The adsorbed metals are incorporated in a number of rare minerals like hogbomite, nigerite, staurolite, gahnite, sapphirine, and many others (Allard and Carpenter, 1988).

Horizons described above are common in the map area; sillimanite quartz muscovite schists in the Inner Piedmont, identical mineralogy in the Charlotte belt (with or without kyanite or andalusite as possible marker minerals instead of sillimanite), and sericite schists in the Slate belt. The omnipresent pyrite gives a distinctive purplish color to the saprolite. The mineralogy of these horizons is highly variable over short distances along and the across strike reflecting the vagaries of hydrothermal alteration processes; the rocks vary from pure quartz to nearly pure aluminosilicate or muscovite and/or sericite. These altered rocks are identical to the host rocks of a number of gold mines throughout the world, including the producing gold mines in South Carolina, on strike with the rocks mapped in our area, and a very short distance away (Fig. 4).

An examination of old maps and mining records of the area reveal a number of former mines and showings along the horizons just described, a clear indication that they should be explored in detail. The thickness of the units are exaggerated on the map (Plate 1) for obvious reasons since they are generally just a few feet thick. We strongly recommend a combination of detailed geological mapping, soil geochemical surveys, and diamond drilling these horizons for gold and/or base metals. The Hemlo case history (Quartermain, 1985) suggests the need for patience and perseverance. The difficulties in forecasting the location of gold deposits is well illustrated in Hemlo where an excellent outcrop of rusty pyrite-bearing exhalites occurring on the Trans-Canada Highway attracted the attention of hundreds of geologists to no avail. Seventy six holes were drilled before the Teck-Corona Main zone was located, a short distance away from this famous, highly visible, barren outcrop.

Recommendations

The areas underlain by the aluminosilicate horizons should be mapped in more detail and geochemical surveys should be done along these units. All samples of felsic volcanics within or adjacent to these alteration zones should be routinely analysed for Na_2O. The occurrence of Na_2O-depletion haloes around ore deposits is well substantiated (Hashimoto, 1977). Many Canadian exploration companies have enough faith in the method to analyze all their samples for Na_2O and to drill any anomalous areas. As an example, Davidson (1981, page 143) reports two samples (analyses 1 and 3, table 23) showing Na_2O of 0.03 and 0.00. The area where these samples were collected clearly deserves detailed scrutiny. The same could be done with all the analyses reported in the theses shown in the Appendix. It is important to remember that this depletion does not always give usable external characteristics to the rocks, which may look very normal. This exploration can be done for base metals (Cu, Pb, Zn) or for gold.

McDuffie Gold Belt

The McDuffie gold belt (Hurst et al., 1966) lies immediately south of the map area with its northeast extremity in the southwest corner of the Woodlawn quadrangle and in the southeast corner of the Aonia quadrangle. We have not studied this belt but the following comments may be pertinent to explorationists.

The South Aonia pluton, described earlier, is unique within the map area for the large number of shear zones and quartz veins which crisscross the pluton in many directions.

The gold is reported to be hosted by the quartz veins which are either in the pluton itself or in the host rocks at the contact with the pluton. The intense fracturing of this granite is linked to its presence within a short distance of the Modoc fault zone. The gold could have originally resided in the exhalative horizon of the Modoc zone seen in the extreme southeast corner of the map area (cherts and muscovite quartz schists) or could come from other lithologies in the Kiokee belt. The gold was mobilized along the ductile shear zones of the Modoc as proposed in the model of Colvine (1989) and Groves et al. (1989). The pluton was emplaced in a belt of argillites and intermediate pyroclastic lithologies and acted as a resistant buttress in front of the colliding Modoc fault block.

Recommendations

The South Aonia granitoid body is mostly under the waters of Clark Hill Lake creating a most difficult situation for mining and exploration from a physical and environmental standpoint. However, the pluton extends to the southwest in Wrightsboro and Cadley quadrangles away from the lake. The area underlain by the pluton and the host rocks in the vicinity of the pluton should be thoroughly drilled. One difficulty lies in the determination of the prevalent direction of the gold-bearing quartz veins which is essential for a productive drilling campaign. A study of old records would be a first step.

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APPENDIX

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Dunnagan, William B., 1986: The geology of the Washington West 7 1/2' Quadrangle, Georgia, [M.S. thesis]: Athens, University of Georgia, 152 p.

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Rozen, Robert W., 1978: The geology of the Elberton East Quadrangle, [M.S. thesis]: Athens, University of Georgia, 110 p.

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Turner, William L., 1987: The geology of the Vesta 7 1/2' Quadrangle, Georgia, [M.S. thesis]: Athens, University of Georgia, 204 p.

Von Der Heyde, Wolfgang, 1990: Geology of the Washington East 7 1/2' Quadrangle, Wilkes County, Georgia, [M.S. thesis]: Athens, University of Georgia, 130 p.

Wells, Douglas E., 1983: Geology and petrochemistry of the Rock Branch Quadrangle, Elbert County, Georgia, [M.S. thesis]: Athens, University of Georgia, 163 p.

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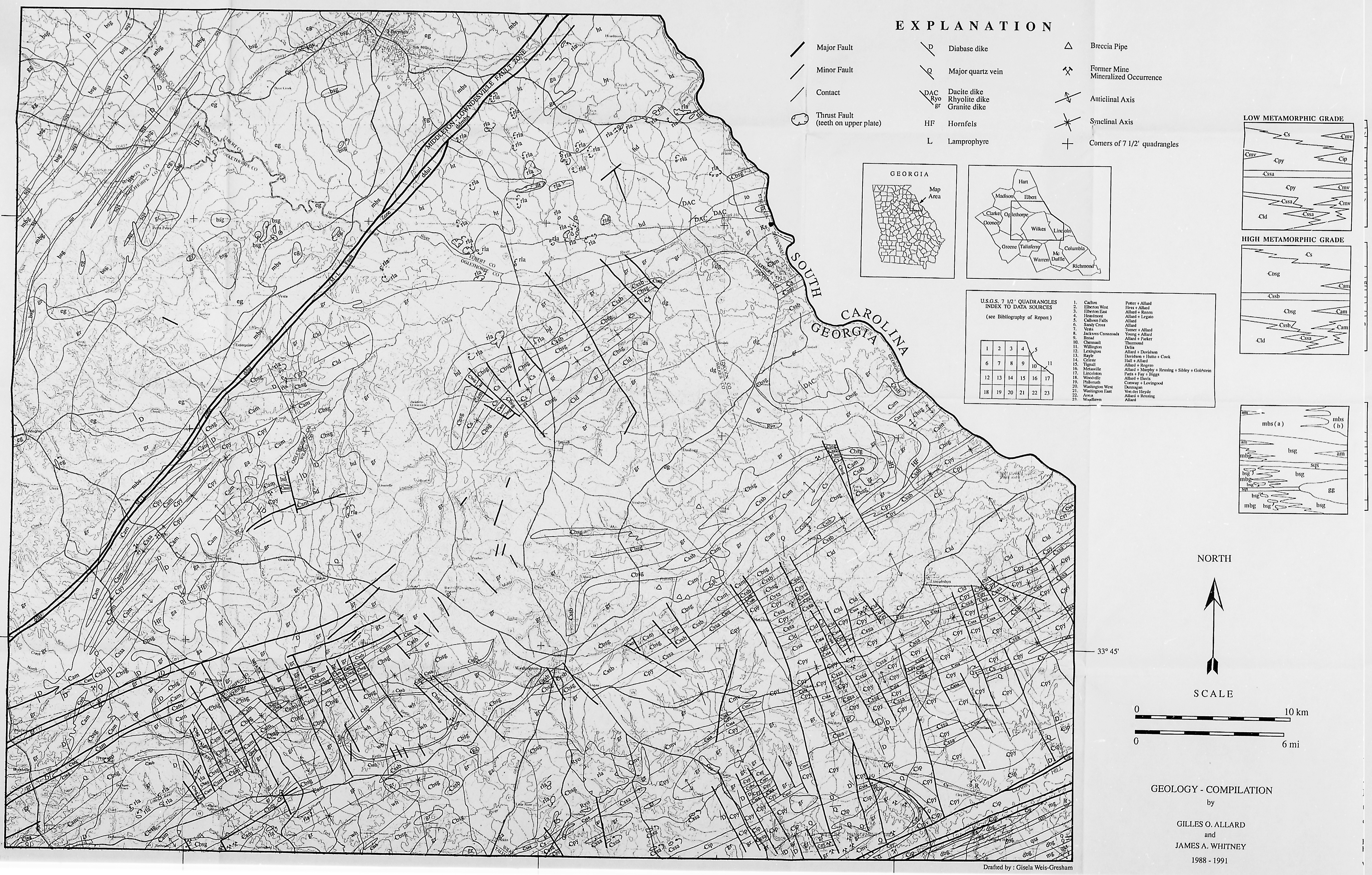
GEOLOGIC MAP OF INNER PIEDMONT, CAROLINA TERRANE, AND MODOC ZONE - NORTHEAST GEORGIA



GEOLOGY - COMPILATION
by
GILLES O. ALLARD
and
JAMES A. WHITNEY
1988 - 1991

EXPLANATION

CRETACEOUS (?) DEPOSITS

Ks Conglomeratic Cretaceous (?) sediments.

RUSSELL LAKE ALLOCHTHON

rla Allochthonous metaperidotite, metapyroxenite, and metagabbros.

MODOC FAULT ZONE

mg Ductiley deformed migmatitic granite

qss Ductiley deformed quartz-sillimanite-sericite schist.

dbg Ductiley deformed migmatitic biotite gneiss and amphibolite.

MIDDLETON-LOWNDESVILLE FAULT ZONE

ddul Ductily deformed undifferentiated lithologies

ddmbs Ductily deformed megacrystic schists

ddgr Ductily deformed granite

CAROLINA TERRANE

Ꞓs Sedimentary sequence. Argillites with interlayered mafic volcanics and volcanic sediments.

Ꞓip Intermediate composition pyroclastic unit. Composed of pyroclastic tuff and tuff breccias of andesitic compositions.

Ꞓssa Sericite schist. Pyritiferrous quartz-sericite schists formed from hydrothermally altered pumice lapilli tuff and pumiceous tuffs minor chert and iron formation.

Ꞓssb Sillimanite schist. Pyritiferrous quartz-muscovite-sillimanite schist. Higher grade equivalent of Cssa.

Ꞓpy Meta pyroclastic sequence. Felsic pyroclastic lithologies including vitric tuffs, crystal tuffs, lithic lapilli tuffs, tuff breccias, and sericitic tuffs. Interlayered mafic volcanics, cross-cutting mafic and felsic dikes are common.

Ꞓbsg Biotite schists and gneisses. Undifferentiated biotite schists, mica schists, and interlayered amphibolites. Higher grade equivalent of Cpy.

Ꞓmv Mafic meta volcanics. Basaltic to andesitic in compositions. Pillow structures common, occasionally containing relict vesicles.

Ꞓam Amphibolite. High grade equivalent of Cmv.

Ꞓld Lincolnton metadacite. Complex dacitic center composed of porphyritic dacitic flows and quartz porphyry stocks and dikes.

INNER PIEDMONT

INNER PIEDMONT FLANK

mbs Biotite schists and megacrystic microline biotite gneiss. (a) Biotite schists and gneisses cut by (b) megacrystic biotite gneiss of probably intrusive origin containing microcline megacrysts. Ductily deformed in proximity of the Middleton-Lowndesville zone. Amphibolite horizons also prevalent (undifferentiated on map).

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gg Granitic orthogneiss, age unknown.

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POST-KINEMATIC PLUTONS (MISSISSIPPIAN - PENSYLVANIAN ?)

dg Danburg Granite. Coarse grained biotite granite.

eg Elberton Granite. Fine grained, homogeneous, biotite granite.

SYN-KINEMATIC PLUTONS (SILURIAN - DEVONIAN ?)

gr Granite. Differentiated, highly variable biotite granodiorite to granite. Commonly containing numerous cross-cutting phases.

ds Delhi Syenite. Hornblende syenite containing minor amounts of fayalite and calcic clino-pyroxene.

ga Gabbro.

PRE-KINEMATIC PLUTONS (CAMBRIAN ?)

to Hornblende tonalite.

di Hornblende diorite to quartz diorite.

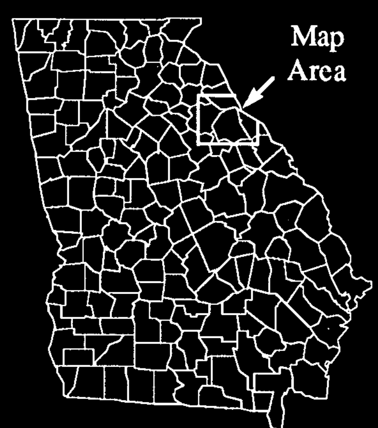
Heardmont Complex
ht Hornblende tonalite
hd Hornblende meladiorite to quartz diorite.

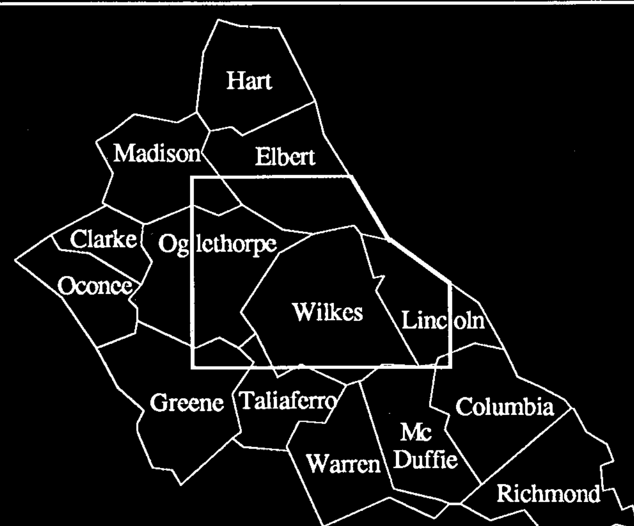
wh War Hill intrusive center, dominantly tonalite to quartz porphyry.

EXPLANATION

Major Fault	D Diabase dike	Breccia Pipe
Minor Fault	Q Major quartz vein	Former Mine Mineralized Occurrence
Contact	DAC Dacite dike Ryo Rhyolite dike gr Granite dike	Anticlinal Axis
Thrust Fault (teeth on upper plate)	HF Hornfels	Synclinal Axis
	L Lamprophyre	Corners of 7 1/2' quadrangles

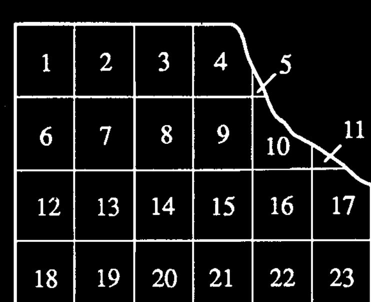
GEORGIA





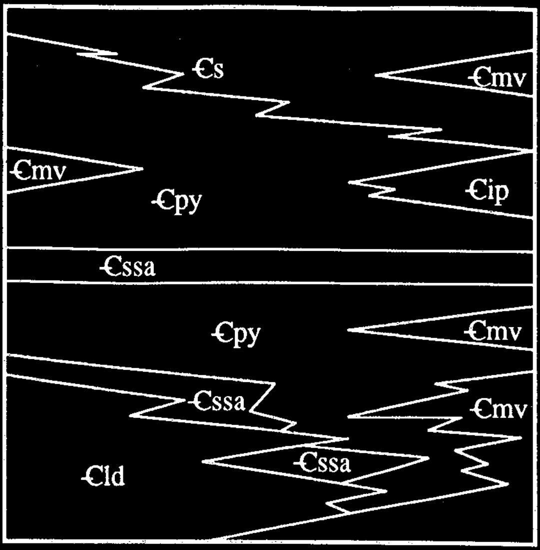
U.S.G.S. 7 1/2' QUADRANGLES
INDEX TO DATA SOURCES

(see Bibliography of Report)

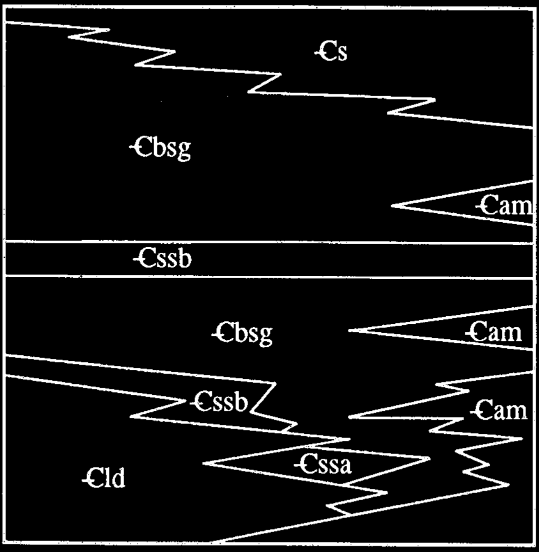


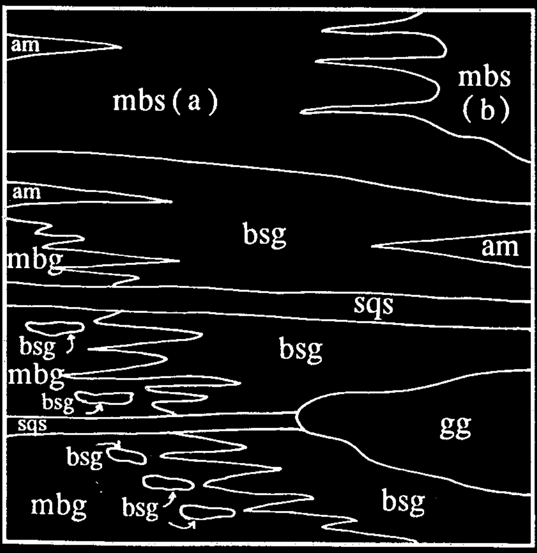
1.	Carlton	Potter + Allard
2.	Elberton West	Hess + Allard
3.	Elberton East	Allard + Rozen
4.	Heardmont	Allard + Legato
5.	Calhoun Falls	Allard
6.	Sandy Cross	Allard
7.	Vesta	Turner + Allard
8.	Jacksons Crossroads	Young + Allard
9.	Broad	Allard + Parker
10.	Chennault	Thurmond
11.	Willington	Delia
12.	Lexington	Allard + Davidson
13.	Rayle	Davidson + Hutto + Cook
14.	Celeste	Hall + Allard
15.	Tignall	Allard + Rogero
16.	Metasville	Allard + Murphy + Reusing + Sibley + Goldstein
17.	Lincolnton	Paris + Fay + Biggs
18.	Woodville	Allard + Davis
19.	Philomath	Conway + Lovingood
20.	Washington West	Dunnagan
21.	Washington East	Von der Heyde
22.	Aonia	Allard + Reusing
23.	Woodlawn	Allard

LOW METAMORPHIC GRADE



HIGH METAMORPHIC GRADE





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