The Structure, Stratigraphy, Tectonostratigraphy, and Evolution of the Southernmost Part of the Appalachian Orogen

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By MICHAEL W. HIGGINS, ROBERT L. ATKINS, THOMAS J. CRAWFORD, RALPH F. CRAWFORD, III, REBEKAH BROOKS, *and* ROBERT B. COOK

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CONTENTS

	Page
Abstract	1
Introduction	2
Previous concepts	5
Acknowledgments	10
Georgiabama thrust stack	10
Bill Arp thrust sheet	10
Ducktown assemblage	28
Zebulon thrust sheet	28
Wolf Creek Formation	31
Clairmont thrust sheet	31
Wahoo Creek thrust sheet	33
Atlanta thrust sheet	34
Promised Land thrust sheet	37
Sandy Springs thrust sheet	39
Paulding thrust sheet	41
West Point thrust sheet	45
Ropes Creek thrust sheet	52
Hillabee greenstone (informal)	53
Soapstone Ridge thrust sheet	55
Little River thrust stack	57
Little River allochthon	57
Macon melange	58
Potato Creek and Juliette slices	62
Po Biddy slice	65
Northern Florida platform sequence	65
Structure	67
Modoc zone	71
Metamorphism	71
Paleogeographic reconstruction	71
Unresolved problems	72
Rome-Kingston thrust stack	72
Chickamauga terrane	72
Kingston thrust sheet	73
Clinchport thrust sheet	79
Rome thrust sheet	79
Rockmart Slate, Athens Shale, Tellico Formation, and Talladega Group	79
Rockmart Slate, Athens Shale, and Tellico Formation	79
Talladega Group	82
Previous thrust concepts	86
The "Hayesville thrust fault"	87
Thrusting	88
Thrusting within the Georgiabama thrust stack	89
Metamorphism and deformation	92
The Brevard Zone	94
Plutonism	96
Cambrian (and Ordovician?) plutons	98
Silurian-Devonian plutons	98
Carboniferous plutons	99
Evolution of the southernmost Appalachians	100
Phase I: Opening of the Iapetus Ocean	100
Phase II: Closing of the Iapetus Ocean—The Iapetan orogeny	101
Comparison with the northern Appalachians	104
Comparison with the Indonesian region	105
References cited	108
Appendix A.—Stratigraphic nomenclature	124
Chickamauga terrane and Kingston, Clinchport, and Rome thrust sheets	124
Chilhowee Group	124
Conasauga Group	124
Chickamauga Group and Supergroup	124
Bill Arp thrust sheet	125
Grenville basement rocks	125
Allatoona Complex (named), Corbin Gneiss (revised and adopted), Red Top Mountain Schist (named), Fort Mountain and Salem Church Gneisses (abandoned), Cohutta Schist (abandoned)	125
Wacoochee Complex (adopted)	126
Apalachee Formation (named)	126
Great Smoky Group	126
Frolona and Bill Arp Formations (adopted)	126
Ola and Kalves Creek Formations (named)	127
Richard Russell Gneiss (revised)	127
Pine Mountain Group (revised)	128
Zebulon thrust sheet	128
Zebulon Formation (named)	129
Senoia Member of the Zebulon Formation (revised)	129
Atlanta thrust sheet	129
Ison Branch and Barrow Hill Formations (named)	130
Sandy Springs thrust sheet	130
Dog River Formation (abandoned)	130
Andy Mountain Formation (abandoned)	130
Tallulah Falls Formation (restricted)	130
Paulding thrust sheet	131
Paulding Volcanic-Plutonic Complex (named)	131
Waresville Amphibolite or Formation (abandoned)	131
Pumpkinvine Creek Formation (abandoned)	131
Ropes Creek thrust sheet	131
Ropes Creek Metabasalt (revised)	132
Mud Creek Formation (abandoned)	133
Cedar Lake Member (revised)	133
Villa Rica Gneiss (revised) and Mulberry Rock Gneiss (abandoned)	133
Univeter Formation (abandoned)	134
Canton Schist or Formation (abandoned), Cherokee alteration zone of the Ropes Creek Metabasalt (informally named)	134
Hillabee greenstone (informal)	135
Appendix B.—Geochemistry	137
Bill Arp thrust sheet	137
Paulding thrust sheet	137
Ropes Creek thrust sheet	138
Soapstone Ridge thrust sheet	139

ILLUSTRATIONS

Page

PLATE 1. Generalized geologic-tectonic map of the southernmost part of the Appalachian orogen, Georgia and Alabama .... In pocket
2. Schematic diagrams illustrating the evolution of the southernmost part of the Appalachian orogen, Georgia and Alabama .... In pocket

FIGURE 1. Stacking order of tectonostratigraphic units and thrust sheets 3
2. Generalized geologic map of the Atlanta, Ga., and Griffin, Ga. 1° × 30′ quadrangles 6
3. Map showing present known distribution of autochthogenetic rocks and allochthogenetic rocks in the southernmost Appalachians 9
4. Map showing present known distribution of the Bill Arp thrust sheet 16
5. Map showing present known distribution of Grenville basement in the southernmost Appalachians 17
6. Photographs showing graded beds in the Bill Arp Formation in the Austell-Frolona anticlinorium 20
7. Photograph showing calcareous concretions in metagraywacke in the upper part of the Bill Arp Formation 21
8. Generalized geologic map of the Pine Mountain anticlinorium 24
9. Photographs of rock samples of the Ducktown assemblage 29
10. Map showing present known distribution of the Zebulon thrust sheet 30
11. Photograph showing exotic block of amphibolite in schist of the Zebulon Formation 31
12. Map showing present known distribution of the Clairmont thrust sheet 32
13. Photographs showing blocks in the Clairmont melange 33
14. Photographs showing structures in blocks in the Clairmont melange 34
15. Photographs showing structural styles in the Clairmont melange 35
16. Map showing present known distribution of the Wahoo Creek thrust sheet 36
17. Photograph showing slabby-weathering, finely layered gneiss in the Wahoo Creek Formation 37
18. Photograph showing finely laminated, metamorphosed calcareous tuff with calc-silicate and epidote-amphibolite layers in the Wahoo Creek Formation 37
19. Map showing present known distribution of the Atlanta thrust sheet 38
20. Photographs showing metamorphosed calcareous tuffs in the Ison Branch Formation 39
21. Map showing present known distribution of the Promised Land thrust sheet 40
22. Photograph showing interlayered mafic and felsic tuffs of the Promised Land Formation 41
23. Map showing present known distribution of the Sandy Springs thrust sheet 42
24. Photographs showing the Sandy Springs thrust fault 43
25. Map showing present known distribution of the Paulding thrust sheet 44
26. Photograph showing typical exposure of the Paulding Volcanic-Plutonic Complex 45
27. Map showing present known distribution of the West Point thrust sheet 46
28. Photograph of a block of altered ultramafic rock in scaly schist of the West Point melange 47
29. Photograph of a sample of amygdular metabasalt from large slab in the West Point melange 47
30. Photographs of matrices and blocks in the West Point melange 48
31. Photographs of eclogite clasts in the West Point melange 50
32. Map showing present known distribution of the Ropes Creek thrust sheet 51
33. Photographs showing pillow basalts in the Ropes Creek Metabasalt 52
34. Photographs showing metavolcanogenic iron formations and manganiferous schists in the Ropes Creek Metabasalt 53
35. Photograph showing deformed magnetite-garnet-chlorite schist from the West Point melange 54
36. Map showing present known distribution of the Soapstone Ridge thrust sheet 56
37. Photograph showing Soapstone Ridge thrust fault at base of Soapstone Ridge Complex 57
38. Photographs showing slices of Soapstone Ridge thrust sheet rocks structurally emplaced with Corbin Gneiss in the Allatoona Complex 58
39. Generalized geologic map of the Macon melange and Little River allochthon 59
40. Photographs showing matrices in the Potato Creek and Juliette slices of the Macon melange 64
41. Photographs showing structural discontinuities in the Macon melange 66
42. Photographs showing exotic blocks in the Macon melange 68
43. Generalized geologic map of the Gladesville-Juliette area in central Georgia as depicted by Matthews (1967), Prather (1971), Carpenter (1971), and Georgia Geological Survey (1976) 70
44. Generalized geologic map of the Gladesville-Juliette area in central Georgia as depicted by our mapping 70
45. Photograph showing rounded clast of metagabbro in the Macon melange 70
46. Photograph showing centimeter-scale, disrupted igneous layering in a mafic slab in the Juliette slice of the Macon melange 70
47. Photograph showing finely laminated, chloritic, graphitic, and pyritiferous marble in the Po Biddy slice of the Macon melange 71
48. Photograph showing polymictic conglomerate from the Tellico Formation above the Rockmart Slate 80
49. Photographs showing dark graptolitic Middle Ordovician Rockmart Slate resting in sharp contact upon Middle Ordovician Lenoir Limestone 82
50. Diagram illustrating approximately along-strike changes in the Tellico-Talladega clastic wedge 85

FIGURE 51. Photographs of the Carters Dam fault zone at Carters Dam 90
52. Map showing distribution of major groups of granitic plutons in the southernmost Appalachians 97
53. Photographs showing xenoliths of Bill Arp Formation metagraywackes in Austell Gneiss 99
54. Map showing the Indonesian region and most of the southern Appalachians at the same scale 106
55. Photograph showing sheared Grenville basement gneiss (Woodland Gneiss) in the Pine Mountain anticlinorium 128
56. Map showing the location of the type section of the Paulding Volcanic-Plutonic Complex 132
57. Data from rocks of the Paulding Volcanic-Plutonic Complex and the Hillabee dacites 163
58. Data from the Ropes Creek Metabasalt 166
59. Data from rocks of the Soapstone Ridge thrust sheet, the Ropes Creek Metabasalt, and ultramafic rocks associated with the Ropes Creek Metabasalt 173

TABLES

Page

TABLE 1. Summaries of thrust sheets in the Georgiabama thrust stack 11
2. Stratigraphic units and depositional correlations in the Great Smoky and Pine Mountain Groups of the Ocoee Supergroup in Georgia 18
3. Summaries of thrust sheets in the Little River thrust stack 60
4. Stratigraphic units in the Chickamauga terrane and Rome-Kingston thrust stack in Georgia and in Alabama 74
5. Summaries of thrust sheets in the Rome-Kingston thrust stack 76
6. Summary of the Chickamauga terrane 78
7. Major-oxide and normative-mineral compositions, trace-element abundances, and rare-earth-element abundances in the Corbin Gneiss 140
8. Major-oxide and normative-mineral compositions, trace-element abundances, and rare-earth-element abundances in graphitic schists and phyllites from the Ocoee Supergroup in the Bill Arp thrust sheet in Georgia 146
9. Major-oxide and normative-mineral compositions, trace-element abundances, and rare-earth-element abundances in rocks from the Paulding Volcanic-Plutonic Complex 150
10. Major-oxide and normative-mineral compositions, trace-element abundances, and rare-earth-element abundances in the Ropes Creek Metabasalt 152
11. Major-oxide and normative-mineral compositions, trace-element abundances, and rare-earth-element abundances in rocks from the Soapstone Ridge thrust sheet 157

THE STRUCTURE, STRATIGRAPHY, TECTONOSTRATIGRAPHY, AND EVOLUTION OF THE SOUTHERNMOST PART OF THE APPALACHIAN OROGEN

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ABSTRACT

The southernmost part of the Appalachian orogen in Georgia and Alabama is composed of three stacks of folded thrust sheets. The crystalline part of the orogen (including rocks now covered by the Coastal Plain) is composed of two thrust stacks, the (lower) Georgiabama thrust stack and the (upper) Little River thrust stack. Together with the Rome-Kingston thrust stack in the Valley and Ridge province, these thrust stacks preserve sequences of rocks formed in a wide variety of environments that virtually spanned the ancient Iapetus Ocean. The lowest thrust sheet in the Georgiabama stack preserves sequences of rocks considered autochthogenetic (allochthonous but derived from or otherwise genetically related to a given craton) to the North American craton, whereas higher thrust sheets in the stack preserve sequences considered allochthogenetic (allochthonous and unrelated to a given craton) to the North American craton. Sequences preserved in the Little River thrust stack are allochthogenetic to the North American craton and autochthogenetic to the African craton; in the Georgiabama thrust stack all but the Bill Arp sheet are allochthogenetic to the North American craton; and all of the rocks in the Rome-Kingston thrust stack are autochthogenetic to the North American craton.

Assembly (stacking) of the Georgiabama thrust stack took place from the Iapetus Ocean toward the North American craton, and from top to bottom, with the first-moving, uppermost thrust sheets travelling the farthest and the later moving, lowermost sheets travelling the least. In contrast, the Little River stack appears to have been assembled from bottom to top as its sheets were being thrust upon the already assembled and moving Georgiabama stack. Thrusting took place continuously from about Middle Ordovician through Carboniferous time, and virtually all of the folding and deformation in the southernmost Appalachians were caused by the thrust sheets and thrust stacks moving toward the North American craton. Most of the metamorphism and plutonism in the southernmost Appalachians was the result of the insulating blanketing effects, the overpressures, and depths of burial caused by the moving thrust sheets and thrust stacks. Thrust sheets with different deformational and metamorphic histories are juxtaposed within the thrust stacks.

The Georgiabama thrust stack is composed of 11 major thrust sheets. The uppermost thrust sheets (Soapstone Ridge and Ropes Creek) are obducted sheets of Iapetus Ocean mantle and crust. These sheets overlie remnants of an ophiolitic, eclogite-bearing subduction melange (West Point), which in turn overlies remnants of its associated oceanic (Paulding) island arc in the Paulding thrust sheet. The Paulding sheet overlies remnants of another (Promised Land) island arc and its fore-arc-basin deposits (Sandy Springs, Promised Land, Atlanta, and Wahoo Creek), with its associated subduction melange (Clairmont). Quartzites in some of the Sandy Springs sheet rocks have detrital zircons with ages of a billion years or older, indicating that the Promised Land arc formed at the edge of a (Sandy Springs) microcontinent. Structurally beneath the Clairmont sheet is the Zebulon thrust sheet, composed of ocean-floor deposits with large contributions from the Ocoee basins and from the Promised Land arc. The lowest sheet in the Georgiabama stack is the autochthogenetic Bill Arp sheet, composed of nonvolcanic, mostly clastic, and poorly sorted metasedimentary rocks deposited in a series of stepped, extensional basins (called Ocoee basins because most of the rocks that fill them belong to the Ocoee Supergroup) formed when the Iapetus Ocean opened; the Ducktown assemblage of volcanic rocks and mafic hypabyssal intrusive rocks in the lowermost part of the clastic sequence was intruded into, and erupted from, rifts around the basin edges; massive sulfide deposits are locally found associated with the assemblage.

The Little River thrust stack is composed of the (structurally lowest to highest) Macon melange, Little River allochthon, and Northern Florida platform sequence. The Little River allochthon is composed of thick sequences of mildly metamorphosed and mildly deformed volcanic, volcaniclastic, volcanic-epiclastic, and lesser amounts of plutonic rocks of latest Precambrian (Late Proterozoic) through Middle Cambrian age that formed in a continental-margin island arc; the igneous rocks are bimodal and calc-alkaline. Atlantic faunal province trilobites in some of the epiclastic rocks indicate that the continental mass where the Little River arc formed was not near North America; it may have been a microcontinent off the African continent. The arc's subduction melange, the Macon melange, is well preserved structurally beneath the Little River allochthon. The Macon melange contains pelagic cherts, manganiferous schists, and clasts of various sizes of Iapetus Ocean crust and upper mantle. Above the Little River allochthon in the subsurface of southernmost Georgia and northern Florida is the Northern Florida platform sequence, composed of fossiliferous unmetamorphosed clastic rocks of

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Ordovician through Devonian age that are interpreted as having been deposited at the edge of the African craton.

The (lowest to highest) Kingston, Clinchport, and Rome thrust sheets, in the Valley and Ridge province, make up the Rome-Kingston thrust stack. These sheets include the Appalachian Cambrian-Ordovician carbonate-shelf sequence and, in the Rome, dark pelites (Athens Shale and Rockmart Slate) that were thrust upon the carbonate-shelf sequence and the Tellico-Talladega clastic wedge bearing clasts of Grenville basement rocks and carbonate-shelf-sequence rocks that spread towards the craton beyond the limits of the dark pelites. All three sheets have upper Ordovician-Silurian clastic wedges that spread cratonward from the advancing thrust sheets in the Georgiabama stack, and Devonian cherts deposited unconformably upon the older rocks.

The earliest record in the southern Appalachians of the opening of the Iapetus Ocean is the thick pile of volcanic and immature clastic rocks that make up the Mount Rogers and Grandfather Mountain Formations in North Carolina, Virginia, and Tennessee and thinner sequences associated locally with massive sulfide deposits in the basal part of the Ocoee clastic metasedimentary sequence (Ducktown assemblage). The metavolcanic rocks were probably erupted around 700 m.y. ago. Above the Ducktown assemblage, volcanogenic components are absent in thick sequences of upper Precambrian (Upper Proterozoic) clastic rocks and in the Cambrian-Ordovician carbonate-shelf sequence. From the time of eruption of volcanic rocks in the Mount Rogers and Grandfather Mountain Formations, and in the lower part of the Great Smoky Group, probably about 700 m.y. ago, through the Lower Ordovician, the eastern margin of the North American continent was too far from any volcanic source to receive volcanogenic material. Reasonable spreading rates suggest that the Iapetus Ocean was wider than 10,000 km when subduction zones and volcanic island arcs were established.

Closing of the Iapetus Ocean must have begun with establishment of one or more subduction zones. The rocks in the Little River allochthon are products of the volcanism associated with one of these subduction zones. These rocks probably span from very latest Precambrian (latest Proterozoic-Ediacaran) through Middle Cambrian time, indicating that at least by 600 m.y. ago the arc and subduction zone were active. Lack of volcanogenic rocks younger than Middle Cambrian in the Little River allochthon suggests that subduction under the Little River arc had ceased by Late Cambrian time. We speculate that the Little River arc overrode the mid-Iapetus ridge during the Late Cambrian, thereby stopping subduction under the arc and effectively speeding up movement of the arc toward the North American continent until oceanic crust and upper mantle could no longer be consumed fast enough, so they buckled, broke (forming the Soapstone Ridge thrust sheet), and were obducted upon Ropes Creek Metabasalt (oceanic crust). Collision began with obduction of Soapstone Ridge oceanic crust and mantle onto Ropes Creek oceanic crust and was followed by obduction of Ropes Creek Metabasalt onto the West Point melange and Paulding island-arc rocks; this stopped subduction under the Paulding arc and terminated volcanism and plutonism in the arc. Continued assembly of thrust sheets involved rocks of the Promised Land arc where subduction, volcanism, and plutonism had ceased, probably when the Clairmont sheet and the arc overrode the spreading center between the arc and North America. Continued movement thrust the Clairmont sheet and the overlying stack upon ocean-floor deposits (Zebulon), and these in turn were thrust upon the lowest, autochthogenetic Bill Arp thrust sheet.

Movement of the Zebulon thrust sheet and overlying stack onto the Bill Arp sheet caused buckling up of the Cambrian-Ordovician carbonate shelf at the oceanward edge of the North American craton, resulting in unconformities at the top of the Upper Cambrian–Lower Ordovician Knox Group and later above the Middle Ordovician Lenoir Limestone. With continued movement, the cratonward edge of the Bill Arp sheet was thrust up along with part of the carbonate shelf above it to cause a landmass that separated the Rockmart-Athens basin from what was left of the Iapetus Ocean. Continued movement pushed parts of the pelitic sequences deposited in that basin (Rockmart Slate, Athens Shale) up the paleoslope onto the unconformity at the top of the carbonate shelf, folding and mildly metamorphosing some of the pelites in the process. Erosion of thrust-up carbonate-shelf-sequence and Bill Arp thrust-sheet rocks supplied clastic material to that basin, and continued movement and erosion of the thrust-up Bill Arp sheet rocks caused deposition and cratonward transgression (the source was also moving toward the craton) of a molasse-like, feldspathic, diamictite-bearing clastic wedge (Tellico-Talladega clastic wedge) that spread cratonward beyond the limit of the dark pelites, and farther cratonward another clastic wedge (Greensport, Colvin Mountain, Sequatchee). Oceanward parts of wedges were mildly metamorphosed as they were overridden by part of the Georgiabama thrust stack. Further cratonward movement of the Clairmont melange and higher thrust sheets in the Georgiabama thrust stack probably loaded the underlying Zebulon and Bill Arp sheets and thereby the oceanward edge of what was left of the carbonate shelf, allowing deposition of the thin Lower-Middle Devonian Armuchee Chert–Frog Mountain Sandstone sequence (including Jemison Chert, which is equivalent to the Armuchee and Frog Mountain). By the Late Devonian the Paulding, West Point, and Ropes Creek thrust sheets had locally transgressed far enough towards the craton to be emplaced upon the Jemison Chert.

The Sandy Springs and higher sheets in the Georgiabama stack overrode the leading edges of lower sheets in the stack along the southeastern edge of the Brevard Zone, where rocks were mylonitized and remylonitized and retrograded and where isoclinal folds formed and were continuously sheared out and transposed, as the zone was transported with the moving thrust sheets, rolling under the leading edge of the overridden part of the thrust stack like the forward trough of a standing wave.

While cratonward movement of the Georgiabama thrust stack continued, collision shoved the remnants of the Macon subduction melange wedge, the Little River island arc, and African sedimentary deposits, preserved as the Northern Florida platform sequence (now beneath the Coastal Plain in southern Georgia and northern Florida), onto the top of the Georgiabama thrust stack, probably in Late Devonian-Carboniferous time. Final cratonward movement of the whole assembled set of thrust stacks took place along the Emerson, Carters Dam, Rome-Helena, Clinchport, and Kingston faults during the late Carboniferous and Permian.

The Iapetus Ocean was probably wider in the southern Appalachians than in the northern Appalachians, and it probably took longer to close. In contrast with the drastically telescoped northern Appalachians, the southern Appalachians contain remnants of sequences of rocks that spanned the Iapetus Ocean.

The southernmost Appalachians fit readily into the Indonesian plate tectonics model; despite transport, deformation, and metamorphism, remnants of subduction melange complexes are preserved beneath remnants of each island arc sequence (Clairmont melange/Promised Land arc, West Point melange/Paulding arc, Macon melange/Little River arc), and both obducted ophiolite and ophiolite in melanges are present.

INTRODUCTION

The concept of plate tectonics has revolutionized the science of geology in the same way that Einstein's theory of relativity revolutionized physics. This concept caused rapid advancement in understanding the northern Appalachians, where geologists applied it to a wide inventory of careful field observations to produce a fascinating account of allochthons, ophiolites, melanges, and the opening and closing of the ancient Iapetus Ocean (Dewey, 1969; Bird and Dewey, 1970; Stevens, 1970; Dewey and Bird, 1971; Williams and others, 1972; Williams and Smyth, 1973; Williams and Talkington, 1977; Laurent, 1977; Rowley and Kidd, 1981). A similar story based on careful field observations soon began to emerge in the central Appalachians (Crowley, 1976; Morgan, 1977; Drake and Lyttle, 1981; Drake and Morgan, 1981; Pavlides, 1981; Lash and Drake, 1984). Observations and interpretations in the southern Appalachians lagged far behind.

We present data in this paper that show that the crystalline terrane of the southern Appalachian orogen in Georgia and Alabama (including rocks now covered by the Coastal Plain) is composed of two enormous stacks of folded thrust sheets (pls. 1, 2; fig. 1). We (Higgins and others, 1984) refer to the lower thrust stack as the *Georgiabama thrust stack* and the upper stack as the *Little River thrust stack.* Together with the Rome-Kingston thrust stack in the Valley and Ridge province, these thrust stacks preserve sequences of rocks formed in a wide variety of environments that virtually spanned the ancient Iapetus Ocean. The lowest thrust sheet in the Georgiabama stack preserves sequences of rocks considered autochthogenetic[7] to the North American craton, whereas higher thrust sheets in the stack preserve sequences considered allochthogenetic[7] to the North American craton (fig. 1). Sequences preserved in the Little River thrust stack are considered allochthogenetic to the North American craton and autochthogenetic to the African craton. All of the rocks in the Rome-Kingston thrust stack are autochthogenetic to the North American craton (fig. 1).

Assembly (stacking) of the Georgiabama thrust stack took place from the Iapetus Ocean toward the North American craton, and from top to bottom, with the first-moving, uppermost thrust sheets travelling the farthest and the later moving, lowermost sheets travelling the least. In contrast, the Little River stack appears to have been assembled from bottom to top as its sheets were being thrust upon the already assembled and moving Georgiabama stack. Thrusting took place continuously from about Middle Ordovician through Carboniferous time, and we suggest that virtually all of the folding and deformation in the southernmost Appalachians were caused by the thrust sheets and thrust stacks moving toward the North American craton. By the same token, we suggest that most of the metamorphism in the southernmost Appalachians was the result of the overpressures, depths of burial, and consequent blanketing effects produced by the moving thrust sheets and thrust stacks. Thrust sheets with different deformational and metamorphic histories are juxtaposed within the thrust stacks.

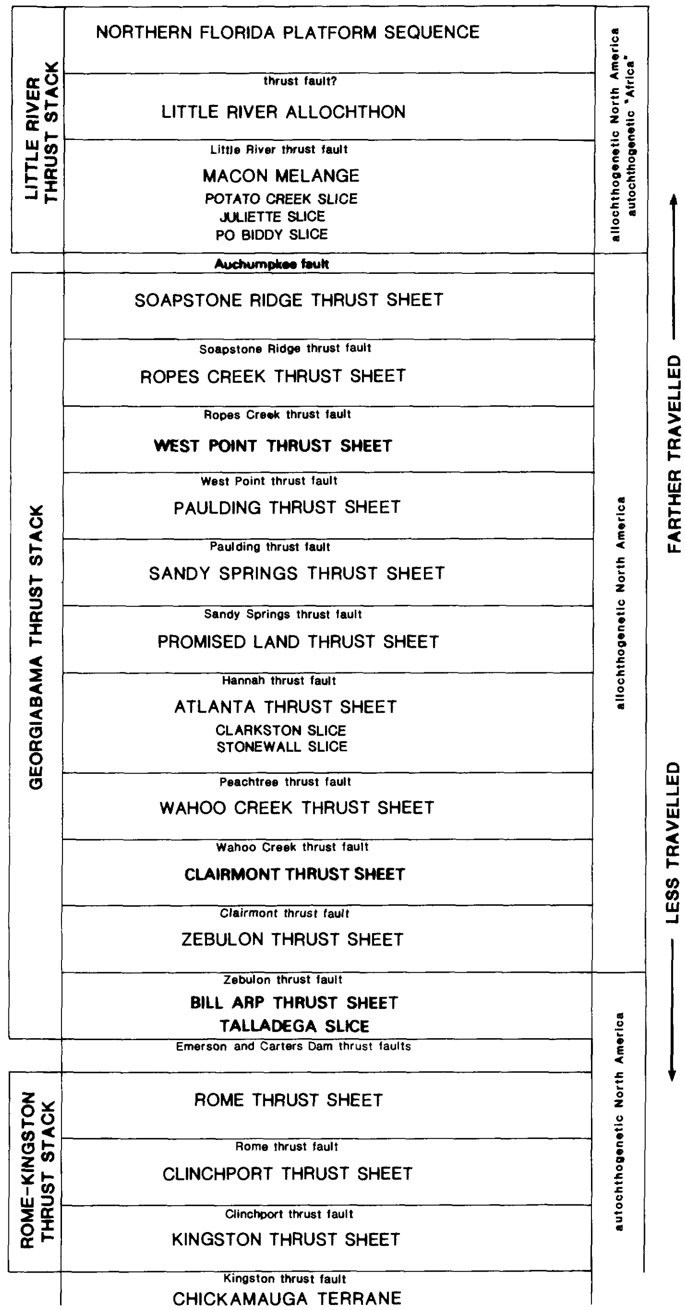


FIGURE 1.—Stacking order of tectonostratigraphic units and thrust sheets.

[7]We use the term "autochthogenetic" for allochthonous rocks derived from or otherwise genetically associated with a given craton, and the term "allochthogenetic" for allochthonous rocks that were apparently not genetically related to a given craton.

Deformation and metamorphism in the northern part of the Appalachian mountain system have traditionally been ascribed to distinct orogenies, each marked in part of the system by fairly well dated features (see Rodgers, 1982, for a recent review). Attempts to tie events in the southern part of the mountain system (south of Roanoke, Va.) to the same orogenies have mostly been unsuccessful, and the importance of "Taconic," "Acadian," and "Alleghanian" events has been the subject of much debate. Part of the difficulty arises from the fact that fossils have been found in very few localities in the crystalline part of the southern Appalachians, and part from the inherent complexities in interpretation of radiometric age dates from multiply deformed, multiply metamorphosed rocks whose origins are not always well understood. However, most of the problems in dating the metamorphism and deformation in the southern Appalachians have arisen from dependence on the "belt concept," which is so firmly entrenched here, and from lack of recognition that the rocks here are in many different thrust sheets. Thus, well-dated rocks in one thrust sheet and well-dated rocks of a different age and with a different history in another thrust sheet have commonly been lumped together in the same "belt," producing a confusing picture and the "geological noise" alluded to by Rodgers (1982, p. 235, 237).

We suggest that the metamorphism and deformation in the southernmost Appalachians was virtually a continuous process beginning with obduction of oceanic crust and mantle in the Soapstone Ridge thrust sheet onto Ropes Creek seafloor basalts, probably in the Ordovician, and lasting until plate collision and closing of the Iapetus Ocean was completed, probably during the Late Carboniferous or Permian. We consider the metamorphism and deformation, and also the plutonism, to be direct results of the thrusting and collisional processes and the depths of burial they caused. Thus, unconformities, periods of igneous intrusion, clastic wedges, metamorphism, and other features generally considered to mark distinct "orogenic events" are probably like rarely preserved frames of a long motion picture rather than vestiges of a spectacular series of stillshots. We suggest that the phase of closing of the Iapetus Ocean should be called the Iapetan orogeny.

The stacking order of the thrust sheets in the Georgiabama and Little River thrust stacks is based on considerable geologic field evidence, and the thrust fault at the base of each thrust sheet locally truncates mappable units in both the upper and lower plates of all but the smallest slices of thrust sheets. Without even considering the possible existence of a master decollement (Cook and others, 1979; Harris and Bayer, 1979; Cook and others, 1981), we consider all of the pre-Permian rocks southeast of the Kingston thrust fault in Georgia and the Helena thrust fault in Alabama (Chowns and McKinney, 1980; Chowns and Carter, 1983) to be allochthonous. Most of the thrust sheets in the Georgiabama thrust stack are found throughout the terrane between the Valley and Ridge province and the Little River thrust stack, so there is no real basis or reason for dividing a Blue Ridge geologic province (or belt) from a Piedmont geologic province in the southernmost Appalachians (pl. 1). Proposed times of thrusting and derivation of the thrust sheets are interpretive and are based on available geologic and geochronologic data. The facies reconstructions and the proposed developmental model presented in this paper are based largely on present understanding of plate tectonics. Many of the units described here are tectonostratigraphic units and do not conform to classic principles of superposition and stratigraphic succession (see Drake and Morgan, 1981).

We develop the following main themes in this paper. (1) There was a continuity of geologic "events" in the development of the southernmost Appalachians that began with the inception of rifting of the ancient margin of North America to form the Iapetus Ocean and lasted until that ocean closed and a new cycle of rifting began, which resulted in the opening of the Atlantic Ocean. (2) Opening of the Iapetus Ocean was a slow process that probably took more than a hundred million years; as it opened it left a series of stepped fault-bounded basins along the oceanward edge of North America, whose long axes approximately paralleled the spreading axis. The basins nearest the spreading axis probably formed first and were filled with sediment first. The basins were filled first with poorly sorted turbidite flysch deposits, probably in enormous coalescing fans. Deposits in the basins had in general a common source and similar depositional environments, but environments were probably diachronous. These deposits record the same type of depositional environment throughout, even though the preserved units may not be directly correlative in age or continuity. When the basins had nearly filled (cratonward ones probably being the latest formed and latest filled), beach deposits and then carbonate shelf sequences with reefs formed on top of the clastic sediments. Part of the most continentward of these sequences is preserved as the carbonate shelf sequence in the Valley and Ridge province. Small parts of others are scattered around the crystalline terrane in such units as the Murphy, "Brevard," and Chewacla Marbles. These carbonate units probably mark the same depositional environment but were probably deposited in separate basins and at slightly different times. (3) At the same time as the last sediments in the basins closest to the craton were deposited and the lower parts of the carbonate shelf sequence in the Valley and Ridge formed (latest Precambrian or earliest Cambrian), the ocean began to close, and subduction zones (with melange wedges) and volcanic arcs were established at the edge of the "African" microcontinent off the African continent, at the edge of a "Sandy Springs" microcontinent, and within the crust of the ocean. (4) The African plate ("African" microcontinent) overrode the mid-Iapetus ridge, probably in the Late Cambrian, stopping volcanism in the Little River island arc at the oceanward edge of the "African" microcontinent and effectively speeding up movement of the plate toward the North American Continent. Oceanic crust and mantle buckled, broke, probably in the Late Cambrian or earliest Early Ordovician, and were obducted onto oceanic crust, thus beginning a thrust-stacking process that lasted until it involved the lowermost Bill Arp thrust sheet, which comprised rocks of the opening-phase basins and their basement. As upper sheets moved onto lower sheets, and these moved in turn onto still lower sheets, they changed the environments they moved into and also those perhaps as much as hundreds of kilometers in front of the advancing sheets, including by Middle Ordovician time the Valley and Ridge basin closest to the craton. Upthrust leading edges of the lower thrust sheet included sedimentary deposits belonging with those still forming in the basin; these deposits were cannibalized along with crystalline rocks in the sheet to form molasse wedges that spread onto the carbonate shelf. Folding took place continuously in front of the advancing thrust sheets with growing antiforms shedding debris into more cratonward basins. Thus, faulting, folding, and sedimentation were intimately interrelated. With continued cratonward advance, uppermost sheets in the stack overrode middle sheets in the stack and transgressed far enough to be emplaced upon shallow-water Lower and Middle Devonian chert of the basin closest to the craton (Valley and Ridge basin). (5) Metamorphism was continuous and was caused by the depths of burial below the thick stacks of moving thrust sheets, and by the blanketing insulation of the sheets, which caused anatectic melting of lower parts of the stack to produce plutonism. (6) The continuous orogenic process migrated along the edge of the North American continent from present northeast to present southwest because the Iapetus Ocean closed like a door hinged at the northeast. Thus, rocks formed in a given environment tend to be regionally diachronous along strike in the orogen. (7) Collision of the African plate caused emplacement of the Little River thrust stack, composed of the Macon subduction melange and Little River island arc of the African plate and northern Florida platform sequence of the African continent, upon the Georgiabama thrust stack. Final collisional stages caused emplacement of the entire assemblage of thrust sheets and stacks farther upon the rocks of the Valley and Ridge basin along the Emerson and Carters Dam faults as the African plate "docked," not with North America but with the accreted terranes from the Iapetus Ocean.

The descriptions, interpretations, and conclusions presented in this paper are based on our detailed geologic mapping of the Atlanta, Ga., Griffin, Ga., Athens, Ga., and Thomaston, Ga. $1^\circ \times 30'$ (1:100,000-scale) quadrangles (the Atlanta and Griffin quadrangles are summarized in fig. 2) and most of the Milledgeville, Ga. $1^\circ \times 30'$ quadrangle, and extensive reconnaissance work throughout the crystalline terrane of Georgia and Alabama, with detailed work in problem areas; our work in the Carolinas has been mostly reconnaissance mapping. We have benefited greatly from earlier work by Hurst (1955, 1973), Grant (1958), Hurst and Crawford (1964), Crawford and others (1966), Bentley and Neathery (1970), Medlin and Crawford (1973), Crawford and Medlin (1973, 1974), Cressler (1970, 1974), Neathery (1975), Dallmeyer and others (1978), Cressler and Crawford (*in* Cressler and others, 1979), Chowns and McKinney (1980), Horton (1981a), Tull (1982), Chowns and Carter (1983), and the unpublished mapping of Willard H. Grant. Stratigraphic nomenclature used in this paper is documented in Appendix A. Melange terminology used in this paper is from Drake and Morgan (1981), Hamilton (1979), Drake (oral commun., 1983, 1984), Moore and others (1985), and Cowan (1985). Precambrian is used preferentially over Proterozoic as a general time term in this paper (see Appendix A). We use ophiolite for any form of oceanic crust or mantle or any combination of the two. For time scales we use those of Harland and others (1982), Palmer (1983), and Salvador (1985), realizing the discrepancies between them and suggesting that they mark real margins of error in our knowledge of radiometric versus paleontologic-stratigraphic (geochronometric versus chronostratigraphic) time (see Salvador, 1985, p. 181, 187). In Newfoundland, *slice* has been used in much the same manner as we use *thrust sheet* (for example, Williams, 1975). We use *slice* for separate pieces of a thrust sheet ("this slice of the Ropes Creek thrust sheet") and also for pieces so large that they might be called separate sheets but so related that we interpret them as sliced-off parts of the same sheet.

PREVIOUS CONCEPTS

For many years the crystalline rocks of the southernmost part of the Appalachian orogen in Georgia and

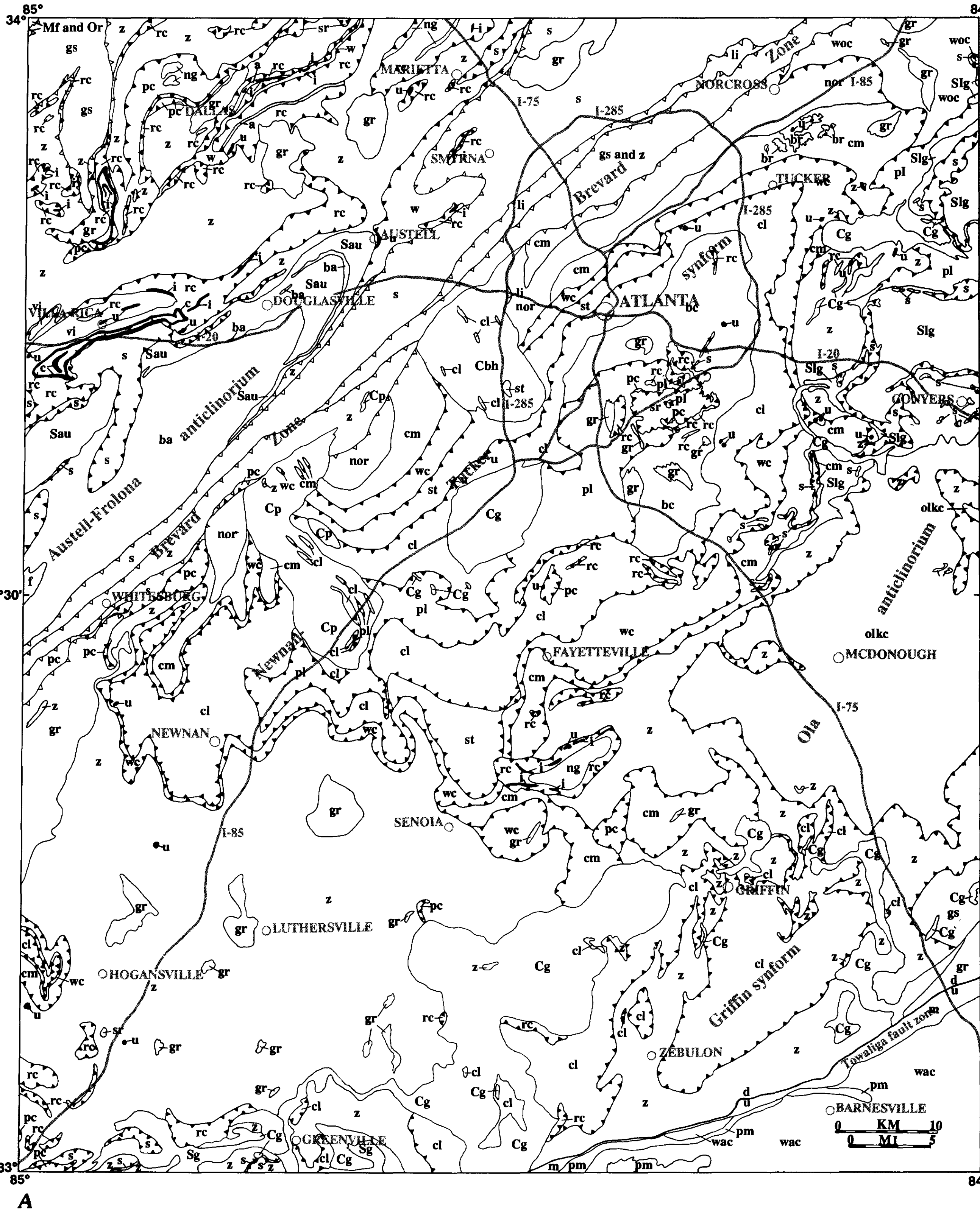
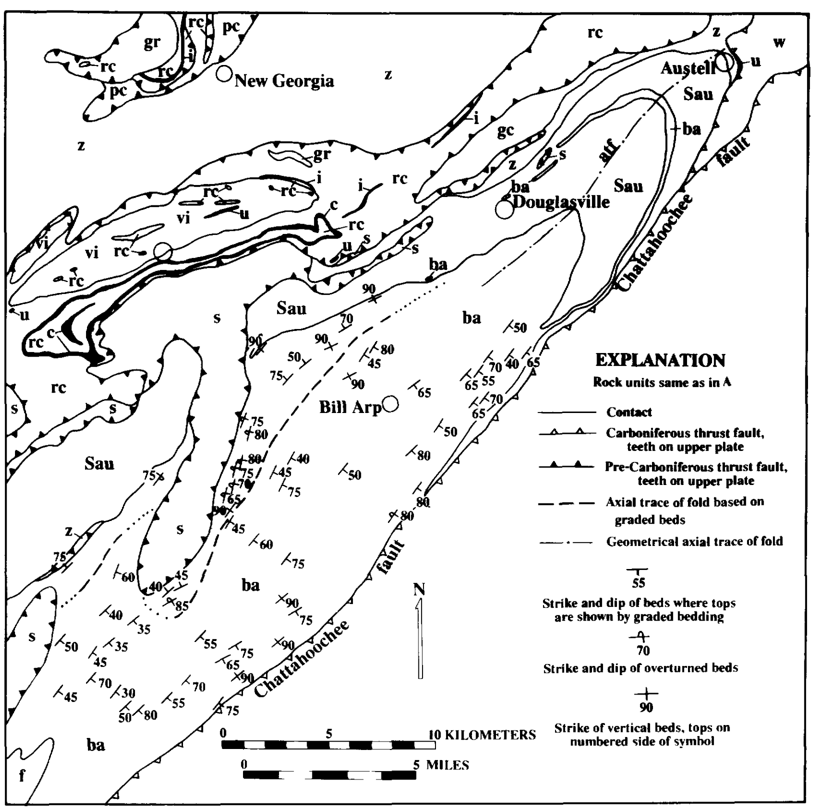


FIGURE 2.—*A*, Generalized geologic map of the Atlanta, Ga., and Griffin, Ga. 1° × 30' quadrangles. *B*, Inset showing attitudes and facing of graded beds in the Bill Arp Formation in the Austell-Frolona anticlinorium. Each symbol represents a locality where four or more graded beds give facing direction. Dips are averaged and rounded. See text for further explanation.

EXPLANATION

No stratigraphic order implied

- sr — Soapstone Ridge thrust sheet
- Ropes Creek thrust sheet:
  - a — alteration zone
  - i — Iron formation, thickness exaggerated
  - c — Cedar Lake Member
  - rc — Ropes Creek Metabasalt
- w — West Point thrust sheet, West Point melange
- pc — Paulding thrust sheet
- s — Sandy Springs thrust sheet
- pl — Promised Land thrust sheet
- Atlanta thrust sheet:
  - cl, bc — cl: Clarkston slice; bc: Big Cotton Indian Formation
  - st — Stonewall slice
- wc — Wahoo Creek thrust sheet
- cm / br — Clairmont thrust sheet; cm: Clairmont melange; br: Beaver Ruin slab
- z — Zebulon thrust sheet
- Bill Arp thrust sheet:
  - ba, gs, pm — ba: Bill Arp Formation; gs: Great Smoky Group nndivided; pm: Pine Mountain Group nndivided
  - f, olkc — f: Frolona Formation; olkc: Ola and Kalves Creek Formations undivided
- Mf and Or — Mississippian Fort Payne Chert and Ordovician Rockmart Slate
- Cg — Carboniferous granitic rocks
- Cbh — Ben Hill Granite
- Cp — Palmetto Granite
- Sg — Silurian granitic rocks
- Slg — Lithonia Gneiss
- Sau — Austell Gneiss
- ng — K-feldspar-poor granitic rocks
- vi — Villa Rica Gneiss
- gr — Granites and granite gneisses of unknown age
- nor — Norcross Gneiss
- li — Long Island Creek Gneiss
- n — Ultramafic rocks, size exaggerated
- m — Mylonitic rocks
- woc — Wolf Creek Formation
- gc — Gneiss at Gotthards Creek
- wac — Wacoochee Complex undivided
- Contact
- Carboniferous thrust fanlt, teeth on upper plate
- Pre-Carboniferous thrust fanlt, teeth on upper plate



B

FIGURE 2.—Continued.

Alabama were divided into poorly defined, locally named belts (Adams, 1933; Crickmay, 1952), generally assigned to two main geologic provinces (or belts), the Blue Ridge and Piedmont (King, 1955). More recently, belts defined mostly on the basis of reconnaissance in North Carolina (King, 1955) have been subdivided into still more belts (named mostly from the Carolinas) and projected and extrapolated through Georgia and Alabama by Griffin (1971) and Hatcher (1972, 1978a), with little new geologic mapping.

Despite the findings of those who had mapped large areas in the southernmost Appalachians (for example Bentley and Neathery, 1970; Crawford and Medlin, 1973; Medlin and Crawford, 1973; Hurst, 1973), the belt concept has become a "ruling concept" and has been used and accepted as the basis (and limitations) for developmental models for the southern Appalachians (Hatcher, 1972, 1978a; Hatcher and Odom, 1980; Price and Hatcher, 1983), for comparing the southern Appalachians with the better known northern and Canadian Appalachians (Hatcher, 1981; Williams and Hatcher, 1982, 1983) and with part of the Canadian Cordillera (Price and Hatcher, 1983), for compilation of the southern part of a major tectonic lithofacies map of the Appalachian orogen (Williams, 1978), for interpretations of geophysical maps of the southern Appalachians (Hatcher and Zietz, 1978, 1980), for interpretations of deep seismic reflection profiles in the southern Appalachians (Cook and others, 1979, 1981; Cook and Oliver, 1981; Iverson and Smithson, 1982, 1983; Cook, 1983; M.D. Thomas, 1983; Ando and others, 1983), and for a proposal that "southern Appalachian thrusting" is a "model for orogeny" (Hatcher and Odom, 1980; Hatcher, 1981).

Williams and Hatcher (1982, 1983) have recently modified the belt concept in the southern Appalachians to one of accreted "suspect terranes," largely on the basis of an earlier paper by Zen (1981). In the Williams and Hatcher papers the belts are reduced in number (lumped) and referred to as "terranes," but they are still depicted as northeast-trending, discrete linear belts that are merely modifications of the southern Appalachian belts of Hatcher (1972, 1978a, 1981), Hatcher and Butler (1979), and Hatcher and Odom (1980).

In part due to the influence of the belt concept, the influence of Alpine structural concepts, and the lingering influence of the geosynclinal theory and the tectogene hypothesis, most of the crystalline terrane of the southern Appalachians has generally been depicted as composed of large fold-nappes that more or less match the belts (for example Hatcher, 1972, fig. 3; 1981; Price and Hatcher, 1983, p. 155). The concept that the terrane between the Brevard Zone and the Towaliga fault zone in Georgia and Alabama is a single "Inner Piedmont allochthon" or "meganappe" (Clarke, 1952; Bentley and Neathery, 1970) has been accepted and expanded (Rankin, 1975, 1976; Hatcher, 1978a, 1981; Hatcher and Zietz, 1978, 1980; Sears, Cook, and Brown, 1981; Sears, Cook, and others, 1981; Williams and Hatcher, 1982, 1983; Sears and Cook, 1984; Sears, 1985). The concept of belt-bound nappes has led to vigorous searches for root zones, generally thought to be subvertical and located at belt boundaries or within narrow belts such as the Brevard Zone ("Chauga belt" of Hatcher, 1972, 1978a), and particularly the "Kings Mountain belt"; more recently there has been a similar search in the same places for subvertical sutures (see Cook, 1983, and Rodgers, 1982, for discussions). The belts and the suspect terranes are considered to have "docked" with the North American craton and with each other as vertical entities, much as large ships dock against piers. With the exception of the "Goat Rock fault," which has been considered to bound one side of a window through to Grenville basement, thrust faults in the southern Appalachians have generally been depicted as long, continuous, unfolded, unrepeated southeast-dipping features with the upper plate always on the southeast side (Hatcher, 1972, 1978a, 1981; Tull, 1978, 1984; Hatcher and Odom, 1980; McConnell and Costello, 1980, 1984; Odom and Hatcher, 1980; Price and Hatcher, 1983; Glover and others, 1983, especially p. 226). Some of these faults are alternately depicted as pre-metamorphic and post-metamorphic (Hatcher, 1978, 1981; McConnell and Costello, 1980, 1984; Hatcher and Odom, 1980; McConnell and Abrams, 1984; Absher and McSween, 1985, p. 592).

Despite the fact that actualistic models show the invalidity of the miogeosyncline-eugeosyncline (geosynclinal) concept and the tectogene hypothesis (Hamilton, 1979), the Valley and Ridge province, and part of the crystalline terrane of the southern Appalachians as well, are still referred to by some authors as the "Miogeocline" (Williams and Hatcher, 1983, for example). The prevailing concept of metamorphism and deformation in the southern Appalachians is still one of a tectogene where "downpulled," deeply buried rocks were metamorphosed and folded after they had "docked," thus producing broad "belts" affected by one distinct event or another.

In our opinion, the belt concept and the geosynclinal theory have greatly hindered understanding of the geology and geologic history of the southern part of the Appalachian orogen. Neither the "belts" nor the "suspect terranes" are (Williams and Hatcher, 1983, p. 34) "internally homogeneous geologic provinces, with features that contrast sharply with those of nearby

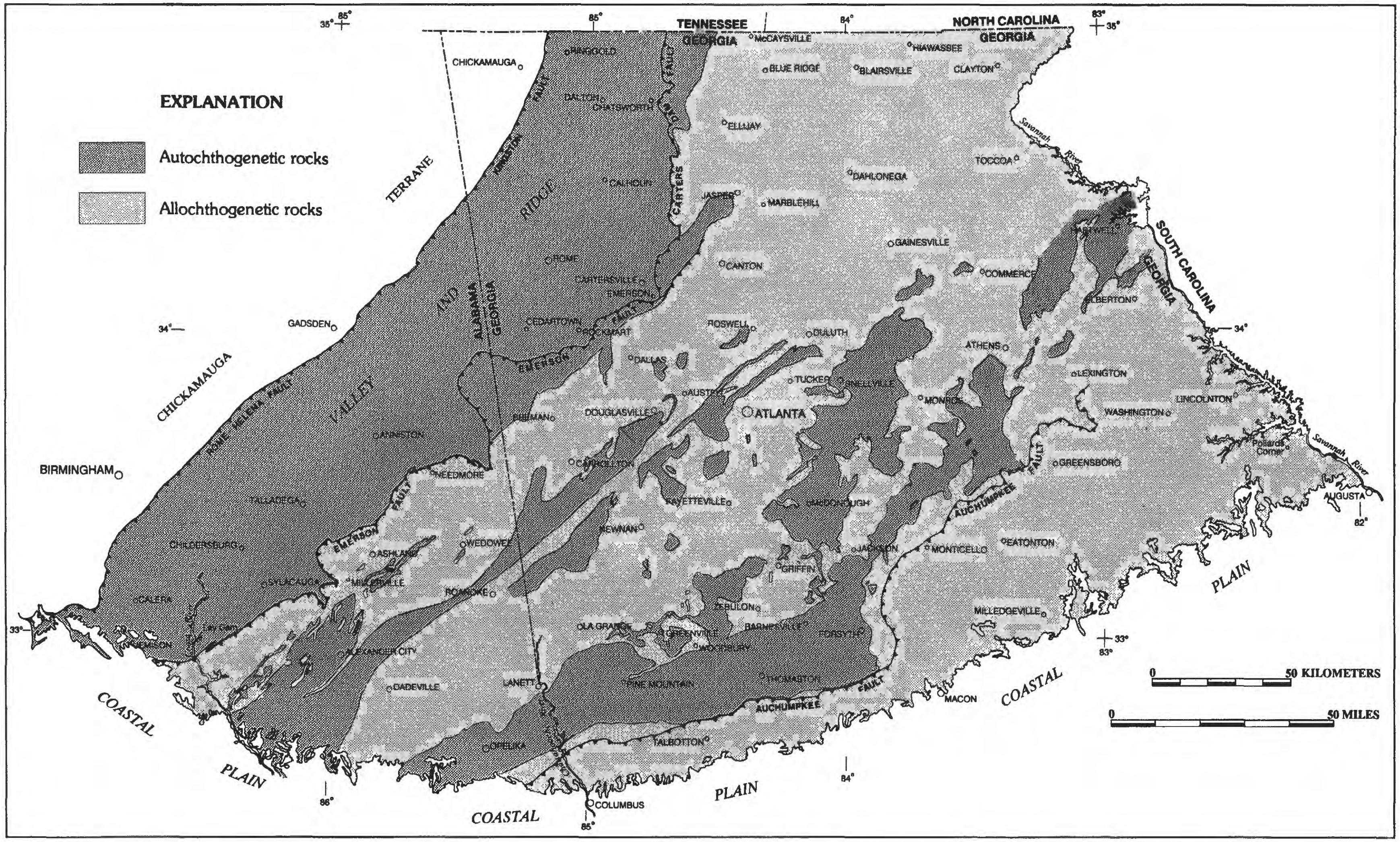


FIGURE 3.—Present known distribution of autochthogenetic rocks and allochthogenetic rocks in the southernmost Appalachians. For greater detail, see plate 1.

provinces." There is no "miogeocline" because there was neither a "eugeosyncline" nor a "geosyncline," and virtually all attempts to correlate units in the Valley and Ridge province with those in the crystalline terrane have not proved valid. The basic structure of the crystalline terrane in the southernmost Appalachians is not one of steeply bounded belts "docked" against one another and the craton like dominoes, but of now-folded, but once nearly horizontal, thrust sheets.

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GEORGIABAMA THRUST STACK

The Georgiabama thrust stack is composed of 11 major thrust sheets in Georgia and Alabama (fig. 1, table 1); additional sheets are probably present to the northeast. Lower sheets in the stack are widely preserved and underlie vast areas of the crystalline terrane. Higher sheets are less widely preserved, and the uppermost sheets occur as scattered remnants (for example, the Soapstone Ridge sheet; pls. 1, 2), because of erosion, or because they broke up during transport and emplacement, or, more likely, both. The lowest, Bill Arp, sheet is considered autochthogenetic, and all higher sheets allochthogenetic (see fig. 3).

BILL ARP THRUST SHEET

The composite Bill Arp thrust sheet is the basal thrust sheet in the Georgiabama thrust stack (fig. 1). It crops out in areas that are essentially windows through the overlying thrust sheets (pl. 1, fig. 4). At the boundary between the crystalline terrane (Piedmont and [or] Blue Ridge of former usage) and the Valley and Ridge province, the Bill Arp thrust sheet is bounded below by the Emerson (formerly the Cartersville; Crawford and Cressler, 1982) and Carters Dam (formerly the Great Smoky) faults, but through most of the crystalline terrane of Georgia and Alabama the Bill Arp sheet may be bounded below by a master decollement (Cook and others, 1979; Harris and Bayer, 1979; Cook and others, 1981) or by splays off a master decollement. The Bill Arp sheet is composed of rocks belonging to the Grenville basement (fig. 5), overlain by rocks belonging to the upper Precambrian Ocoee Supergroup (tables 1, 2). The most characteristic feature of the Bill Arp thrust sheet is its virtual lack (except the Ducktown assemblage, discussed below, and some of the rocks traditionally assigned to the "Murphy Group" of Hatcher [1972] or "Murphy Belt Group" of Hurst [1955]) of volcanic components of any kind (amphibolites, volcaniclastic rocks, volcanogenic sediments, and so forth). This lack of volcanic components is characteristic of all the Ocoee basins, as emphasized more than 25 years ago by King and others (1958) and more recently by Hurst (1973). As far as we know, except for granites, granite gneisses, and the Talladega Group (sensu stricto—discussed in a later section), rocks of the Bill Arp thrust sheet form the only large outcrop areas in the Georgia and Alabama crystalline terrane that are without volcanic components. Metavolcanic rocks in the Bill Arp sheet around and southwest of Copperhill, Tenn., are discussed in the section below on the Ducktown assemblage.

Another characteristic of the Bill Arp thrust sheet is the presence of small, regionally discontinuous, metamorphosed carbonate rocks generally within the upper parts of its thick metasedimentary sequences. As Hurst (1973) recognized, metacarbonate rocks are relatively rare in the crystalline terrane of Georgia and Alabama, being apparently limited to the small metacarbonate rocks in the Ocoee metasedimentary sequences (including Brevard Zone metacarbonates; see below) and the Murphy and Chewacla Marbles.

Still another characteristic of the Bill Arp sheet is that many of its rocks are rich in titanium, barium (Appendix B), and carbon; the carbon is typically in the form of graphite and the titanium in the form of rutile or ilmenite. This enrichment is true of most of the Grenville basement rocks as well as the Ocoee metasedimentary rocks above the basement.

TABLE 1.—*Summaries of thrust sheets in the Georgiabama thrust stack*

STRUCTURAL UNITS	STRATIGRAPHIC OR (AND) TECTONOSTRATIGRAPHIC UNITS	GENERAL CHARACTERISTICS	INTERPRETED ORIGIN
SOAPSTONE RIDGE THRUST SHEET -- TOP OF STACK			
Soapstone Ridge thrust sheet	Soapstone Ridge Complex, Laurel Creek Complex (Hatcher and others, 1984), Goodwater, Boyds Creek, and Doss Mountain Complexes (Bentley and Neathery, 1970; Reynolds, 1972; Neathery, 1975).	Mafic-ultramafic complexes commonly with thin basal units of dunite or (and) peridotite that has been sheared and altered to serpentinite and talc-chlorite schist, overlain either by mixed units of altered ultramafic rock and uralitized and chloritized metagabbroic rocks, or by uralitized and chloritized metapyroxenites, or by both assemblages. Ultramafic rocks commonly rich in nickel and chrome.	Allochthogenetic (obducted) Iapetus oceanic crust and mantle (OPHIOLITE); incomplete, disrupted ophiolite complexes.
ROPES CREEK THRUST SHEET			
Ropes Creek thrust sheet	Ropes Creek Metabasalt and its Cedar Lake Member. Informal: Ketchepedrakee, Mitchell Dam, and Beaverdam amphibolites, Slaughters metagabbro, and Hillabee greenstone.	Generally finely layered, dark-green, dark-red-weathering, hornblende-plagioclase amphibolites (metabasalts), commonly garnet-, sphene-, and pyrite-bearing, locally chloritic and epidotic, locally with actinolite. Metabasalts are locally massive and pillowed. Contains massive volcanogenic sulfide deposits associated with volcanogenic iron formations, manganiferous schists, and thin layers of tourmalinite. Associated granitic plutonic rocks are K-feldspar-poor. Essentially a mafic igneous sheet, devoid of clastic sedimentary rocks.	Allochthogenetic (obducted) ocean ridge assemblage and seafloor basalts (OPHIOLITE); basalts and basaltic tuffs formed at or very near the mid-Iapetus ridge, mixed with lesser amounts of pelagic sediments, and locally containing volcanogenic sulfides and volcanogenic chemical sediments.

TABLE 1.—*Summaries of thrust sheets in the Georgiabama thrust stack*—Continued

STRUCTURAL UNITS	STRATIGRAPHIC OR (AND) TECTONOSTRATIGRAPHIC UNITS	GENERAL CHARACTERISTICS	INTERPRETED ORIGIN
WEST POINT THRUST SHEET			
West Point thrust sheet	West Point melange	Melange. Matrix generally composed of highly sheared talcose and (or) chloritic material or of highly deformed scaly schist, both containing clasts of various sizes and degrees of roundness of a wide variety of mafic and ultramafic rocks and locally of eclogite.	Allochthogenetic subduction melange; part of a subduction melange formed at the oceanward edge of the oceanic Paulding island arc.
PAULDING THRUST SHEET			
Paulding thrust sheet	Paulding Volcanic-Plutonic Complex	Essentially a wholly igneous thrust sheet composed of light-green-weathering, epidote-rich, generally chloritic, green or blue-green hornblende- or (and) actinolite-plagioclase amphibolites (50-60%), intercalated with light-gray to nearly white, amphibole-bearing felsites (20-30%). Dikes and sills of K-feldspar-rich (most) and K-feldspar-poor (least) granitic dikes (15-20%) are ubiquitous, and pods of epidosite are common.	Allochthogenetic island arc assemblage; mafic, intermediate, and felsic tuffs, extensively intruded by granitic rocks; formed in the Paulding island arc.
SANDY SPRINGS THRUST SHEET			
Sandy Springs thrust sheet	Sandy Springs Group: Powers Ferry Formation, Chattahoochee Palisades Quartzite, and Factory Shoals Formation.	Biotite schists, hornblende-plagioclase amphibolites, and biotite-plagioclase gneisses, overlain by clean and micaceous quartzite, overlain by aluminous and garnetiferous schists with quartzite and metagraywacke and lesser amounts of amphibolite.	Allochthogenetic rift-basin fill assemblage from Sandy Springs microcontinent; rift-basin assemblage mixed with volcanic material from Promised Land island arc.

TABLE 1.—*Summaries of thrust sheets in the Georgiabama thrust stack*—Continued

STRUCTURAL UNITS	STRATIGRAPHIC OR (AND) TECTONOSTRATIGRAPHIC UNITS	GENERAL CHARACTERISTICS	INTERPRETED ORIGIN
		PROMISED LAND THRUST SHEET	
Promised Land thrust sheet	Promised Land Formation	Intercalated thin hornblende-plagioclase amphibolites (15-25%) and felsites (65-75%), with local granite gneiss bodies (5-10%). Thicker amphibolites are locally pillowed. Entirely igneous thrust sheet.	Allochthogenetic island arc assemblage; mafic and felsic tuffs with local mafic flows, volcanic-epiclastic rocks, and hypabyssal granitic plutonic rocks. Volcanic and volcanic-epiclastic rocks deposited subaqueously in the Promised Land island arc.
		ATLANTA THRUST SHEET	
Stonewall and Clarkston slices	Stonewall, Ison Branch, Barrow Hill, Clarkston, and Big Cotton Indian Formations.	Stonewall slice: medium-grained biotite gneiss and fine-grained hornblende-plagioclase amphibolite intercalated in various proportions, and lesser amounts of sillimanite-biotite schist. Clarkston slice: Ison Branch Formation: metamorphosed, finely laminated, calcareous, pyritic felsic tuff. Barrow Hill Formation: gondite (spessartine quartzite) interlayered with pink-purple-weathering schist and amphibolite. Clarkston Formation: interlayered pink-purple-weathering schist and amphibolite. Big Cotton Indian Formation: biotite-plagioclase gneisses, hornblende-plagioclase amphibolites, and biotite-muscovite schists in various proportions.	Allochthogenetic island arc and outer-arc basin assemblage; volcaniclastic rocks mixed with pelagic sediments, volcanogenic chemical sediments, and clastic sediments from Sandy Springs microcontinent.

TABLE 1.—*Summaries of thrust sheets in the Georgiabama thrust stack*—Continued

STRUCTURAL UNITS	STRATIGRAPHIC OR (AND) TECTONOSTRATIGRAPHIC UNITS	GENERAL CHARACTERISTICS	INTERPRETED ORIGIN
WAHOO CREEK THRUST SHEET			
Wahoo Creek thrust sheet	Wahoo Creek Formation	Wide variety of metavolcanic, metavolcanic-epiclastic, and metaplutonic rocks, but mainly of thin- and planar-layered, light-gray to nearly white, slabby-weathering muscovite-plagioclase-quartz gneiss with K-feldspar porphyroblasts, and generally lesser amounts of reddish-weathering coarse-grained muscovite schist and silvery sillimanite-muscovite schist. Thinly layered epidote amphibolites and calc-silicate rocks are widespread in all lithologies.	Allochthogenetic island arc assemblage; mostly metamorphosed altered felsic and siliceous volcaniclastic rocks and their hypabyssal equivalents formed in the Promised Land island arc.
CLAIRMONT THRUST SHEET			
Clairmont thrust sheet	Clairmont melange	Polymictic, polykinematic melange with clasts of many sizes of many different rock types. Some of the clasts are lithic matches of rocks in overlying thrust sheets.	Allochthogenetic melange assemblage; probably the upper part of the accretionary prism associated with the Promised Land island arc.
ZEBULON THRUST SHEET			
Zebulon thrust sheet.	Zebulon Formation and its Senoia Member, Wolf Creek Formation. Parts of the Wedowee, Hatchet Creek, Mad Indian, Heard, Jacksons Gap Groups (Bentley and Neathery, 1970). Part of the Dadeville Complex (Bentley and Neathery, 1970).	Interlayered and intercalated hornblende-plagioclase amphibolites and pink-purple weathering, generally aluminosilicate-bearing schists with variable amounts of biotite-plagioclase gneisses and granitic gneisses. In many places amphibolites occur as blocks and slabs (clasts) in the schists. Manganiferous quartzites (gondites - metamorphosed cherts) are common in the upper parts of the unit.	Allochthogenetic ocean floor assemblage; pelagic sediments, distal volcanogenic sediments, basaltic tuffs, and blocks of basalt shed as debris from higher thrust sheets. Probably deposited in a large back-arc basin or small ocean basin.

TABLE 1.—*Summaries of thrust sheets in the Georgiabama thrust stack*—Continued

STRUCTURAL UNITS	STRATIGRAPHIC OR (AND) TECTONOSTRATIGRAPHIC UNITS	GENERAL CHARACTERISTICS	INTERPRETED ORIGIN
	BILL ARP THRUST SHEET		
Bill Arp thrust sheet, Richard Russell thrust slice.	Grenville basement: Allatoona Complex (Corbin Gneiss and Red Top Mountain Schist), Wiley Gneiss of Hatcher (1974), Wacoochee Complex (Woodland Gneiss, Cunningham Granite, Apalachee Formation, and Sparks Schist). Ocoee Supergroup: Great Smoky Group (Richard Russell Gneiss, Copperhill, Ola, Kalves Creek, Frolona, Wehutty, Hughes Gap, Bill Arp, Hothouse, and Dean Formations); Pine Mountain Group (Hollis Quartzite, Manchester Schist, Mountain Creek Formation, and Chewacla Marble). Parts of the Wedowee, Hatchet Creek, Mad Indian, Heard, Jacksons Gap, and Opelika Groups, and the Moffits Mill Complex of Bentley and Neathery (1970).	Poorly sorted fan deposits passing upwards into better sorted basin-fill deposits, beach deposits, and carbonate platform deposits. Schists and graywackes in lower parts are generally rich in TiO_2 and Al_2O_3.	Autochthogenetic rift-basin assemblages.
	BOTTOM OF THRUST STACK		

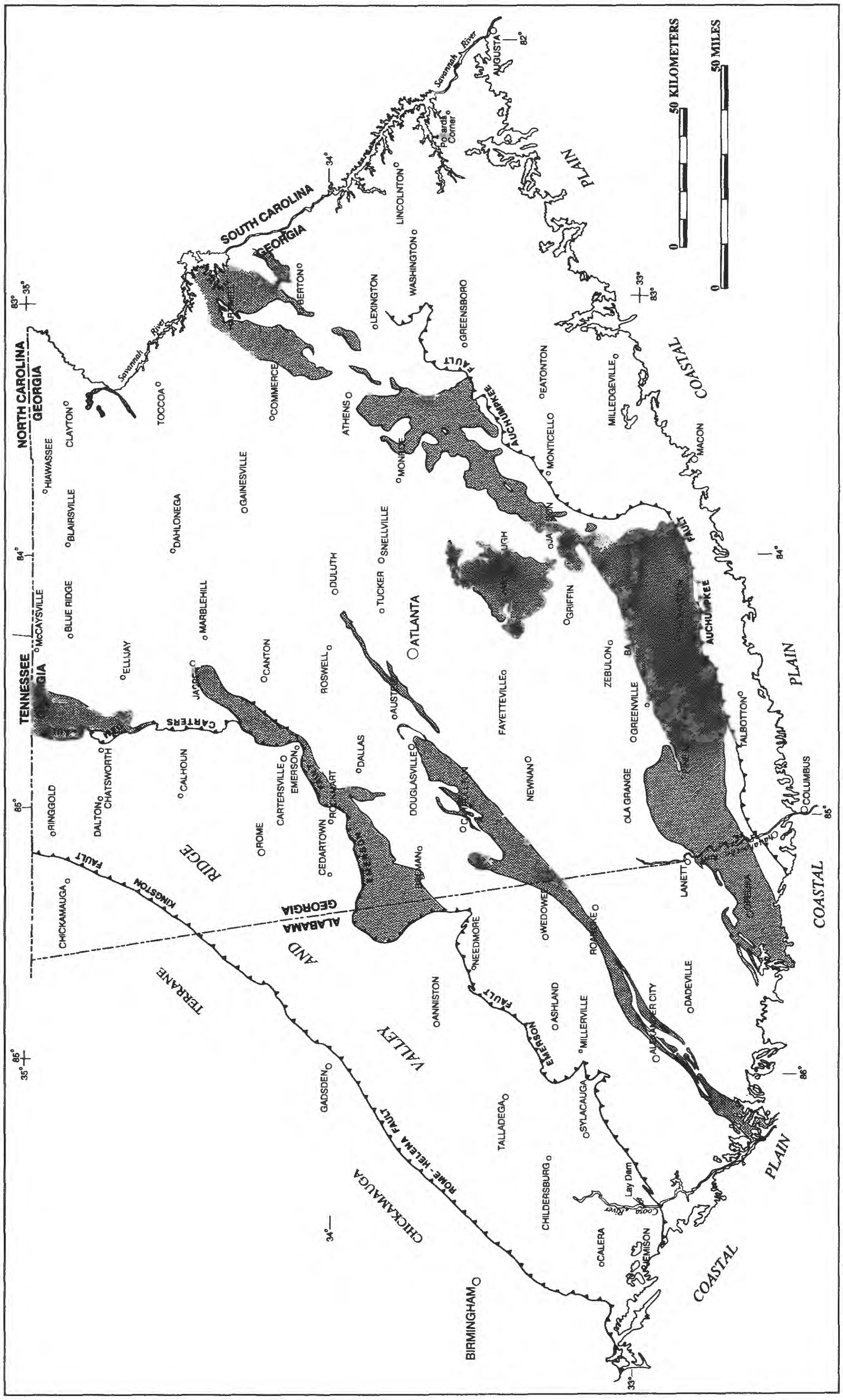


FIGURE 4.—Present known distribution of the Bill Arp thrust sheet in the southernmost Appalachians. For greater detail, see plate 1.

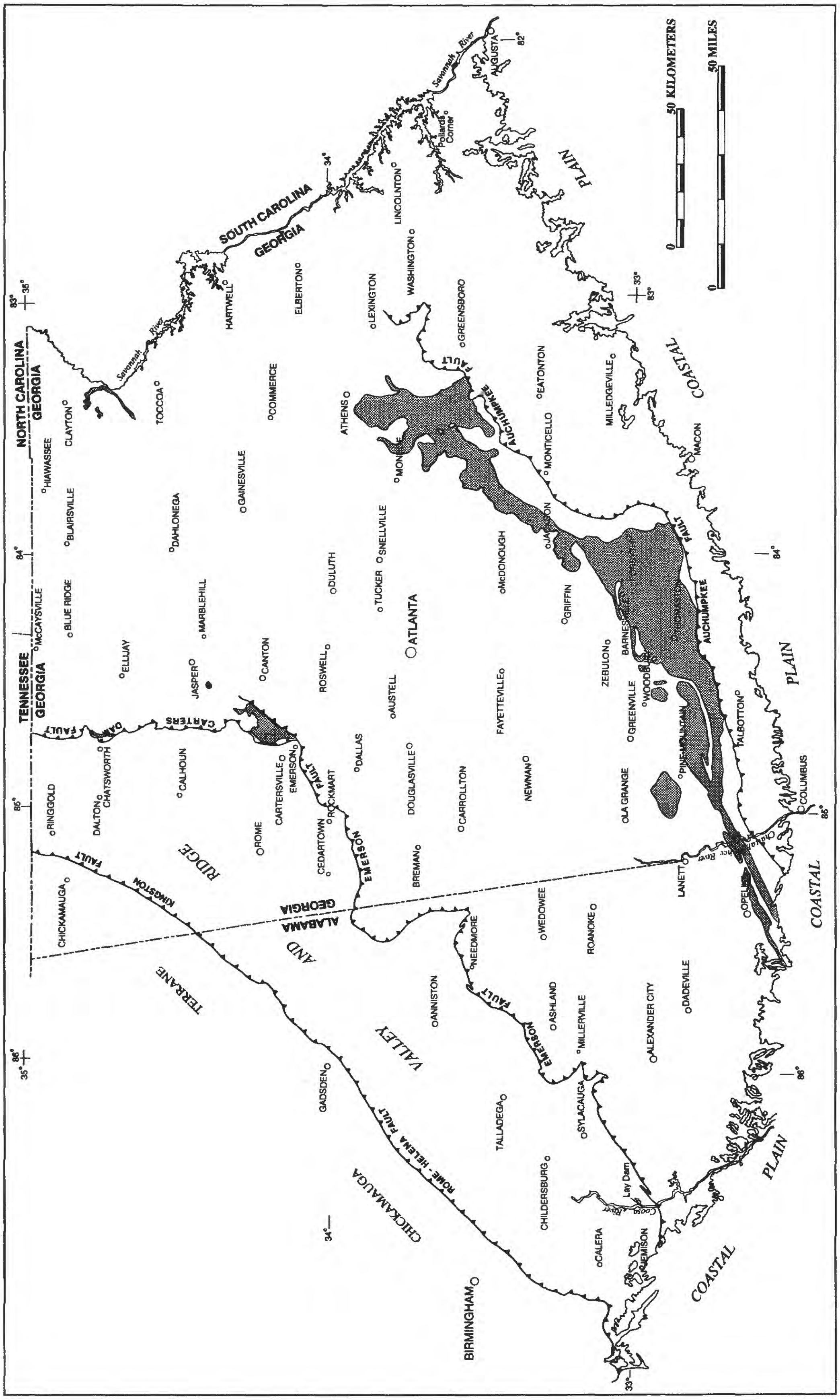


FIGURE 5.—Present known distribution of Grenville basement in the southernmost Appalachians. For greater detail, see plate 1.

TABLE 2.—*Stratigraphic units and depositional correlations in the Great Smoky and Pine Mountain Groups of the Ocoee Supergroup in Georgia*

Murphy syncline	Richard Russell thrust slice	Austell-Frolona anticlinorium	Ola anticlinorium	Pine Mountain anticlinorium
Great Smoky Group	Great Smoky Group	Great Smoky Group	Great Smoky Group	Pine Mountain Group
Dean Formation	--	--	--	--
Hothouse Formation	--	--	--	--
--	--	--	--	Chewacla Marble
		--		
Hughes Gap Formation	--	Bill Arp Formation	--	Mountain Creek Formation
Wehutty Formation	--	Frolona Formation	Kalves Creek Formation	Manchester Schist
--	--	--	Unnamed quartzite	Hollis Quartzite
Copperhill Formation	Richard Russell Gneiss	--	Ola Formation	--

In Georgia, named stratigraphic units thus far recognized as part of the Bill Arp thrust sheet are the Grenville-age Corbin Gneiss and Red Top Mountain Schist of the Allatoona Complex (Appendix A); Wiley Gneiss of Hatcher (1974); Woodland Gneiss, Cunningham Granite, Apalachee Formation, and Sparks Schist of the Wacoochee Complex (Appendix A); the Copperhill, Ola, Wehutty, Frolona, Kalves Creek, Hughes Gap, Bill Arp, Hothouse, and Dean Formations and Richard Russell Gneiss of the Great Smoky Group; and the Hollis Quartzite, Manchester Schist, Mountain Creek Formation, and Chewacla Marble of the Pine Mountain Group (Hewett and Crickmay, 1937; Crickmay, 1952; Hurst, 1955; Hernon, 1964, 1968; Crawford and Medlin, 1974; Dallmeyer and others, 1978). Most of these units are discussed in Appendix A; also see table 2 for correlations. The Nantahala Formation, Tusquitee Quartzite, Brasstown Formation, Murphy Marble, Andrews Formation, Nottely Quartzite, and Mineral Bluff Formation, which have traditionally been assigned to the "Murphy Group" of Hatcher (1972) or "Murphy Belt Group" of Hurst (1955), are not assigned to any group in this paper because our current mapping indicates that many of these units will have to be revised or abandoned (Higgins, R.F. Crawford, III, and Cressler, unpub. data). In Alabama, rocks of the Bill Arp thrust sheet (many are the same units found in Georgia) have been given various names, including parts of the Wedowee, Hatchet Creek, Mad Indian, Heard, Jacksons Gap, and Opelika Groups, and the Moffits Mill Complex (Bentley and Neathery, 1970; Neathery, 1975). We have not yet separated the Bill Arp thrust sheet from the overlying Zebulon thrust sheet in much of the Alabama crystalline terrane, where in most areas rocks belonging to the two sheets have been mapped together as formations or groups (Bentley and Neathery, 1970; Neathery, 1975; Alabama Geological Survey, 1973). The bulk of the rocks above the Grenville-age basement in the Bill Arp thrust sheet are probably late Precambrian and part of the Ocoee Supergroup (King and others, 1958).

In the area of figure 2, the Great Smoky Group (undivided) and Bill Arp Formation constitute parts of a turbidite flysch assemblage that was probably part of a submarine fan. The Great Smoky consists of fine-grained metasiltstones in sedimentation units as much as 3 m thick interbedded with fine-grained schist and phyllite sedimentation units about 3 to 30 m thick. Interspersed with the finer grained rocks are fine- to medium-grained metagraywacke conglomerates containing blue quartz granules, as well as very graphitic schists and phyllites that locally can be mapped. This sequence is interpreted to be a proximal turbidite assemblage.

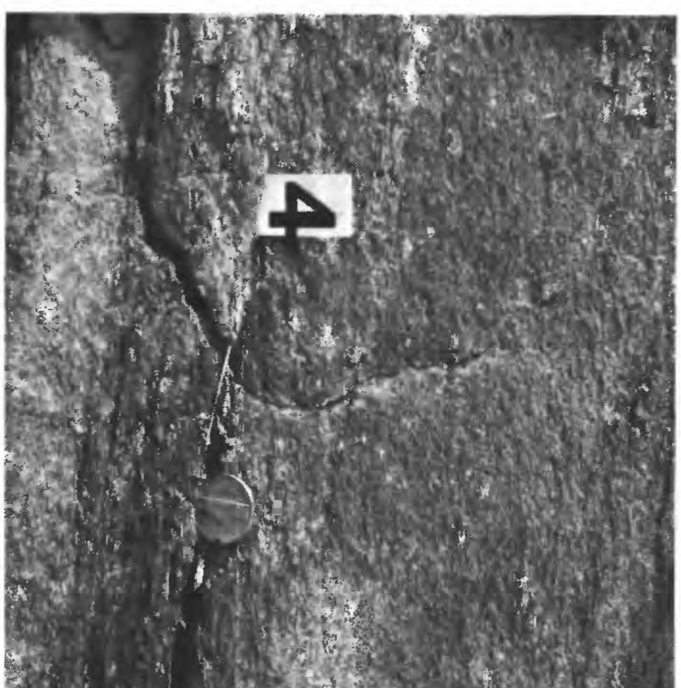
About 25 km southeast of the Great Smoky Group (undivided), in the Austell-Frolona anticlinorium (fig. 2), the Bill Arp Formation in the Bill Arp thrust sheet can be roughly divided into two gradational sequences. The lower and older sequence consists of medium-grained, graded metagraywacke about 0.3 to 3 m thick, rhythmically alternating with fine- to medium-grained schist units of about the same thickness. Well-preserved graded bedding is virtually ubiquitous in this sequence and clearly documents the anticlinal character of the major Austell-Frolona fold (figs. 2, 6) and the stratigraphic (and tectonostratigraphic) position of the Bill Arp Formation. The metagraywacke beds have straight and even bases and appear to lack high-energy features such as flute casts, sole marks, or flame structures. Within the Austell-Frolona anticlinorium, the lower sequence grades gradually upwards into a younger sequence of more massive, less well graded, thicker (1–4 m) metagraywacke beds that have thinner (generally less than 1 m) schist intervals. The metagraywacke beds in this sequence are commonly more calcareous than those in the lower sequence, and in several outcrops (on both limbs of the fold) they contain deformed calcareous concretions (Sanders and others, 1979) as much as a meter long (fig. 7). The entire sequence above the Frolona Formation in the Austell-Frolona anticlinorium probably represents slope turbidites grading upward into slightly less distal turbidites within a fan. If our interpretations are valid, then the combination of proximal facies on the northwest (Great Smoky Group undivided) with more distal turbidites to the southeast suggests that the Ocoee basins in this part of Georgia were filled from the northwest, by the construction of enormous coalescing submarine fans. This conclusion is supported by geochemical data (Appendix B) indicating that the source for some of the metasedimentary rocks in the Great Smoky sequence was the Grenville-age Corbin Gneiss in the Allatoona Complex basement (Odom and others, 1973; T.W. Stern, oral commun., 1984), east of Cartersville, Ga.

In the Austell-Frolona anticlinorium, the Bill Arp Formation is underlain by the Frolona Formation (Crawford and Medlin, 1974; pl. 1; fig. 2; table 2). The Frolona consists mostly of muscovite schists that are generally graphitic and garnetiferous and also generally contain staurolite or kyanite. Discontinuous micaceous quartzites, clean quartzites, and quartz-pebble metaconglomerates are also common in the Frolona. An important characteristic of the Frolona is the widespread occurrence in some of its schists and quartzites of small, well-formed crystals of rutile.

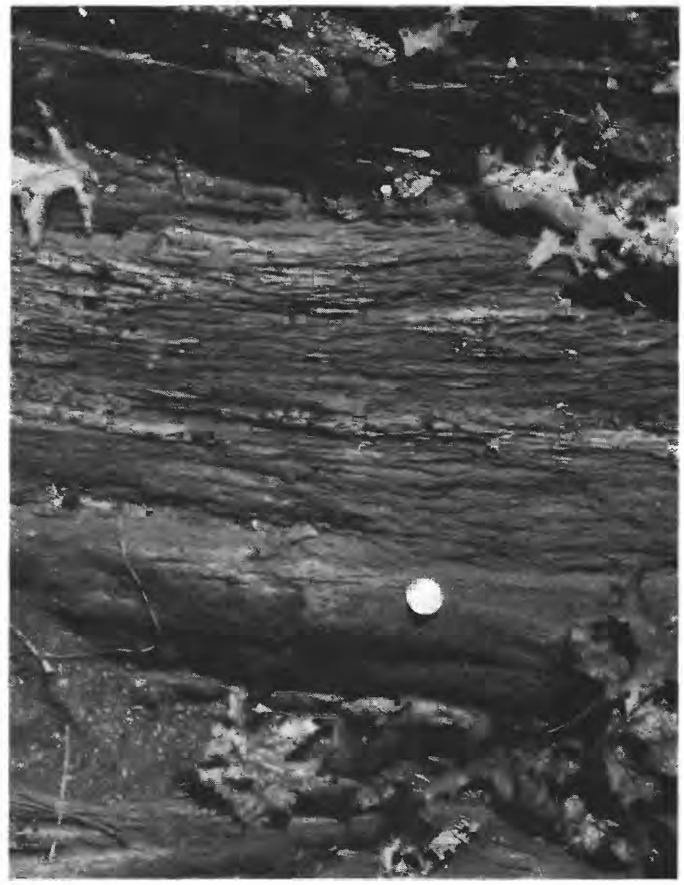
About 50 km southeast of the Austell-Frolona anticlinorium, the Bill Arp thrust sheet is again exposed in

A

B



C



D

E

FIGURE 7.—Deformed calcareous concretions in younger (upper) facies of the Bill Arp Formation in the Austell-Frolona anticlinorium. Roadcut along westbound lanes of Interstate 20 just west of Georgia Highway 5, in the Winston, Ga. 7.5-min quadrangle. Concretion near center of photo is approximately 1 m long.

the Ola anticlinorium (fig. 2), where the sheet is composed of the Ola and Kalves Creek Formations. The Ola is a thick sequence of medium- to coarse-grained schists with lensoidal units of biotite-plagioclase gneiss (metagraywacke or metasiltstone). The overlying Kalves Creek Formation is composed of medium- to coarse-grained schists, minor amounts of biotite-plagioclase gneiss, and distinctive yellow- to white-weathering, graphite-sillimanite schist that commonly breaks into spindles upon weathering. The Kalves Creek is lithologically similar to the Frolona Formation, its probable depositional equivalent. The Ola is lithologically similar to the Copperhill Formation in northern Georgia, and the Kalves Creek Formation is lithologically identical to the Wehutty Formation, which overlies the Copperhill (see Dallmeyer and others, 1978). Schists in the Wehutty contain small, well-formed rutile crystals.

Still farther to the southeast, the Pine Mountain Group in the Pine Mountain anticlinorium (Hewett and Crickmay, 1937; Clarke, 1952; Bentley and Neathery, 1970; Sears, Cook, and others, 1981; Appendix A) is a sequence of schists, biotite gneisses (metagraywackes), quartzites, and lesser amounts of marble, without volcanic components. The schists and gneisses are lithically identical to parts of the Great Smoky Group to the north. Nearly white graphite-sillimanite schists of the Manchester Schist are lithic matches of the Wehutty and Kalves Creek Formations and part of the Frolona Formation, and these schists contain small amounts of rutile (also see Hewett and Crickmay, 1937, p. 29, and Bentley and Neathery, 1970, p. 36). These schists are overlain by the Mountain Creek Formation (Appendix A), a schist and metagraywacke unit that is identical with the Bill Arp and Hughes Gap Formations to the north (table 2). We suggest that all of these units represent the same depositional environments within the Ocoee basins.

Hewett and Crickmay (1937) and Bentley and Neathery (1970) considered the Pine Mountain Group to consist of only the Hollis Quartzite, Manchester Schist, and Chewacla Marble, and they placed the Sparks Schist in the basement (Wacoochee Complex of Bentley and Neathery, 1970). We agree that the rocks that have been assigned to the Sparks Schist or Formation (Sears, Cook, and others, 1981) belong to the Grenville basement, for the following reasons. (1) Structural relations between the rocks beneath the Hollis Quartzite (including Sparks Schist) suggest an unconformity. Near their contact with the Hollis these rocks have been deformed into parallelism with the Hollis, but away from that contact the structure in the basement rocks is discordant to that in the Hollis and overlying rocks, as noted by Hewett and Crickmay (1937) and Clarke (1952). (2) The rocks beneath the Hollis are extensively granitized and cut by thin, commonly rootless, granitic bodies, whereas these features are not found in the overlying rocks as recognized by Crickmay (1952, p. 23) and Bentley and Neathery (1970, p. 34). What has previously been mapped as Sparks Schist or Sparks Formation (Hewett and Crickmay, 1937; Clarke, 1952; Bentley and Neathery, 1970; Sears, Cook, and others, 1981) consists of two different

←

FIGURE 6.—Graded bedding in metagraywacke and schist of the Bill Arp Formation in the Austell-Frolona anticlinorium. *A*, Small cut on south side of Mason Creek Road just east of Baggett Road, in the Winston, Ga. 7.5-min quadrangle. Sharp bases and diffuse tops of metagraywacke beds indicate tops to the north (right in photo); beds are near vertical. Knife is 8 cm long. *B*, Closer view of some of the beds shown in *A*. Arrows point to sharp bases of coarser parts of beds (tops to right). Number 2 is 2 cm high. *C*, Cut along Johnston Road, approximately 30 m southeast of powerlines, in the Winston, Ga. 7.5-min quadrangle. Sharp bases and diffuse tops indicate that tops are to the north (right in photo). Coin is 2 cm in diameter. *D*, Exposure in ditch along unnamed dirt road just north of Hinesley Cemetery about 20 m east of tributary to Little Snake Creek in the Hulett, Ga. 7.5-min quadrangle. Tops toward top of photo (to southeast). Coin is 2 cm in diameter. *E*, Roadcut along Mason Creek Road between powerlines and Berea Road in the Winston, Ga. 7.5-min quadrangle. Tops of beds toward top of photo. Knife is 8 cm long.

rock types: (1) sheared gneisses (including granulitic gneisses) that are now "schists," and (2) true metasedimentary pelitic schists. It can locally be shown that the sheared gneisses grade into massive granulite. The pelitic schists are greatly deformed, red, silvery, and gray, extensively granitized, coarse-grained rocks that occur as the country rock between the granulitic plutons and also as xenoliths and roof pendants in the plutons; the name Sparks Schist should only be used for these pelitic schists (see Appendix A). Locally the Sparks Schist contains thin metagraywacke beds.

We consider the Pine Mountain Group to consist of (from lowest to highest) the Hollis Quartzite, Manchester Schist (as modified in this paper), Mountain Creek Formation (named in Appendix A), and Chewacla Marble. The name Manchester Schist is retained for the unit of graphitic sillimanite schist that overlies the Hollis. This schist is overlain (apparently gradationally) by the Mountain Creek Formation, which consists of pelitic schists interbedded with metagraywackes. The Manchester is the depositional equivalent of the Wehutty and Kalves Creek Formations and part of the Frolona Formation, all belonging to the Great Smoky Group of the Ocoee Supergroup (table 2). The Mountain Creek Formation is the depositional equivalent of the Hughes Gap and Bill Arp Formations of the Great Smoky Group. We assign the Pine Mountain Group to the Ocoee Supergroup, but we retain the separate group status of the Pine Mountain because of its traditional use in the Pine Mountain block.

In Georgia the Pine Mountain area (fig. 8) contains granulitic rocks that have been considered "Grenville basement" (Odom and others, 1973; Rankin, 1975, 1976; Schamel and Bauer, 1980; Schamel and others, 1980; Sears, Cook, and others, 1981; Sears, Cook, and Brown, 1981; Hatcher, 1983; Williams and Hatcher, 1982, 1983; Hatcher and others, 1983, 1984; Sears and Cook, 1984). Assignment of these rocks to "Grenville basement" was made because of the similarity of the structurally overlying Pine Mountain Group to late Precambrian Ocoee Supergroup sequences, or the Murphy Group sequence, or Chilhowee Group sequences in northern Georgia, or lower Paleozoic sequences in the Valley and Ridge province, and because of Odom and others' (1973) report of a U-Pb zircon age in excess of a billion years from Pine Mountain "basement" rocks. The reported zircon age must be considered with caution because it was reported only in an abstract (Odom and others, 1973), giving no analytical data other than the age, and there has been no subsequent publication of the data. Nevertheless, massive and poorly foliated charnockitic and other granulitic rocks are present structurally beneath the Pine Mountain Group (Great Smoky Group equivalents) in the Pine Mountain area in Georgia (also see Stieve, 1984; Sears and Cook, 1984) and are reasonably assigned to Grenville basement. This assignment means that the Sparks Schist, which has been intruded, granitized, and metamorphosed by the Grenville plutons, is probably one of the oldest rocks in the crystalline terrane of the southernmost Appalachians. To the northeast (from south of Barnesville, Ga.; pl. 1), the place of the Sparks Schist is taken by the Apalachee Formation, a coarse-grained, granitized, greatly deformed, schistose, reddish garnet–sillimanite–K-feldspar–plagioclase–biotite (and biotite–plagioclase) gneiss with scarce amphibolite, which weathers to a chocolate-colored soil. The garnets in the Apalachee are commonly in aggregate clots as much as 5 cm in diameter. Both the Sparks and the Apalachee are found south of Barnesville, but age relations between them have not been determined. This basement complex, composed of the Sparks Schist, Apalachee Formation, and various Grenville-age plutonic rocks, was called the Wacoochee Complex by Bentley and Neathery (1970), and this Alabama name has precedence even though the rocks are better exposed in Georgia; we here assign all of the Grenville and older basement rocks in the Pine Mountain anticlinorium to the Wacoochee Complex (Appendix A).

There are problems with interpretations of the structure of the Pine Mountain area. Clarke (1952) first suggested that the Goat Rock, Towaliga, and Brevard "faults" are the same fault, thus interpreting the rocks south of the Goat Rock and between the Towaliga and the Brevard as part of the same enormous allochthon. This idea was expanded by Bentley and Neathery (1970), Rankin (1975), Schamel and Bauer (1980), Schamel and others (1980), Sears, Cook, and Brown (1981), Sears, Cook, and others (1981), Sears and Cook (1984), Hatcher (1984), and Sears (1985). The northern boundary of the Pine Mountain sequence, the Towaliga fault (or fault zone; see Grant, 1967, 1968), has most recently been considered to be a normal fault (Schamel and Bauer, 1980; Schamel and others, 1980; Sears, Cook, and Brown, 1981; Sears, Cook, and others, 1981; Sears and Cook, 1984), which along with the Goat Rock fault (or fault zone) is interpreted to bound a structural and erosional "Pine Mountain window" through the "crystalline Piedmont allochthon" (Sears and Cook, 1984, p. 281) or the "Piedmont–Blue Ridge allochthon" (Sears, 1985) to Grenville basement. The rocks within the "window" (Pine Mountain Group and Grenville basement) are interpreted to reside in large refolded nappes (Schamel and Bauer, 1980; Sears, Cook, and Brown, 1981; Sears, Cook, and others, 1981; Sears and Cook, 1984; Sears, 1985).

The nappe interpretation of the Pine Mountain block depends on (Sears and others, 1981, p. 45–46) (1) correlation of the "upper schist member" of the Manchester Formation of Clarke (1952) with the Sparks Schist of Hewett and Crickmay (1937); (2) correlation of the Sparks Schist in Georgia with the Halawaka Schist (of Bentley and others, 1982) in Alabama; (3) assignment of the Halawaka Schist, which Bentley and others (1982) included with Wacoochee belt ("basement") units in Alabama, to the Pine Mountain Group; and (4) correlation of the "quartzite member" of the Manchester Formation of Clarke (1952) with the Hollis Quartzite. We agree with Sears, Cook, and others (1981) that the "quartzite member" of the Manchester Formation is the Hollis Quartzite; it maps directly into Hollis Quartzite to the north (fig. 8) and is in the correct place in the stratigraphic section. However, points 1 and 3 above are not correct; the "upper schist member" of the Manchester Formation of Clarke (1952) is not equivalent to the Sparks Schist of Hewett and Crickmay (1937); the "upper schist member" is Manchester Schist of the Pine Mountain Group, whereas the Sparks is part of the Grenville basement. The Halawaka Schist of Bentley and others (1982) belongs with the Sparks Schist in the Wacoochee Complex of Grenville basement. The structure of the Pine Mountain anticlinorium is compatible with some of the Georgia cross sections in Sears and others (1981, p. 43, fig. 2 a, and less so b), but not with the Georgia section in Sears and Cook (1984, p. 283, fig. 2b), nor with any of the sections presented by Sears (1985).

We do not consider the Pine Mountain block to be a window for the following reasons. (1) What has been mapped as the Goat Rock fault (a) locally coincides with the Auchumpkee thrust fault at the base of the Little River thrust stack (figs. 1, 39), (b) does not represent a normal fault along which uplift of the Pine Mountain block took place, and (c) certainly is not the same fault as the Towaliga or the Brevard. (2) Our work shows that there is no evidence for equivalency of the Brevard Zone and the Towaliga fault zone, and certainly no evidence that the rocks between the Brevard and the Towaliga reside in a single "Inner Piedmont meganappe," "Piedmont allochthon," or "Piedmont–Blue Ridge allochthon." In fact, there is an abundance of data to the contrary. (3) We have found no rocks south of the Pine Mountain block (fig. 8) that are also present north of the block; the southern border of the block is the Macon melange. Small slices of the Zebulon thrust sheet are found along the northern edge of the southern border of the block.

The northwestern boundary of the Pine Mountain block is a complex zone of mylonites, polymylonitic rocks, and brittle cataclastic rocks that has long been called the Towaliga fault or fault zone (Crickmay, 1933, 1939, 1952; Clarke, 1952; Grant, 1967, 1968; Bentley, 1969; Higgins, 1971; Schamel and Bauer, 1980; Schamel and others, 1980; Sears, Cook, and others, 1981; Sears, Cook, and Brown, 1981). Our work indicates that there is a Towaliga normal fault with the northwest side downthrown relative to the southeast side, and also a complex Towaliga fault zone with a more complicated movement history.

The Towaliga fault zone is a discontinuous zone of mylonite, blastomylonite, button schist, and mylonite gneiss as much as 2 km wide (shown as b & g in pl. 1). The ductile mylonitic nature of these rocks suggests that they formed at high pressures and relatively high temperatures, and they are thus considered older than the normal fault that has caused uplift of the Pine Mountain block relative to the rocks to the northwest. These rocks are poorly understood, but we suggest that they formed in deep-seated parts of an imbricate thrust zone that occurred in the lower thrust sheets and basement in the Georgiabama thrust stack. This thrust zone probably resulted from northwestward adjustment of the Grenville basement and Bill Arp thrust sheets as they were overridden by the Georgiabama thrust stack. Complex movement along the fault zone probably also involved a strike-slip component (Grant, 1967, 1968) in response to the stack arriving at an angle to the trends in the Bill Arp thrust sheet protoliths and the Grenville basement.

The normal fault along which the Pine Mountain block has been uplifted relative to the rocks to the northwest is generally marked by a relatively thin zone of brittle microbreccias with a fabric that generally dips to the northwest 40–60° (also see Grant, 1967, 1968); some of these are microbreccias formed from the earlier mylonitic rocks. It cuts across the earlier ductile zone and the fabric of mylonitic rocks in that zone. The northwest dip of fabric in the microbreccias has generally been taken to indicate that the normal fault dips northwest (as shown in fig. 8 and pl. 2), but this dip direction has not been proven. The Towaliga fault has also generally been considered to have great vertical displacement; this may not be true, either. In the stretch between Barnesville, Ga., and Woodbury, Ga. (pl. 1, fig. 8), rocks of the Pine Mountain Group (Great Smoky Group depositional correlatives; see Appendix A) (Hollis Quartzite, Manchester Schist, and Mountain Creek Formation) in the Bill Arp thrust sheet on the southeast side of the fault zone are juxtaposed against rocks of the Zebulon Formation in the Zebulon thrust sheet on the northwest side of the zone (mylonitic rocks intervene in many places), suggesting relatively large vertical displacement. However, northeast of Barnesville and southeast of Pine Mountain, Pine

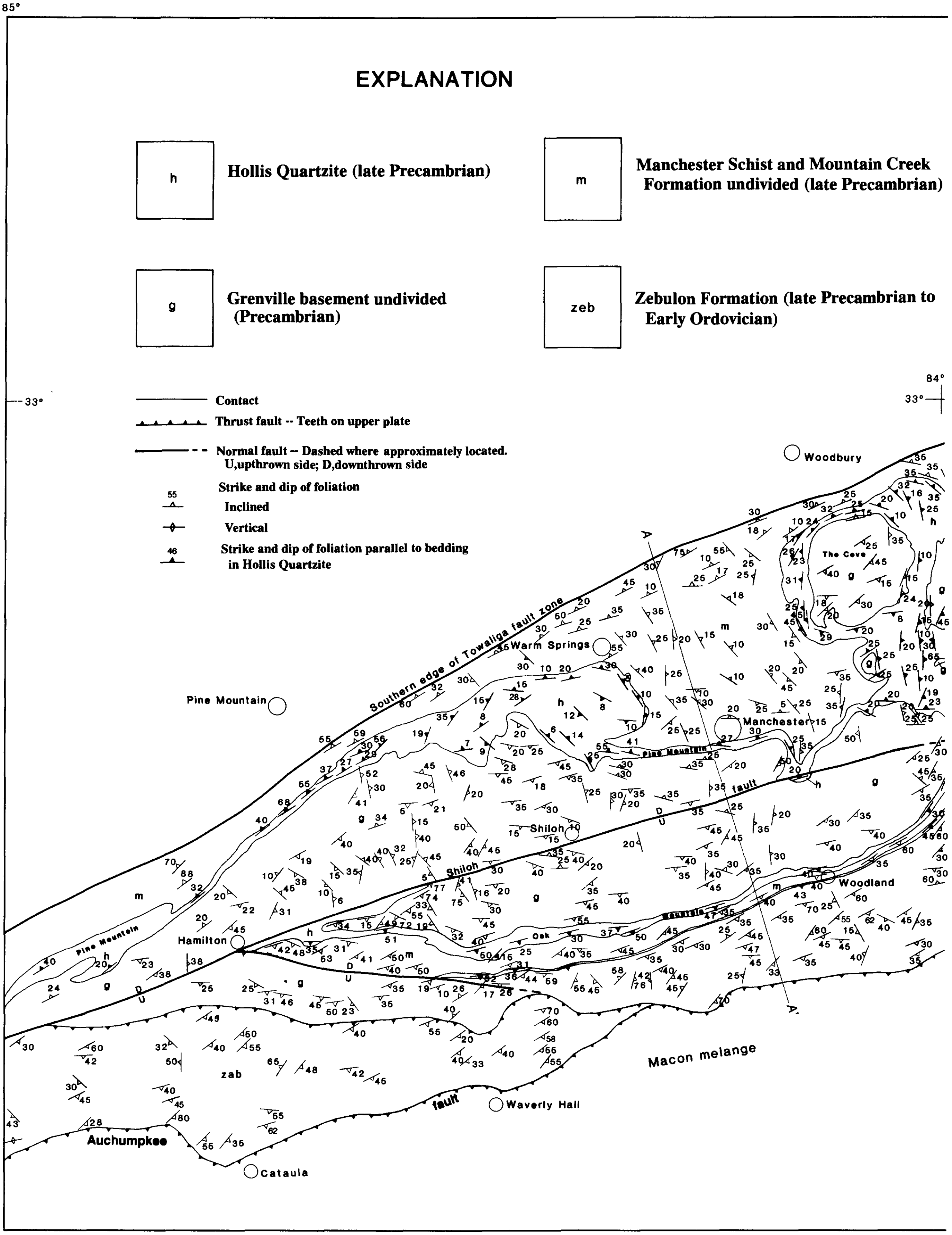
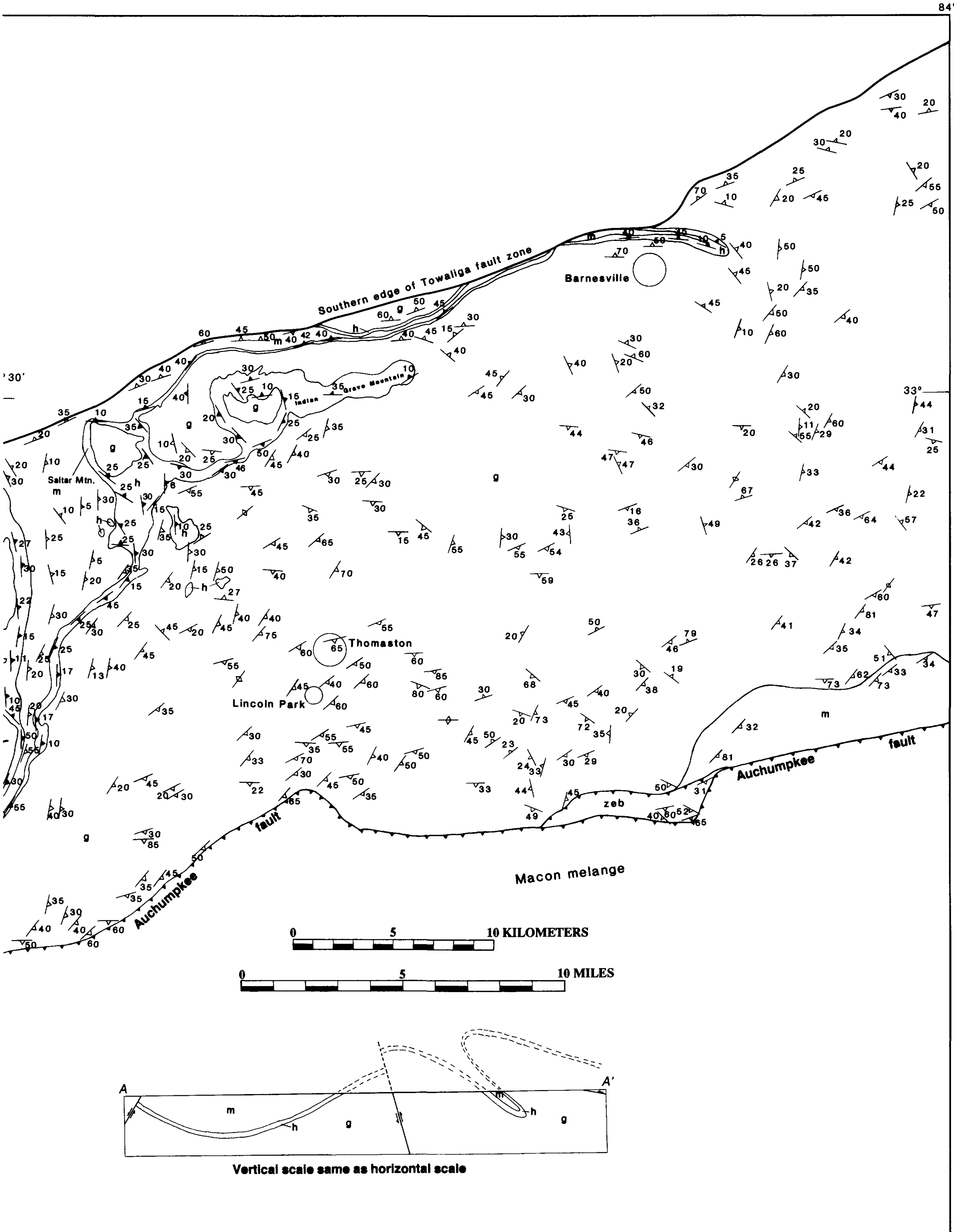


FIGURE 8.—Generalized geologic map of the Pine Mountain anticlinorium in the Thomaston,



Ga., and Griffin, Ga. 1° × 30′ quadrangles (Clarke, 1952; Hewett and Crickmay, 1937).

Mountain Group rocks (not including the Hollis Quartzite) are found on both sides of the fault zone (locally the fault is intraformational), indicating that the displacement may not be as great as generally thought (nor as shown in pl. 2).

Southeast of the Towaliga fault, and trending parallel to it, is the Shiloh fault (Schamel and Bauer, 1980; Sears, Cook, and others, 1981), which is also a normal fault with its southeast side upthrown relative to its northwest side (fig. 8). The age of the normal faulting is unknown, but the one-sided-horst nature of the geometry it has created is compatible with a suggestion that it occurred as the Little River thrust stack moved onto the Georgiabama thrust stack. Could the loading from the southeast (present direction) have seesawed the crust to initiate the present fault configuration?

Most of the Blue Ridge physiographic province in northern Georgia is underlain by rocks of the Ocoee Supergroup, rocks that have previously been considered part of a "Murphy Group" of Hatcher (1972) or "Murphy Belt Group" of Hurst (1955), and relatively rare Grenville-age basement rocks in the Bill Arp thrust sheet.

Rocks of the Ocoee Supergroup (mostly Great Smoky Group) underlie large areas in northern Georgia. Rocks that have traditionally been assigned to the "Murphy Group" or "Murphy Belt Group" occupy the Murphy syncline, which has long been considered to be a major synclinorial feature extending from south of Canton, Ga., to near the Tennessee River south of Bryson, N.C. (Hadley, 1970, fig. 1; Hadley and Nelson, 1971; Dallmeyer and others, 1978, fig. 2; pl. 1, this paper); the flanks of the syncline are occupied by rocks of the Great Smoky Group. Grenville-age basement rocks are known only in structurally complex anticlinoria to the west of the Murphy syncline (Bayley, 1928; Fairley, 1965; Crawford and Cressler, *in* Cressler and others, 1979; McConnell and Costello, 1984); rocks that possibly belong to the Grenville basement (Wiley Gneiss of Hatcher, 1974) occur some distance to the east of the Murphy syncline around the flanks of another complex structure that has been called the "Tallulah Falls dome" (Hatcher, 1973, 1976, 1983). Small infolded remnants of the Zebulon, Ropes Creek, and Soapstone Ridge thrust sheets are scattered widely over the area (pl. 1).

Between the Carters Dam fault and the western flank of the Murphy syncline, known Grenville basement crops out in three main areas: (1) east and northeast of Cartersville; (2) in the Salem Church area near Jasper; and (3) around Fort Mountain near Chatsworth (pl. 1). We assign all of these basement rocks to the Allatoona Complex (Appendix A).

The Great Smoky Group in the Murphy synclinorium consists (in ascending order) of the Copperhill, Wehutty, Hughes Gap, Hothouse, and Dean Formations (table 2). The Richard Russell Gneiss (Appendix A), in a separate thrust slice on the eastern flank of the physiographic Blue Ridge, is composed of sheared but massive biotite gneiss and lesser amounts of schist and lacks metavolcanic rocks; we assign it to the Ocoee Supergroup. It is probably coeval with the lower units of the Great Smoky Group.

The "Murphy Group" has generally been considered to be composed (in ascending order) of the Nantahala Formation, Tusquitee Quartzite, Brasstown Formation, Murphy Marble, Andrews Formation, Nottely Quartzite, and Mineral Bluff Formation. Hurst (1955, p. 8) suggested the possibility of an unconformity beneath the Nantahala Formation and assigned the Great Smoky Group in Georgia to the Precambrian and the "Murphy Group" to the Cambrian. Tull and Guthrie (1983) suggested that an unconformity equivalent to the "pre-Lay Dam Formation unconformity" of Tull (1982) beneath the Talladega Group in Alabama is present within the "Murphy Group," either above or within the Andrews Formation. They suggested that the Murphy Marble is stratigraphically equivalent to the lowermost part of the "Sylacauga Marble group," beneath the unconformity, and that the Nottely Quartzite and the Mineral Bluff Formation are equivalent to the lower part of the Talladega Group. They suggested that the upper part of the "Sylacauga Marble group" is absent above the Murphy Marble because of a deeper level of erosion below the unconformity, and they interpreted the Kahatchee Mountain Group of Tull (1982) to be the stratigraphic equivalent of the "Murphy Group" below the Murphy Marble as well as "perhaps of the upper part of the Precambrian Great Smoky Group." More recently, Guthrie (1984) suggested, on the basis of lithostratigraphic relationships, that the Kahatchee Mountain Group in Alabama is equivalent to parts of the Walden Creek and Chilhowee Groups, that the lower part of the "Murphy Group" in northern Georgia may be a facies of the Chilhowee Group and be Early Cambrian in age, and that "an upper age constraint for the KMG [Kahatchee Mountain Group] is provided by Early Ordovician conodont elements in the overlying Sylacauga Marble Group" (p. 143).

The "Sylacauga Marble group" is now known to be part of the Valley and Ridge (in the Rome thrust sheet) and is probably mostly part of the Knox Group (Harris and others, 1984), just as Shaw (1970, 1973) mapped it more than a decade ago. Most interpretations of the stratigraphy and regional correlations of the "Murphy Group" have centered on correlation of the Murphy Marble with lower Paleozoic carbonate units in the

Valley and Ridge province; the most common correlation has been with the Lower Cambrian Shady Dolomite in the Rome thrust sheet, and thus the lower units of the "Murphy Group" have been correlated with the Chilhowee Group. However, in Georgia, the Murphy Marble is a relatively "clean" marble (Hurst, 1955; Fairley, 1965; Power and Forrest, 1973), not the type of carbonate deposit that would be expected oceanward from the shelf environment of the lower Paleozoic carbonate units in the Valley and Ridge province. Moreover, because the marble crops out in a syncline, palinspastic restoration would require that it have been deposited 20–30 km oceanward from the Valley and Ridge carbonates; the fact that it has been transported along with all the underlying rocks along the Carters Dam fault requires an even greater separation. Thus, it seems unlikely that the Murphy Marble is directly correlative with any of the Valley and Ridge carbonate units, including the "Sylacauga Marble group."

Power and Forrest (1973) interpreted the upper part of the Great Smoky Group (Dean Formation) to be in stratigraphic contact with the "Murphy Group." In a description of the deposits filling the Murphy basin, they interpreted the Dean Formation to be an alluvial flood-plain deposit, the overlying Nantahala Formation to be a tidal-flat or lagoonal deposit, the Tusquitee Quartzite to be a beach-sand deposit, the Brasstown Formation to be an open-marine shelf deposit, and the Murphy Marble to be a reef or carbonate bank deposit. They stated of the Andrews Formation (Power and Forrest, 1973, p. 707): "The calc-schists of the Andrews Formation represent a mixture of carbonate rock with clastic sediments. The carbonate reef of the Murphy marble no longer stood above the level of the surrounding sea floor, and terrestrial material was carried to and across the carbonate bank. There must, therefore, have been general shoaling of the marine shelf on which the Brasstown Formation was deposited." They went on to interpret the Nottely Quartzite as a beach or off-shore bar deposit that (1973, p. 707) "represents the climax of shoaling and regression of the shoreline that prevailed during deposition of the Andrews Formation" and the Mineral Bluff Formation as marking "a return to open-marine shelf conditions."

The problem with an interpretation of a coastal-plain-like origin for rocks that have been considered the "Murphy Group" is that (1) many of these units contain coarse lithic conglomerates and feldspar-clast and quartz-pebble conglomerates, which must have been derived from a nearby source; (2) blue quartz granules and pebbles in some of the conglomerates are characteristic of the Grenville basement and some of the lithic pebbles are from the basement; and (3) the angularity of some of the lithic clasts, quartz clasts, and detrital feldspars requires extremely rapid, very-near-source deposition. In our opinion, these coarse clastic rocks were deposited from active fault scarps at the edge of stepped basins during early stages of the opening of the Iapetus Ocean.

Our mapping in the Cartersville, Ga. $1° \times 30'$ quadrangle and our field checking of the "Murphy syncline" to the north and northeast in Georgia and North Carolina indicate that the sequences in the Mineral Bluff area (Hurst, 1955) and to the northeast are not the same as the sequence in the Cartersville quadrangle. Rather than occurring in a stratigraphic sequence deposited on a coastal plain, the marbles in the Murphy syncline in the Cartersville quadrangle are clasts (mostly slabs) in the West Point melange (see section on West Point melange). The marbles are probably unrelated to the Murphy Marble in North Carolina. What has been mapped as the Brasstown and Valleytown Formations, Andrews Schist, and part of the Great Smoky Group constitutes the West Point melange. In addition to the lack of upper "Murphy Group" rocks in the area, the lower part of the "Murphy Group" and the upper units of the Great Smoky Group are not what they have been previously reported and interpreted to be (including the interpretations in Higgins and others, 1986). What has been called the Nantahala Schist or Nantahala Formation by earlier workers is the same unit that has been mapped as Hiwassee Schist and as the Wilhite Formation. The "Nantahala-Hiwassee-Wilhite" unit consists of very carbonaceous graphitic button schist with coarse metaconglomerates and microconglomeratic metasandstones. Both the metaconglomerates and the metasandstones contain blue quartz granules, detrital feldspars, and, locally, detrital micas, and the metaconglomerates contain pebbles derived from the Grenville basement rocks (chiefly Corbin Gneiss), and black slate and graphitic schist chips, probably from cannibalization. The graphitic and conglomeratic unit is stratigraphically and structurally near Grenville basement in the Allatoona Complex; it is not above a thick sequence of Great Smoky Group rocks. Great Smoky Group rocks structurally above the graphitic schist and metaconglomerate unit are represented by the Copperhill Formation, which in the Cartersville quadrangle contains dikes and sills of amphibolite (Ducktown assemblage) associated with the opening of the Iapetus Ocean. The "Nantahala-Wilhite-Hiwassee" unit is separated from the basement only by a nearer shore, very coarse conglomeratic unit, which we consider to be a depositional facies of the Pinelog Formation.

With regard to the marbles that don't appear to be in a melange: we don't think a direct correlation can or should be made between any of the metamorphosed carbonate units (Murphy, "Brevard," Chewacla) in the crystalline terrane in the southernmost Appalachians and units in the Cambrian-Ordovician carbonate shelf sequence in the Valley and Ridge province. They may all be roughly the same age as or slightly older than the carbonate shelf sequence, but they are all transported and probably formed in separate basins (pl. 2). This interpretation is probably also true of the Pine Mountain Group; these Great Smoky lithic and depositional equivalents were probably deposited in a different basin from the Great Smoky in the Austell-Frolona anticlinorium, Ola anticlinorium, and Murphy syncline. In fact, the Bill Arp thrust sheet is probably composed of sliced-off remnants of three or more different Ocoee basins. The carbonate units in the Brevard Zone are also considered to be in the Bill Arp thrust sheet and to represent the same general depositional conditions as the other carbonate units near the top of the Ocoee basins.

DUCKTOWN ASSEMBLAGE

Although the lack of volcanogenic components (including mafic intrusive rocks) is a salient characteristic of the Bill Arp thrust sheet, an exception occurs in the Copperhill Formation, the lowest unit of the Great Smoky Group, in northern Georgia (pl. 1). There, both coarse- and relatively fine-grained amphibolites crop out in apparent concordancy with the Copperhill metasedimentary rocks (Hurst, 1955; Slater, 1982, 1985; Abrams, 1985; Slater and others, 1985). Hurst (1955, p. 62–63) considered these rocks to be either "a diabasic or gabbroic sill" that had intruded the Great Smoky metasedimentary rocks or "thin basalt flows" within the sequence; he (1955, p. 63) preferred the sill origin because of metasedimentary inclusions occurring as "large, tabular masses near the center of the sill in the Epworth quadrangle." Abrams (1985) considered the amphibolites to be metadiabase, presumably in dikes. The amphibolite sill(s) or dike(s) are also present northwest and north of McCaysville in the Copperhill and Ducktown areas, Tennessee (Hurst, 1955; Slater, 1982, 1985; Slater and others, 1985), and east of the Murphy syncline. The amphibolites are locally closely associated with thin pyritiferous iron formations and massive sulfide deposits as recognized by Abrams (1985).

In addition to the amphibolite sill(s) and (or) dike(s), fine- to medium-grained metamorphosed felsic tuffs (fig. 9*A*), coarse tuff breccias (fig. 9*B*), and coarse, poorly sorted volcanic-epiclastic conglomerates (fig. 9*C*) occur with the massive sulfide deposits at Ducktown; we call these rocks the Ducktown assemblage. These rocks seem to confirm the volcanogenic nature of the Ducktown deposits (Slater, 1985; Slater and others, 1985). However, rather than being associated directly with thick sequences of volcanic rocks with virtually no nonvolcanogenic clastic metasedimentary rocks (though the Cherokee alteration zone of the Ropes Creek Metabasalt has fine-grained schists that are probably metamorphosed pelagic sediments), as are the Ropes Creek and Little River sulfide deposits (discussed in later sections), the massive sulfide deposits in the Ducktown area occur within nonvolcanogenic clastic metasedimentary rocks (mostly graywacke and schist of the Copperhill Formation), as well as within volcaniclastic and volcanic-epiclastic rocks.

Because they occur in the lowermost part of the Great Smoky Group, in the lowermost metasedimentary rocks in one of the Ocoee basins and partly within nonvolcanic clastic sequences, and because they appear to be found only around the rift zones, we follow Slater and others (1985, p. 180–181) and suggest that the metavolcanic and metavolcanic-epiclastic rocks of the Ducktown assemblage represent rift volcanism associated with the formation of the basin. As such, they represent the same early stage of basin-formation igneous activity as the Mount Rogers and Grandfather Mountain Formations farther northeast—they mark the beginning stages of extension that resulted in the opening of the Iapetus Ocean.

ZEBULON THRUST SHEET

The next highest thrust sheet in the Georgiabama thrust stack, the Zebulon thrust sheet, is bounded below by the Zebulon thrust fault. Like the Bill Arp sheet, the Zebulon sheet underlies large areas in the crystalline terrane of the southernmost Appalachians (fig. 10). The Zebulon sheet is composed of the Zebulon Formation, a thick unit of intercalated, generally pink- to purple-weathering schists (commonly containing abundant aluminosilicate minerals and garnet), ocher-weathering hornblende-plagioclase amphibolites, and lesser amounts of a wide variety of biotite-plagioclase gneisses (metagraywackes) and minor granitic gneisses (Appendix A). In addition to the intercalated amphibolites, amphibolites also occur as clasts (blocks) in the schists (fig. 11). In its uppermost parts the Zebulon Formation has thin (generally less than a meter thick) beds of gondite (spessartine quartzite) and magnetite-bearing gondite interpreted as metamorphosed volcanogenic chemical sediments. Higgins and Atkins (1981) named this gondite-bearing interval the Senoia Formation, but it has not been mapped separately from the Zebulon Formation in most areas and

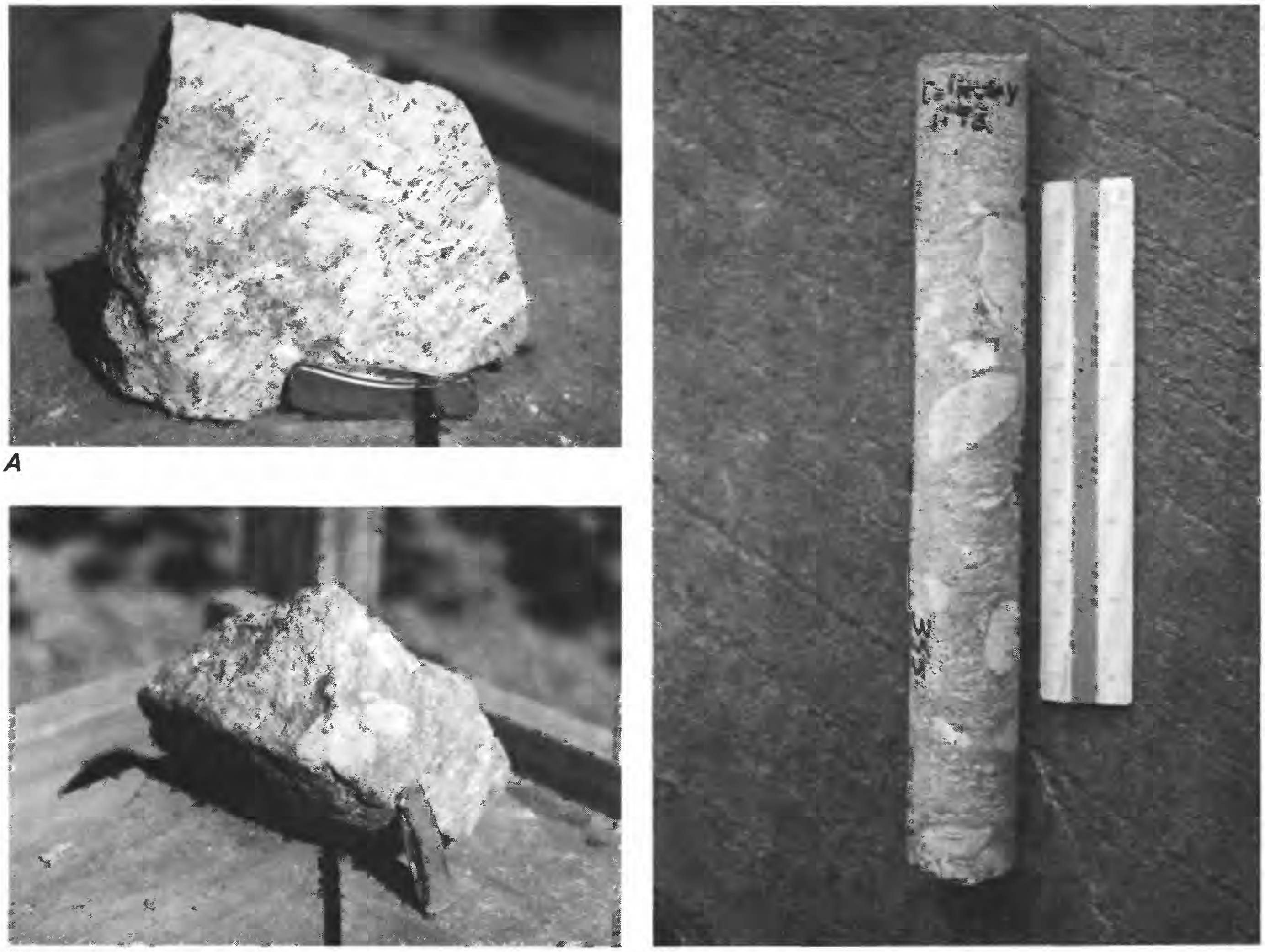


FIGURE 9.—Rock samples and drill-core of the Ducktown assemblage from the Cherokee mines of the Tennessee Chemical Company, Ducktown, Tenn. *A*, Metamorphosed felsic tuff from the open-pit mine. Dark minerals are amphiboles. Knife is 6 cm long. *B*, Metamorphosed tuff breccia from the open-pit mine. Knife is 6 cm long. *C*, Metavolcanic-epiclastic conglomerate in core from 364 m (1,193 ft) below surface in the underground mine (courtesy of W. Randy Slater, Tennessee Chemical Company).

is presently considered a member of the Zebulon (Appendix A).

In contrast with the underlying, all-metasedimentary Bill Arp thrust sheet, the Zebulon sheet is an intimate mixture of metavolcanic (including metavolcanogenic sediments) and metasedimentary components. Except in small areas around local shear zones and where the sheet is involved in the retrogression of the Brevard Zone, the rocks of the Zebulon thrust sheet are at kyanite or sillimanite grade and are not retrograded; the amphibolites are neither chloritized nor otherwise altered.

In Alabama, rocks of the Zebulon thrust sheet have been given various names (table 1), including parts of the Wedowee, Hatchet Creek, Mad Indian, Heard, Jacksons Gap, and Opelika Groups and parts of the Dadeville Complex (Bentley and Neathery, 1970; Neathery, 1975; Sears, Cook, and others, 1981). Most of the rocks in the Zebulon sheet have not been previously named in Georgia (except for McConnell and Abrams' [1984] assignment of some of the Zebulon to their Univeter Formation—abandoned, see Appendix A). Rocks of the Zebulon thrust sheet crop out over large areas in the Georgia crystalline terrane, from just north of the Towaliga fault zone and just north of the Macon melange nearly to the Valley and Ridge province (pl. 1). Slices of the Zebulon sheet are found as synformal infolds in the Bill Arp sheet in the Ola and Pine Mountain anticlinoria and in northern Georgia.

The assemblage of metamorphosed shales, discontinuous mafic tuffs, clasts of basalt, volcanogenic

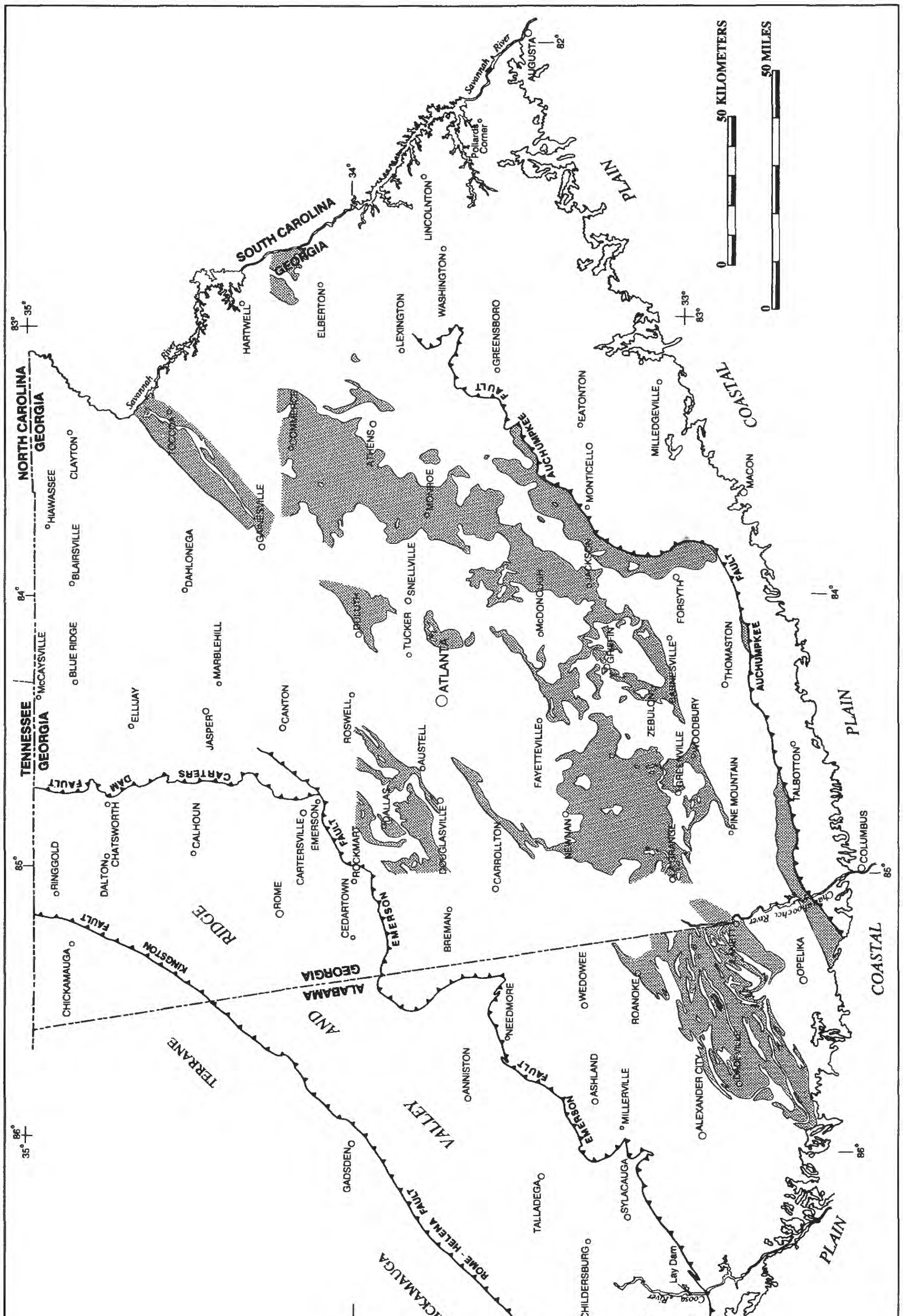


FIGURE 10.—Present known distribution of the Zebulon thrust sheet in the southernmost Appalachians. For greater detail, see plate 1.

FIGURE 11.—Exotic block of amphibolite (A) in schist of the Zebulon Formation in cut along U.S. Highway 29, 0.75 km southwest of the Grantville city limits in the Grantville, Ga. 7.5-min quadrangle.

manganese-rich and to a lesser extent iron-rich chemical sediments, and graywackes suggests that the Zebulon may have been an ocean-floor deposit that received clastic material eroded from the Ocoee basins at the edge of the North American continent and volcanic material from the Promised Land island arc. Locally the Zebulon is melange with blocks of amphibolite and (less common) ultramafic rocks in schist.

WOLF CREEK FORMATION

Southeast of the Brevard Zone and northeast of the Newnan-Tucker synform (fig. 2) is a unit of low-grade-in-appearance button schists, phyllonites, and fine-grained, thinly laminated, commonly sheared amphibolites that Higgins and Atkins (1981) named the Wolf Creek Formation. The rocks of the Wolf Creek have been considered part of the Brevard Zone (Crickmay, 1939; Grant, 1949); our interpretation of the Brevard Zone (see below) agrees well with this assignment for the Wolf Creek. The Wolf Creek Formation is structurally overlain by the Clairmont thrust sheet and has been thrust upon Bill Arp thrust sheet rocks in the Brevard Zone, so it belongs tectonostratigraphically with the Zebulon thrust sheet. The button schists, phyllonites, and fine-grained amphibolites of the Wolf Creek probably represent sheared schists, biotite gneisses (metagraywackes), and amphibolites of the Zebulon Formation.

CLAIRMONT THRUST SHEET

Locally present above the Zebulon thrust sheet is the Clairmont thrust sheet, composed of the Clairmont Formation (figs. 1, 2). The present known distribution of the Clairmont thrust sheet in the southernmost Appalachians is shown in figure 12. The Clairmont is a spectacular melange in which fragments, chips, blocks, and slabs of amphibolite (fig. 13*A*), amphibolite and light-gray granofels (fig. 13*B*), light- to medium-gray, equigranular biotite granitic gneiss (figs. 13*C*, *A*), epidosite, light-gray granofels, metagranite, and "clean" quartzite (fig. 13*D*) "float" in a polydeformed, locally porphyroclastic but also generally porphyroblastic, streaky to finely layered, locally scaly, light- to dark-gray biotite-plagioclase (± K-feldspar) gneiss matrix. It would be a "type III" melange in Cowan's (1985) recent classification. The matrix also contains autoclastic chips, blocks, and slabs ("native blocks" of Hsu, 1968). Foliation and folds within all types of clasts (including the autoclastic clasts; see fig. 14*A*) terminate abruptly against the surrounding matrix (figs. 13, 14). The matrix itself has a tectonic fabric that has ductilely "flowed" around and between some of the more brittle clasts (fig. 15), but the matrix is also pervasively penetrated by innumerable anastomosing, recrystallized shear planes that do not pass into or through the clasts.

The tectonized nature of the matrix and the relation of the matrix to the clasts in the Clairmont melange indicate clearly that it is a tectonic melange, and, because of the matrix textures and the autoclasts, a polykinematic melange. The wide range of clast sizes (from tiny fragments in the matrix to slabs several kilometers long and wide), and the fact that folded, multiply folded, and unfolded clasts are present, indicate that these are foreign clasts or "exotic blocks" (Hsu, 1968). The fact that the clast lithologies are nowhere matched by continuous mappable units (even the largest slabs appear to be "floating" in the melange matrix) indicates that the Clairmont is not a simple broken formation or autoclastic tectonic melange formed during emplacement of the overlying thrust sheets. This conclusion is supported by the fact that seven or more different rock types representing sedimentary (including rocks probably deposited in very different environments), volcanic, and plutonic protoliths are common as clasts. We have not been able to lithically match most of the clasts in the Clairmont melange with other units in the Georgiabama thrust stack. However, the interlayered amphibolite and felsic granofels clasts lithically match rocks of the Promised Land thrust sheet. In addition, we mapped several large outcrop areas of rocks that lithically match Wahoo Creek Formation rocks within the Clairmont on the northwest flank of the Newnan-Tucker synform, which we interpret as megaclasts in the melange. Structural features within these masses are discordant to the surrounding melange matrix (foliation in the megaclasts generally has shallow dips whereas foliation of the matrix adjacent to and under

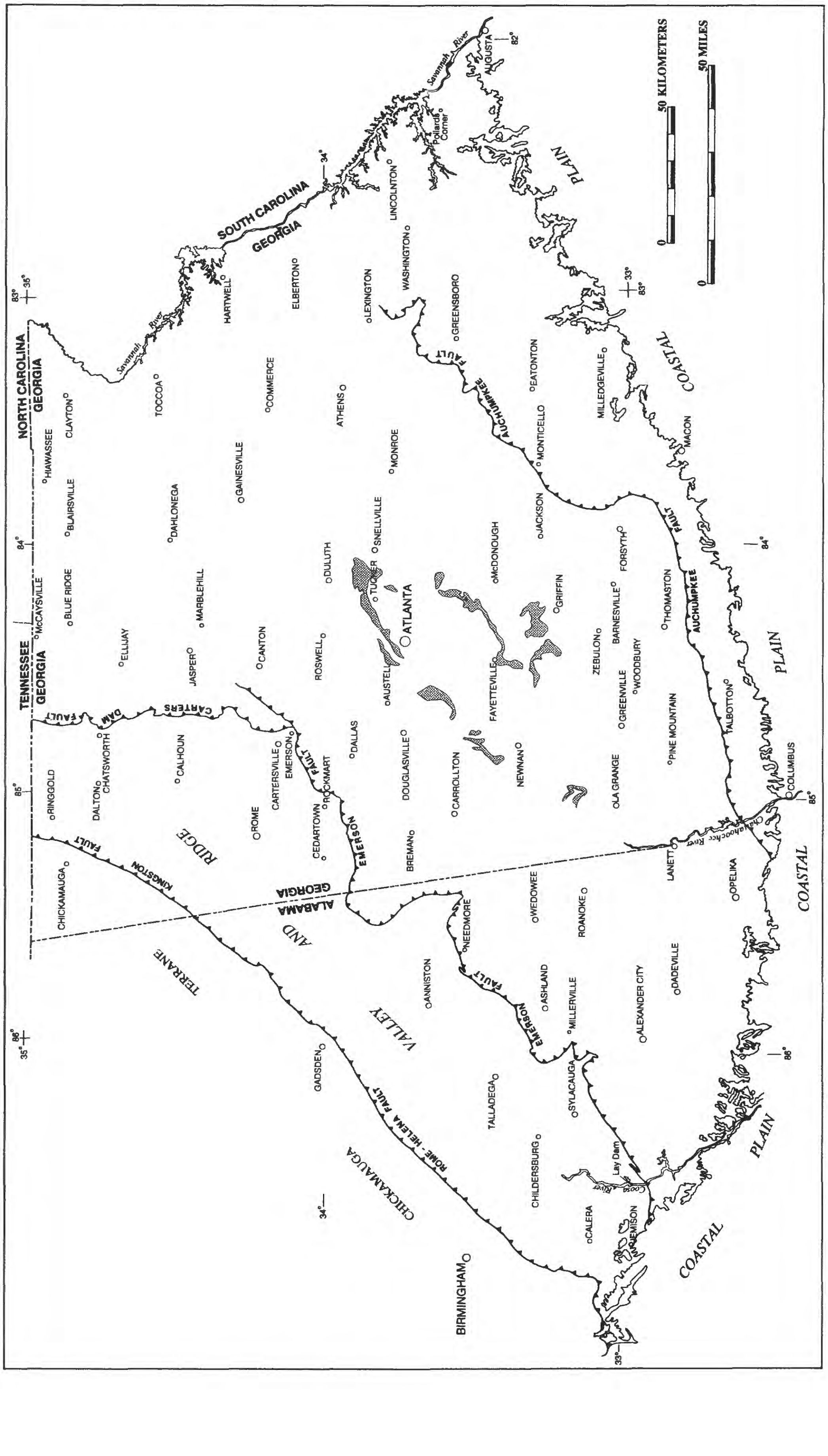


FIGURE 12.—Present known distribution of the Clairmont thrust sheet in Georgia and Alabama. For greater detail, see plate 1.

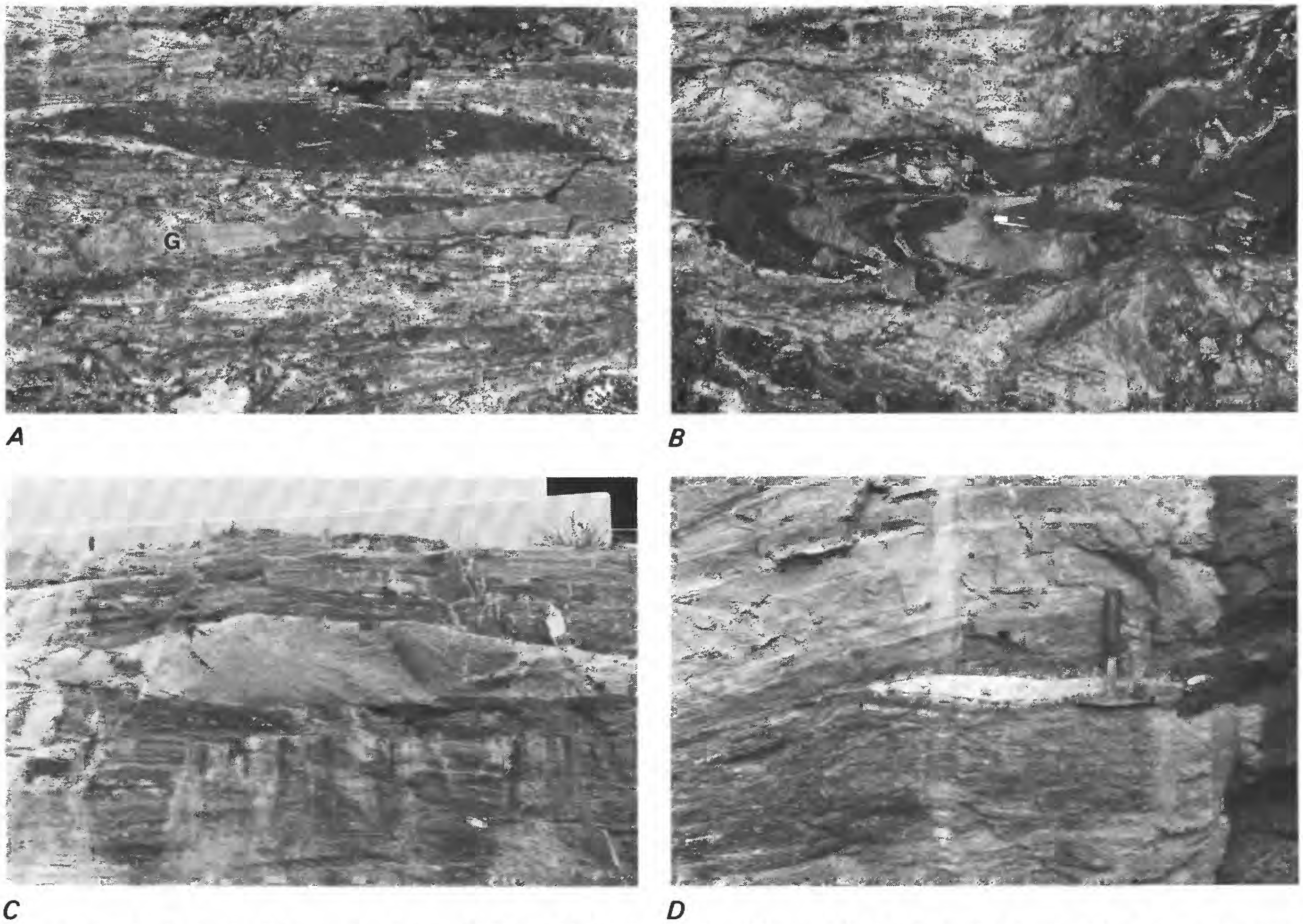


FIGURE 13.—Blocks in the Clairmont melange. *A*, Exotic block of amphibolite. Folds and foliation in the amphibolite block do not pass into the matrix. A block of light-gray granofels (G) is just beneath the amphibolite block. Roadcut at corner of Clairmont Road and exit ramp from northbound lanes of Interstate 85 in the Northeast Atlanta, Ga. 7.5-min quadrangle. Knife below amphibolite block is 8 cm long. *B*, Exotic clast of folded amphibolite and light-gray granofels. Same outcrop as figure *A*. The clast is a lithic match of rocks in the Promised Land Formation (see fig. 22). Knife is 8 cm long. *C*, Exotic block of light-gray, equigranular biotite-granite gneiss. Roadcut along southbound lanes of Interstate 85 just south of Monroe Drive in the Northeast Atlanta, Ga. 7.5-min quadrangle. Large block is approximately 2 m long. *D*, Quartzite block in scaly schistose matrix. Same outcrop as *C*.

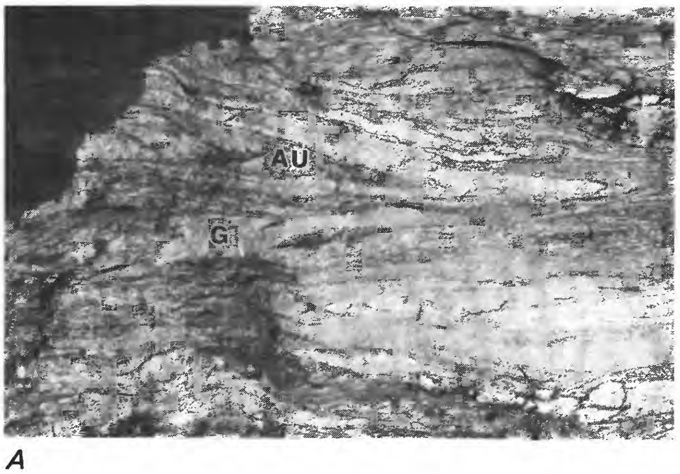
them is more steeply dipping). We (Higgins and others, 1984) refer to these megaclasts as the Beaver Ruin slabs (br in fig. 2).

Beneath the main mass of Clairmont melange on the northwestern flank of the Newnan-Tucker synform, but separated from the Clairmont by the Norcross Gneiss granitic sill (fig. 2), is another part of the melange that Higgins and Atkins (1981) named the Inman Yard Formation. This part of the melange, probably more tectonized even than the main mass, belongs with the Clairmont, even though it lacks some of the exotic clasts found in the Clairmont. The basal parts of the melange in the Inman Yard area are mylonitic, contain button schists, and are difficult to separate from adjacent mylonitic rocks of the Brevard Zone. The name Inman Yard Formation is here abandoned.

The variety of clast lithologies in the Clairmont melange and the melange's extremely complex deformational history suggest that it may be the remnant of part of a subduction melange wedge. The amphibolites are interpreted as clasts of Iapetus ophiolite. In the section on evolution of the southernmost Appalachians, we interpret the Clairmont melange as the remnant of a subduction melange associated with the volcanic arc in which the rocks in the Wahoo Creek, Atlanta, Promised Land, and Sandy Springs thrust sheets formed.

WAHOO CREEK THRUST SHEET

Structurally overlying the Clairmont thrust sheet is the Wahoo Creek thrust sheet, composed of the Wahoo



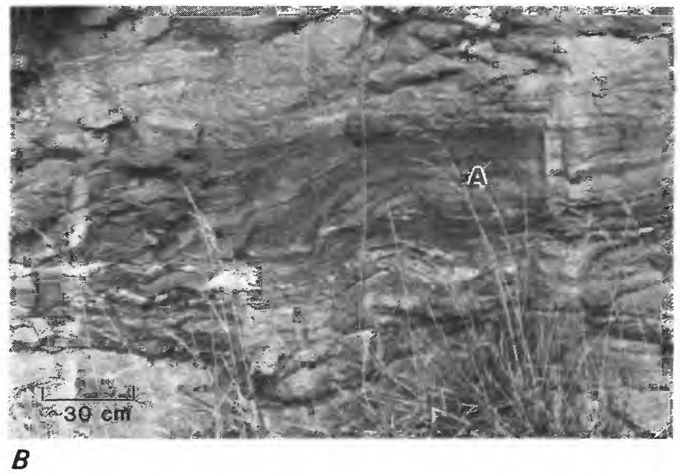


FIGURE 14.—*A*, Clairmont melange in same outcrop as figure 13*A* showing autoclasts (native blocks; AU, for example). Folds and S-planes in the autoclasts terminate against the matrix. A small clast of light-gray granofels (G) is seen in the left-center of the photo; this clast is approximately 1 m long. *B*, Large exotic block of amphibolite (A) showing folds terminating against Clairmont melange matrix. Roadcut at Buford Highway (U.S. Highway 23) and North Druid Hills Road, in the Northeast Atlanta, Ga. 7.5-min quadrangle.

Creek Formation. The present known distribution of the Wahoo Creek sheet is shown in figure 16. The Wahoo Creek is a unit of varied lithology (Higgins and Atkins, 1981; Wallace, 1981), but it consists mainly of thin- and planar-layered, locally laminated, light-gray to nearly white, slabby-weathering, fine- to medium-grained muscovite-plagioclase-quartz gneiss, massive but slabby-weathering light-gray to nearly white gneiss with K-feldspar porphyroblasts (fig. 17), and generally lesser amounts of reddish-weathering coarse-grained muscovite schist and of silvery sillimanite-muscovite schist. In many exposures the gneisses have porphyroblasts of K-feldspar and the layered gneiss has layers and lenses of calc-silicate. Thin layers of epidote-hornblende-plagioclase amphibolites are locally common within the layered gneiss (fig. 18). The finely layered nature of some of the gneisses in the Wahoo Creek, and their mineralogic and petrographic characteristics (also see Wallace, 1981), the calc-silicate layers and lenses, and the interlayered amphibolites (metamorphosed mafic tuffs) suggest that part of the Wahoo Creek is a metamorphosed, altered volcaniclastic sediment that has locally been highly tectonized. The more massive gneisses with K-feldspar porphyroblasts may have been granitic plutonic rocks or thick volcaniclastic deposits, and the schists were probably volcanic-epiclastic deposits.

The work of Wallace (1981) and of Grant (1958) suggests that what we have mapped and described as the Wahoo Creek Formation is probably several different mappable units (formations). Grant (1958) separated what we call the Wahoo Creek into several different units.

The Wahoo Creek thrust fault is locally exposed; though generally imbricate, it appears to lack much mylonitization.

ATLANTA THRUST SHEET

The composite Atlanta thrust sheet, which structurally overlies the Wahoo Creek thrust sheet, is composed of the (lower) Stonewall slice and the (upper) Clarkston slice (fig. 1). The present known distribution of the Atlanta sheet in the southernmost Appalachians is shown in figure 19. The Stonewall slice is composed of the Stonewall Formation (Higgins and Atkins, 1981) on the northwest limb of the Newnan-Tucker synform (Atkins and Higgins, 1980; fig. 2) and in a smaller outcrop area near the southern end of the synform. The Stonewall Formation consists of medium-grained biotite gneiss and fine-grained hornblende-plagioclase amphibolite, intercalated in various proportions, and lesser amounts of sillimanite-biotite schist. Structurally overlying the Stonewall slice, or the Wahoo Creek thrust sheet where the Stonewall is missing, is the Clarkston slice, composed of (in ascending structural order) the Ison Branch, Barrow Hill, Clarkston, and Big Cotton Indian Formations (Higgins and Atkins, 1981; Appendix A).

The Ison Branch Formation is a very thinly laminated metamorphosed calcareous tuff (fig. 20) that generally contains 10-20 percent pyrite, as well as trace amounts of other sulfide minerals, and conspicuous graphite. Chaotic folds, interpreted to be soft-sediment slump features (fig. 20) are locally preserved in the metatuff. Small relict flattened pumice lapilli are seen in some layers of the metatuff in thin section.

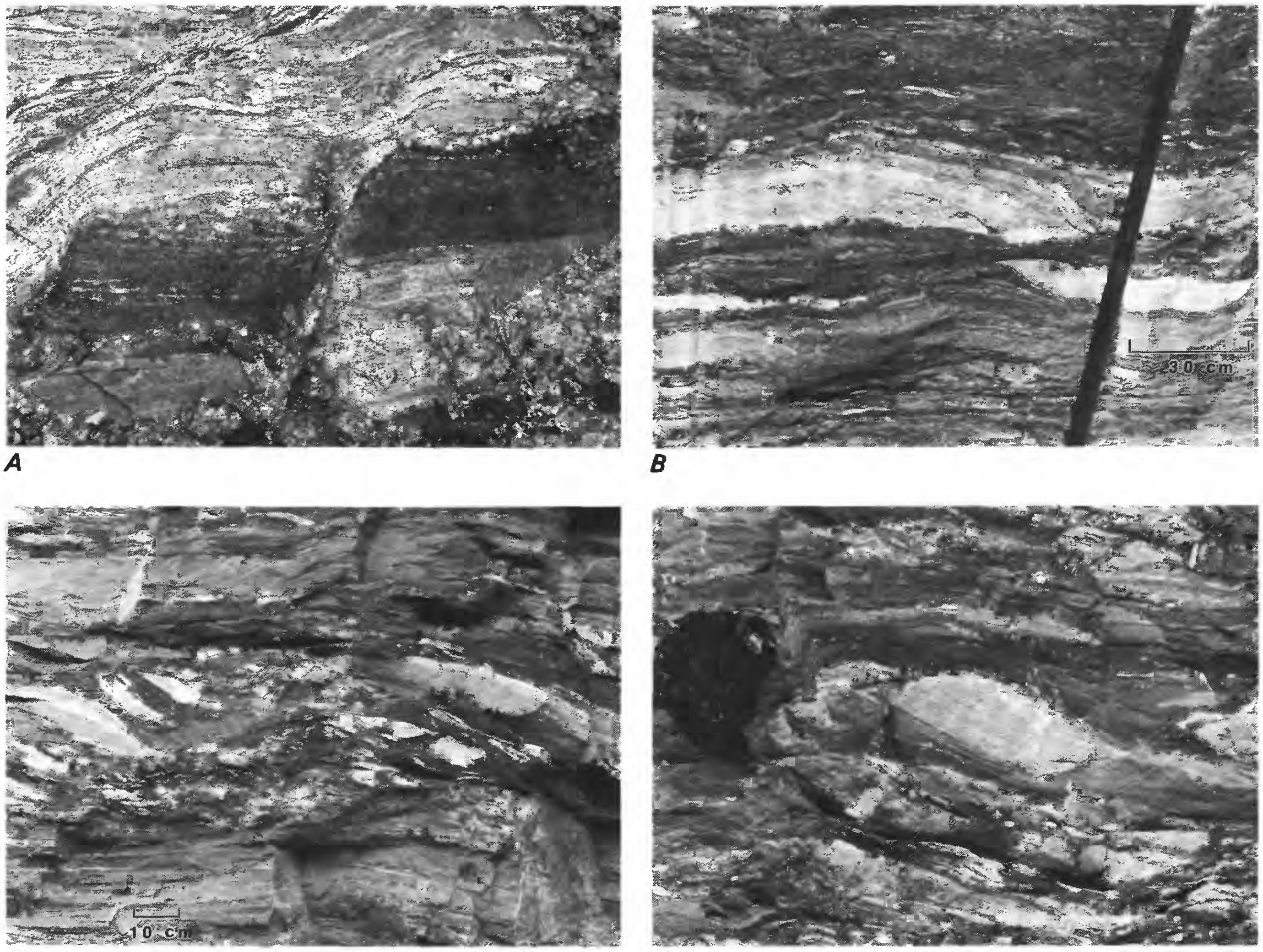


FIGURE 15.—Structural styles in the Clairmont melange. *A*, In outcrop near intersection of East Atlanta Road and Gas Plant Road, Stockbridge, Ga. 7.5-min quadrangle, showing amphibolite clast in streaky biotite-plagioclase gneiss matrix. Note brittle deformation of the amphibolite clast and ductile deformation of the matrix. Dark part of clast is approximately 0.3 m thick. *B*, Ripped-apart block of nearly white granofels in scaly matrix. Same outcrop as figure 13*C*. *C*, Nearly white granofels pulled apart in scaly matrix. Same outcrop as *B*. *D*, Block of light-gray granofels boudinaged in Clairmont melange. Same outcrop as *B*. Dark spot in left of photo is tar.

The Barrow Hill Formation overlies the Ison Branch Formation with probable gradational contact. The Barrow Hill is composed of thin layers (less than a meter thick) of gondite (spessartine quartzite) and magnetite-bearing gondite interbedded with pink- to purple-weathering garnet-sillimanite-muscovite-biotite schists and ocher-weathering hornblende-plagioclase amphibolites. Except for the gondites, the Barrow Hill is identical to the overlying Clarkston Formation. The gondites almost certainly represent distal volcanogenic chemical sediments (manganese-rich, and to a much lesser extent iron-rich, cherts) deposited in a deep-water environment (Stanton, 1976a; Grapes, 1978; and references in both).

In the Newnan-Tucker synform the Ison Branch and Barrow Hill Formations are present as discontinuous slivers along the base of the Promised Land thrust sheet above the Clarkston slice, indicating either that the Clarkston slice in the Newnan-Tucker synform is inverted in relation to the Clarkston slice in the Griffin synform (fig. 2) or that thin slivers of Ison Branch and Barrow Hill Formations were sliced off their original positions by the Hannah thrust fault at the base of the Promised Land sheet and emplaced with the Promised Land as it was thrust upon the Atlanta sheet in the Newnan-Tucker synform.

The Clarkston Formation is composed of pink- to purple-weathering sillimanite-garnet-quartz-plagioclase-biotite-muscovite schist (locally slightly

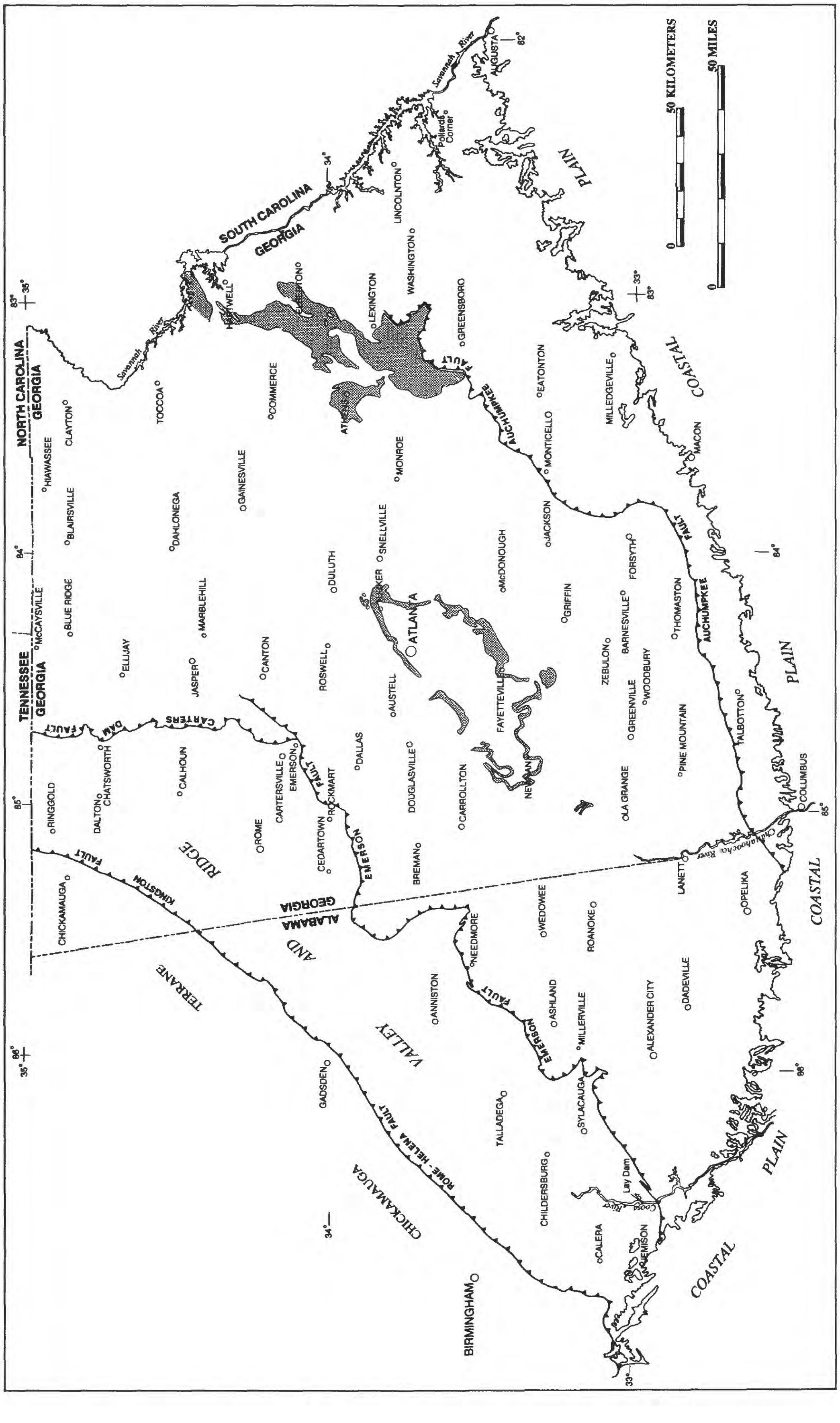


FIGURE 16.—Present known distribution of the Wahoo Creek thrust sheet in the southernmost Appalachians. For greater detail, see plate 1.

FIGURE 17.—Slabby-weathering, finely laminated gneiss of the Wahoo Creek Formation along Briarcliff Road, about 0.3 km north of North Druid Hills Road in the Northeast Atlanta, Ga. 7.5-min quadrangle.

FIGURE 18.—Finely laminated, metamorphosed calcareous tuff of the Wahoo Creek Formation containing thin calc-silicate laminae (light-colored laminae) and thin epidote-amphibolite (dark) layers. Large block blasted for construction of parking lot of Brownings Restaurant, approximately 1 km south of U.S. Highway 29, on east side of Mountain Industrial Boulevard, in the Norcross, Ga. 7.5-min quadrangle. Knife is 8 cm long.

graphitic) and ocher-weathering hornblende-plagioclase amphibolite. The schist and amphibolite are generally interlayered on a scale of 1–20 m. In contrast to the Zebulon Formation, which it resembles, the Clarkston does not contain clasts of amphibolite.

The Big Cotton Indian Formation in the northeast center of the Newnan-Tucker synform is composed of biotite-plagioclase gneisses, hornblende-plagioclase amphibolites, and biotite-muscovite schists. Without the gneisses, the Big Cotton Indian would be similar to the Clarkston, and, in fact, it is probably a facies of the Clarkston.

As far as we know, the Clairmont, Wahoo Creek, and Atlanta thrust sheets are not found northwest of the Brevard Zone. Many of the rocks in the Wahoo Creek and Atlanta thrust sheets are metamorphosed subaqueous volcaniclastic rocks, but most of the rocks in these sheets are metamorphosed shales with metamorphosed manganiferous volcanogenic chemical sediments characteristic of deep-water deposition. Their association with the volcaniclastic rocks suggests deposition in a back-arc, or more likely an outer-arc, basin.

PROMISED LAND THRUST SHEET

Structurally above the Atlanta thrust sheet is the Promised Land thrust sheet, bounded below by the Hannah thrust fault (pls. 1, 2). The present known distribution of the Promised Land sheet is shown in figure 21. The Promised Land sheet is composed entirely of the Promised Land Formation (Higgins and Atkins, 1981). It occupies the axial area of the Newnan-Tucker synform, where it has been thrust upon the Clarkston and Big Cotton Indian Formations of the Atlanta thrust sheet. The Promised Land sheet also underlies a large area northeast of the Newnan-Tucker synform. A thin (less than 3 m) unit of scaly muscovite-quartz and quartz-muscovite mylonite (mylonite schist), previously called the Hannah Member (abandoned; see Appendix A) of the Promised Land Formation (Higgins and Atkins, 1981), is locally mappable along the Hannah thrust fault at the base of the Promised Land sheet.

The Promised Land Formation is composed of various proportions of finely interlayered metamorphosed felsic tuffs and amphibolites (fig. 22) and larger bodies of granitic gneisses. Locally, some of the thicker amphibolite layers are pillowed, but the far more common thin layers were probably mafic tuffs.

The Promised Land thrust sheet is composed entirely of igneous rocks; it consists of about 65–75 percent metamorphosed felsic tuffs, about 5–10 percent granitic metaplutonic and metasubvolcanic gneisses, and about 15–25 percent metamorphosed mafic tuffs and thin flows. The local presence of pillows in some of the metamorphosed flows and the thin layering in the metamorphosed mafic and felsic tuffs indicate that these rocks were mostly deposited subaqueously. The assemblage in the Promised Land is interpreted as representing remnants of a sequence associated with a volcanic arc. As far as we know, the Promised Land sheet is not found northwest of the Newnan-Tucker synform.

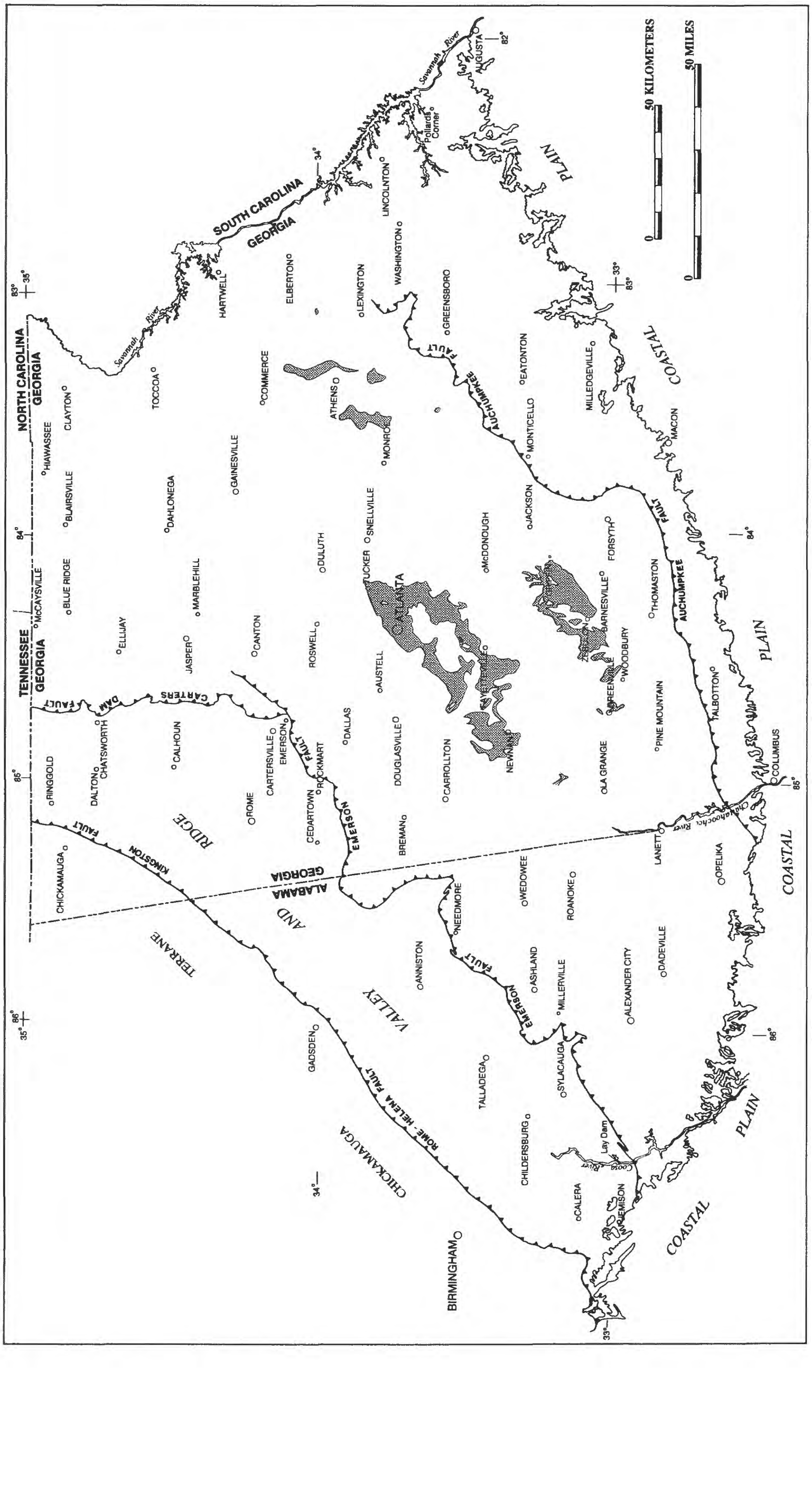
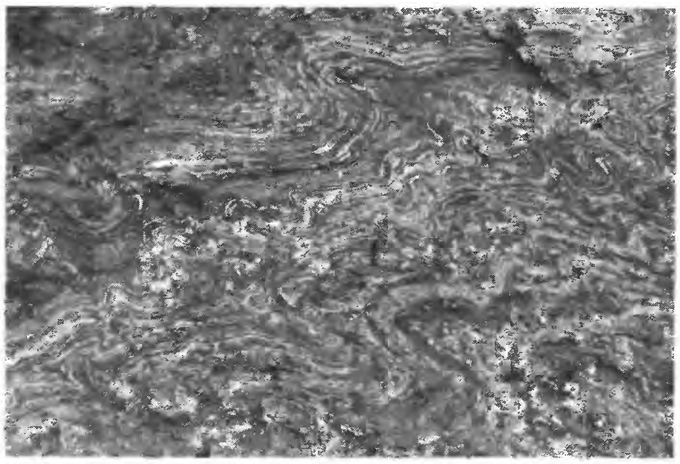


FIGURE 19.—Present known distribution of the Atlanta thrust sheet in the southernmost Appalachians. For greater detail, see plate 1.

A

B



C

FIGURE 20.—Metamorphosed calcareous tuff of the Ison Branch Formation. *A*, Laminated tuff in roadcut along Futral Road, approximately 2 km southeast of the Central of Georgia Railroad in the Orchard Hill, Ga. 7.5-min quadrangle. *B*, Layered tuff in roadcut along Georgia Highway 16, at corner of first road past Griffin, Ga., city limits, in the Luella, Ga. 7.5-min quadrangle. *C*, Chaotic fold patterns in laminated tuff in cut along Hill Street just north of U.S. Highway 19/41 Business, in the Griffin South, Ga. 7.5-min quadrangle. Knife is 8 cm long.

SANDY SPRINGS THRUST SHEET

The next highest thrust sheet in the Georgiabama thrust stack, the Sandy Springs thrust sheet, is bounded below by the Sandy Springs thrust fault. The present known distribution of the Sandy Springs sheet is shown in figure 23. The Sandy Springs thrust fault is exposed at several places (fig. 24). Though folded and metamorphosed, it appears to be a "clean" thrust lacking much mylonitization or brecciation. Hurst (1973) first recognized that the Sandy Springs Group is in thrust contact with the underlying Zebulon Formation (he considered rocks we assign to the Zebulon to be part of the "Ashland Group"). He also implied that part of the Sandy Springs Group (he labeled it "Sandy Springs?") is present southeast of the Brevard Zone; this was later confirmed by the work of Kline (1980, 1981). The Sandy Springs sheet is composed of the Sandy Springs Group (Higgins and McConnell, 1978), made up of (in ascending order) the Powers Ferry Formation, Chattahoochee Palisades Quartzite, and Factory Shoals Formation (Appendix A). Higgins and McConnell (1978) included the Rottenwood Creek Quartzite in the Sandy Springs Group; however, our remapping has shown that this quartzite is actually the Chattahoochee Palisades Quartzite, so the name Rottenwood Creek Quartzite was abandoned by Higgins and others (1984). Higgins and Atkins (1981) named the Chattahoochee Palisades Quartzite southeast of the Brevard Zone the Lanier Mountain Quartzite Member of the Snellville Formation, and named the Powers Ferry Formation the Norris Lake Schist Member of the Snellville Formation. We here abandon the names Snellville Formation, Lanier Mountain Quartzite Member, and Norris Lake Schist Member (Appendix A).

The Powers Ferry Formation is composed of biotite-plagioclase gneisses (metagraywackes), aluminous schists that commonly contain garnet, and lesser amounts of intercalated amphibolites. The Chattahoochee Palisades Quartzite is a kyanite- or staurolite- or sillimanite-bearing, and generally garnet-bearing, quartzite or muscovite-quartz schist. The Factory Shoals Formation is composed mainly of aluminous

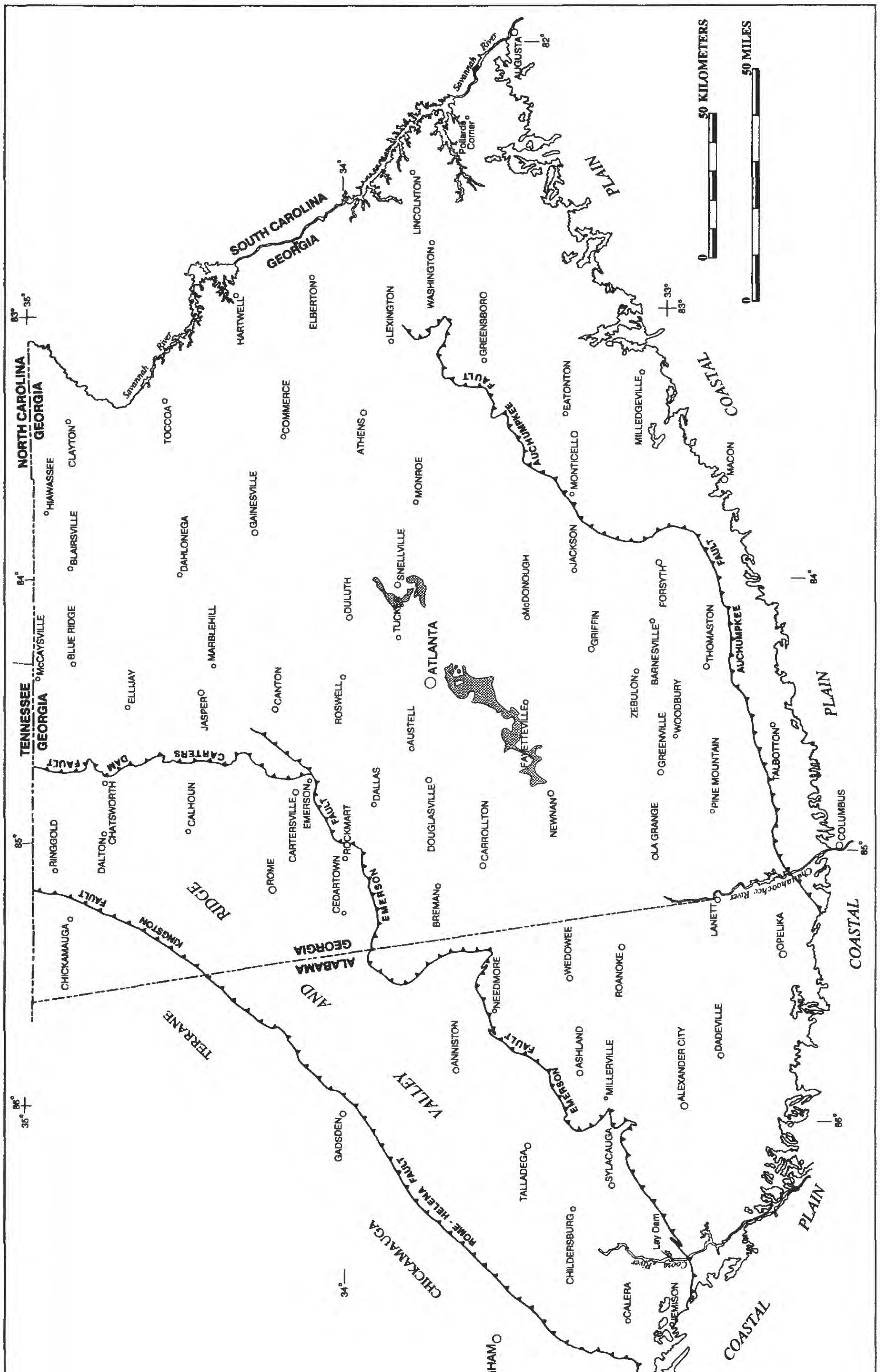


FIGURE 21.—Present known distribution of the Promised Land thrust sheet in the southernmost Appalachians. For greater detail, see plate 1.

FIGURE 22.—Interlayered mafic and felsic tuffs of the Promised Land Formation in outcrop behind shopping center at Stewart Avenue and Cleveland Avenue, in the Southwest Atlanta, Ga. 7.5-min quadrangle. These rocks are lithic matches of some blocks in the Clairmont melange (see fig. 13*B*). Three generations of folds are seen in this outcrop; the two axial traces marked B and K are the Buck Branch and Klondike generations of Atkins and Higgins (1980), or F_1 (B) and F_2 (K).

(kyanite- or staurolite- or sillimanite-bearing) garnet-biotite-muscovite schist with intercalated thin metagraywackes and less common graphitic micaceous quartzites and quartz schists.

Detrital zircons from the Chattahoochee Palisades Quartzite at two localities have yielded Grenville-age U-Pb dates (T.W. Stern, oral commun., 1984), indicating that the source for some of the sediments in the Sandy Springs Group was Grenville-age basement. This source constrains assignment of the Sandy Springs rocks in developmental models for the southernmost Appalachians.

Northwest of the Brevard Zone and the Newnan-Tucker synform, rocks of the Sandy Springs Group are tightly folded with higher and lower thrust sheets, but southeast of the Brevard and east and northeast of the Newnan-Tucker synform, the Chattahoochee Palisades Quartzite caps low ridges; where streams have cut through these ridges they have cut through the Sandy Springs thrust sheet and into underlying thrust sheets. Although isoclinally folded before or during thrust emplacement, the rocks of the Sandy Springs sheet and higher sheets southeast of the Brevard Zone appear less deformed than those northwest of the Brevard; the difference in deformation is discussed in a later section.

PAULDING THRUST SHEET

Structurally above the Sandy Springs thrust sheet is the Paulding thrust sheet, bounded below by the Paulding thrust fault. The present known distribution of the Paulding sheet in the southernmost Appalachians is shown in figure 25. The Paulding sheet is composed of the Paulding Volcanic-Plutonic Complex (Appendix A), made up of light-green-weathering, epidote-rich, generally chloritic, green or blue-green hornblende- or (and) actinolite-plagioclase amphibolites (about 50–60 percent) intimately interlayered with light-gray to nearly white, amphibole-bearing granofels and biotite-bearing gneisses (metamorphosed felsic and intermediate tuffs—about 20–30 percent). Ubiquitous dikes, sills, and small plutons of K-feldspar-poor granitic rocks and K-feldspar-bearing granitic rocks (fig. 26) form about 15–20 percent of the unit, and pods of epidosite are common. Thin layers and lenses of vermiculitic mica (not included in the percentages) are locally present, but their protolith is unknown. A distinctive siliceous "hardpan" is generally found above the rocks in the Paulding sheet. The Paulding sheet is essentially all-igneous and is devoid of clastic metasedimentary rocks. This lack of clastic metasedimentary rocks, coupled with its distinctive appearance in outcrop and the fact that its mafic rocks are generally epidotic and chloritic, distinguishes it from underlying thrust sheets.

Rocks of the Paulding thrust sheet have been given various names in Alabama (Bentley and Neathery, 1970; Neathery, 1975; Tull and others, 1978; Stow, 1982; Stow and others, 1984), including Waresville amphibolite (abandoned) and the lower part of the Hillabee greenstone (informal, see discussion of Hillabee greenstone in the section on the Ropes Creek thrust sheet); we include these rocks in the Paulding Volcanic-Plutonic Complex (Appendix A). In Georgia, the Waresville Amphibolite (abandoned) of Bentley and Neathery (1970) is included in the Paulding Complex, as are parts of the Pumpkinvine Creek Formation of McConnell (1980; abandoned) and the New Georgia Group (abandoned) of Abrams and McConnell (1981) and McConnell and Abrams (1984).

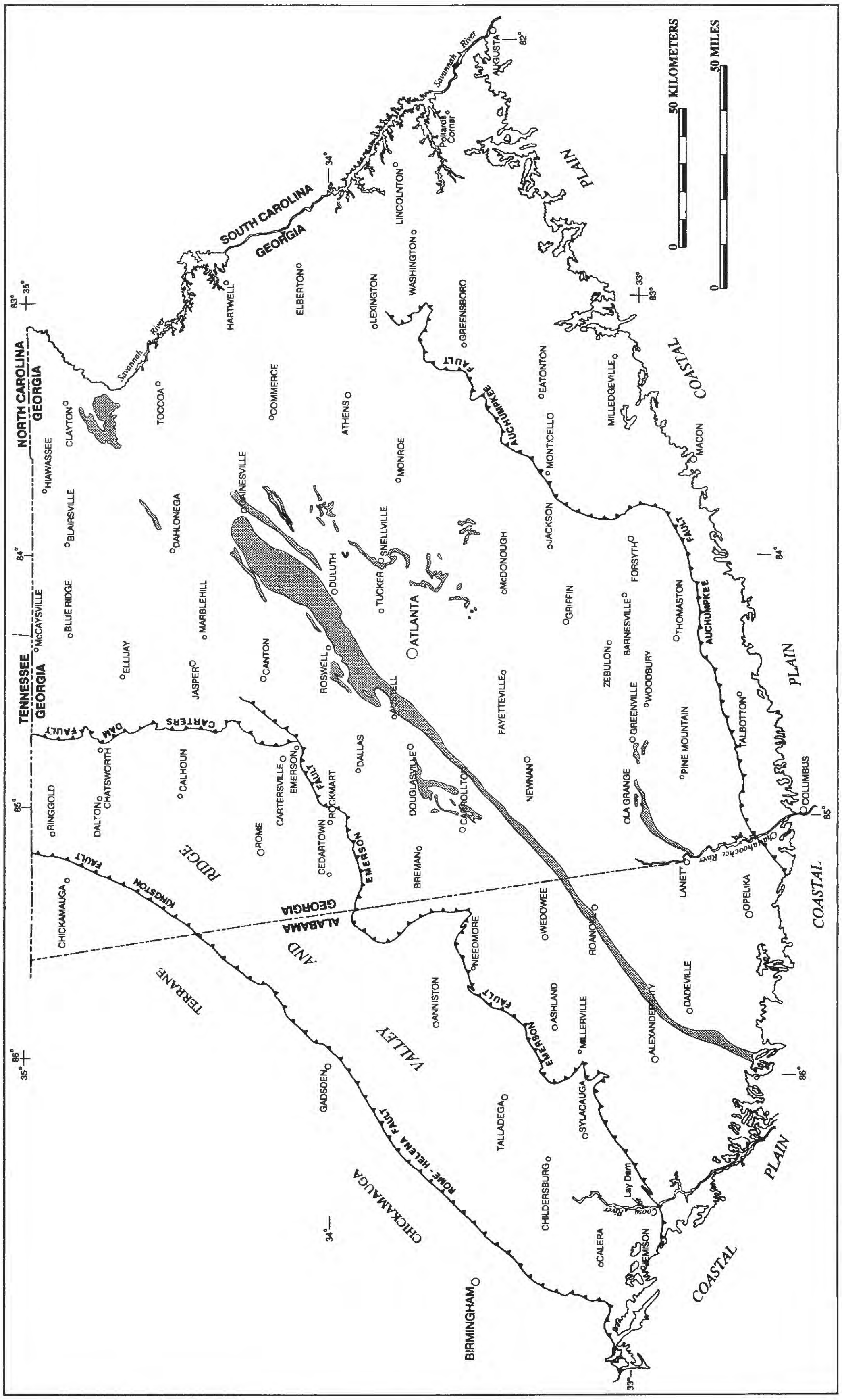


FIGURE 23.—Present known distribution of the Sandy Springs thrust sheet in the southernmost Appalachians. For greater detail, see plate 1.

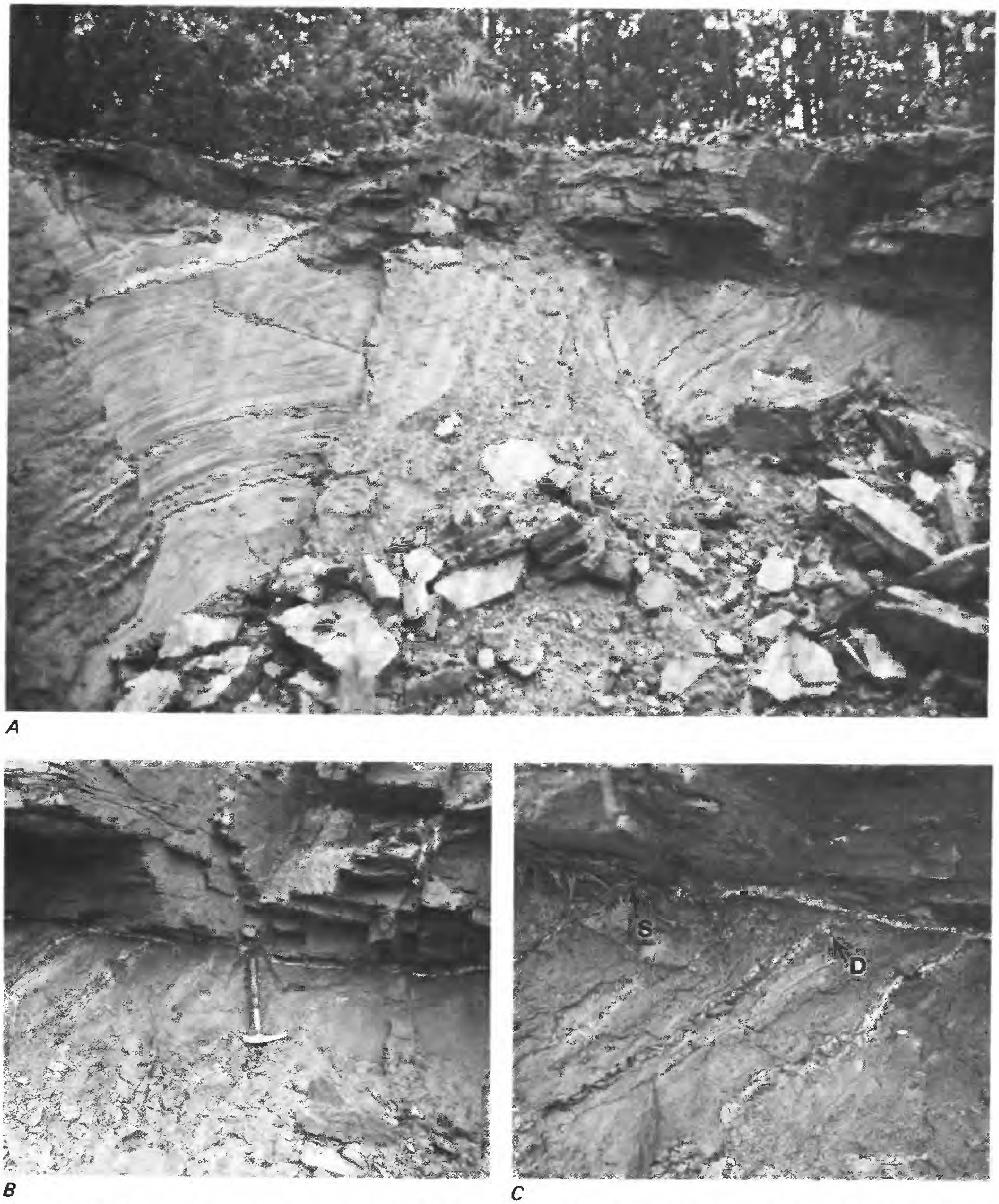


FIGURE 24.—Sandy Springs thrust fault separating moderately dipping gneiss and amphibolite of the Clairmont melange from Chattahoochee Palisades Quartzite in the Sandy Springs thrust sheet. *A*, Borrow pit on south side of Georgia Highway 138 just east of Stockbridge city limits in the Stockbridge, Ga. 7.5-min quadrangle. View is approximately 12 m long. *B*, Closer view of the fault; same outcrop as *A*. *C*, Closer view of the fault showing minor drag folding (D) in the rocks immediately beneath the fault and finely laminated weathering of very thin zone of sheared quartzite (S). Same outcrop as *A*.

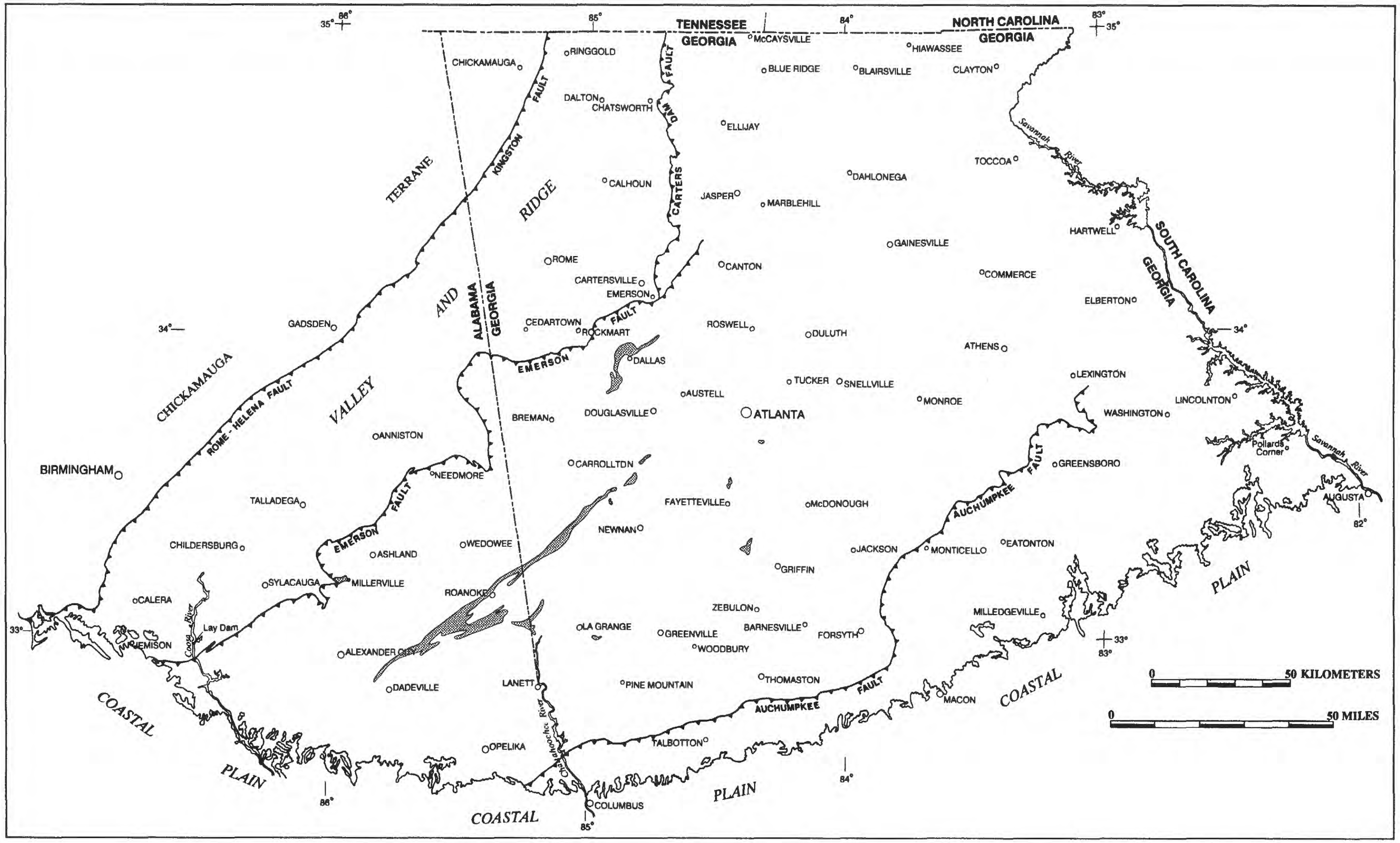


FIGURE 25.—Present known distribution of the Paulding thrust sheet in the southernmost Appalachians. For greater detail, see plate 1.

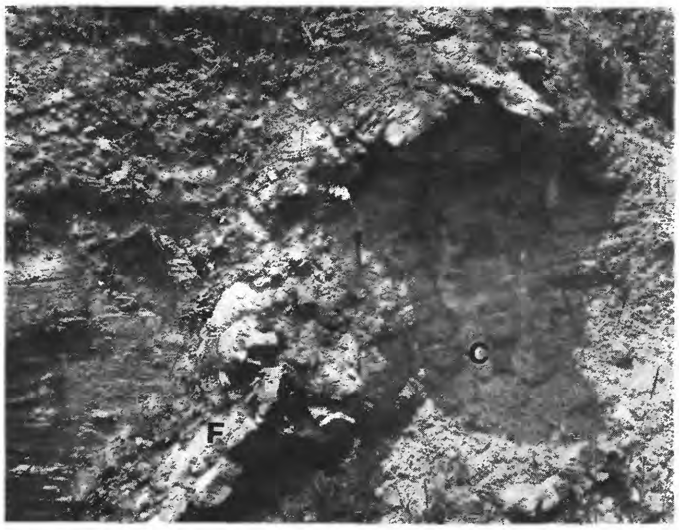


FIGURE 26.—Typical exposure of the Paulding Volcanic-Plutonic Complex. Cut along Vaughn Road 0.3 km south of Georgia Highway 92, in the Brooks, Ga. 7.5-min quadrangle. K-feldspar-poor granitic dike (F) has the same foliation as the chloritic, epidotic amphibolite and granofels it has intruded, whereas more "normal" granitic dikes (C) crosscut the foliation. Typical thin layer of "hardpan" (not visible in photograph) caps the cut. Knife is 8 cm long.

The fact that the Paulding sheet is made up of metavolcanic and metaplutonic rocks, including intermediate and felsic tuffs, and the lack of nonvolcanic sedimentary rocks indicate that this assemblage formed in an island arc. This assignment is supported by the geochemical characteristics of some of the rocks in the Paulding thrust sheet (Stow, 1982, "Millerville samples" for example; Stow and others, 1984; Appendix B).

WEST POINT THRUST SHEET

The next highest thrust sheet is composed of the remnants of an ophiolitic melange, which we here name the West Point melange from the locality where it was discovered by Sears, Cook, and others (1981) along the shores of West Point Reservoir behind West Point Dam on the Chattahoochee River about 4 km northeast of Lanett, Ala. It is mostly a "type III" melange in Cowan's (1985) classification. Outcrops of the melange are relatively rare, probably because of tectonic elimination; where it is found (pl. 1) it is commonly located structurally beneath, and folded with, the Ropes Creek Metabasalt in the Ropes Creek thrust sheet. The present known distribution of the West Point thrust sheet is shown in figure 27, but the West Point may be present in many other areas of Ropes Creek outcrop.

Sears, Cook, and Brown (1981, p. 5) described the West Point Reservoir occurrence as follows:

> East of West Point Dam, along the shore of West Point Lake, at low water, there are magnificently exposed several hundred bodies of hornblende gneiss, metagabbro, dunite, chlorite schist, pyroxenite, talc, olivine pyroxenite, layered olivine-pyroxene rock, garnet chlorite gneiss, anthophyllite schist and minor felsic gneiss floating in a matrix of chloritic schist laced with pegmatites. The bodies occur in a unit at least 100 m thick and continuously exposed along strike for 2 km. The bodies are generally well-rounded, some being perfectly spherical, and are up to 4 m in diameter. Grossly different lithologies are commonly adjacent to one another, along the same foliation trend. Layering in some bodies is truncated at the edges at an angle to the matrix schistosity. Very coarse chlorite masses sheath some of the bodies. Ultramafic bodies have rinds of talc and anthophyllite separating them from the matrix.

Our work indicates that the melange is also present around and below (downstream from) West Point Dam and along the western shore of the reservoir. Thus, we suggest that as much as a kilometer-thick section of melange is preserved in the West Point Dam area.

West Point melange is also exposed in the Murphy syncline, where it is as much as 3 km thick. From Whitestone (we have not yet mapped in detail north of Whitestone) to Canton (pl. 1), the marble that has been called "Murphy Marble," and correlated with the marble at Murphy, N.C., consists of discontinuous masses of several different varieties of marble at different structural-stratigraphic horizons in a scaly, buttony schist matrix; in most exposures the schist matrix has lensoidal clots of muscovite 2–3 cm in size. The marbles range from "very clean," white calcite marble, through dolomitic marble, to "dirty" sandy and micaceous marble, and the size of the marble bodies ranges from several kilometers long and a kilometer or so wide down to oblong bodies only a hundred meters or so long (Bayley, 1928; Fairley, 1965). They occur in schists that have been called Andrews Schist, in schists that have been called Brasstown Formation, and in schists that have been considered part of the Great Smoky Group. In addition to the marble bodies, the matrix contains numerous blocks and slabs of amphibolite, metabasalt, metagabbro, and altered ultramafic rocks (fig. 28). One of the largest of the mafic clasts is the body that Fairley (1965) mapped as metagabbro and Higgins and others (1986) interpreted as being a slice of Ropes Creek Metabasalt above an unknown thickness of West Point melange. The mass of amygdaloidal metabasalt (fig. 29) and metagabbro is a slab in the melange matrix. As Fairley's (1966, pl. 1) map shows, foliation in the schistose matrix that almost surrounds the "metagabbro" body dips consistently and concentrically inward toward the body as if the body were a large "dropstone." As Bayley's (1928, pl. 1) and Fairley's

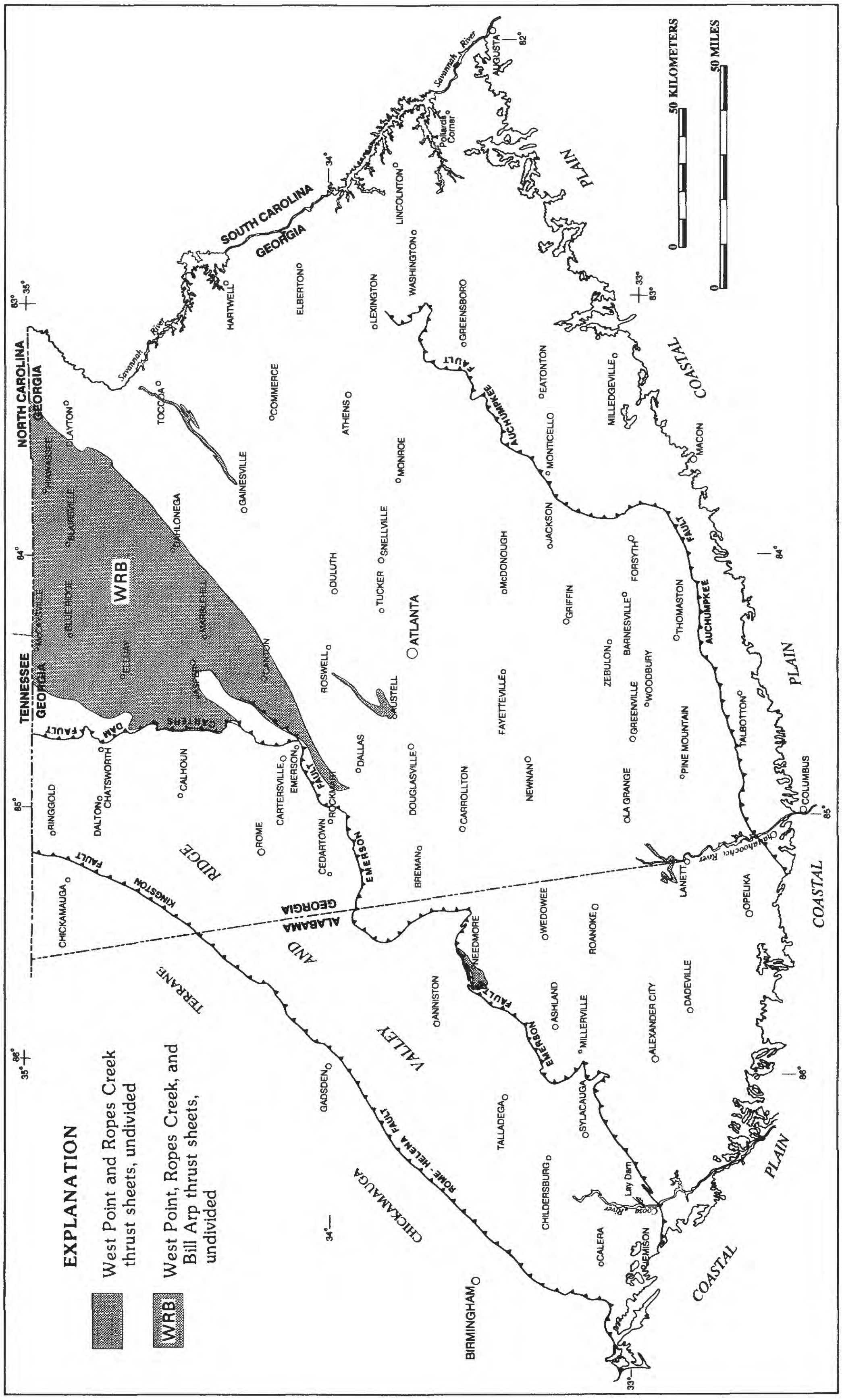


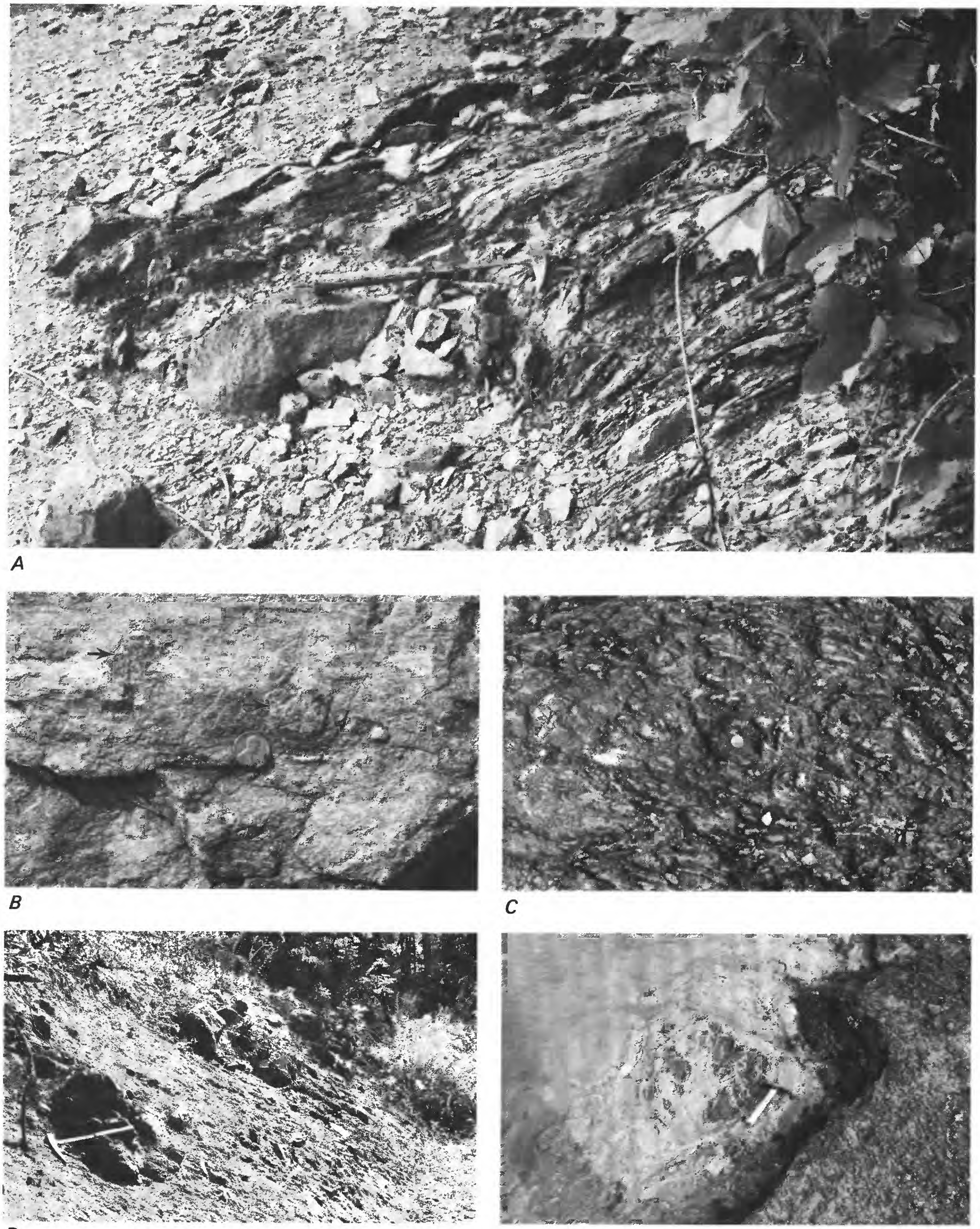
FIGURE 27.—Present known distribution of the West Point thrust sheet in the southernmost Appalachians. For greater detail, see plate 1.

FIGURE 28.—Clast of ultramafic rock in scaly schist of the West Point melange. Borrow pit just east of stream along the north side of the first dirt road running east just south of the school in Marblehill, in the Nelson, Ga. 7.5-min quadrangle.

(1965, pl. 1) maps show, the "metagabbro" is in contact on its southwestern side with marble. However, the marble shows no effects of being intruded by the gabbro.

Perhaps the most striking outcrops of the West Point melange are in the unit in northeast Georgia that Hartley (1973) and Hartley and Penley (1974) mapped as the "Lake Chatuge Sill" west and southwest of Hiawassee, Ga., and in a similar occurrence along the northeastern shore of Lake Chatuge north of Hiawassee (pl. 1) that has been called the "Shooting Creek Complex" (Hatcher and others, 1984). The melange in this area is probably at least several hundred meters thick and may be more than a kilometer thick. What were mapped as sills are Ropes Creek Metabasalt and West Point melange (thrust sheets) that are intimately folded together. A large slice of the Zebulon thrust sheet is present beneath the melange, or beneath the Ropes Creek where the melange is absent. The sill-like map pattern results from erosion through the arched

FIGURE 29.—Sample of amygdular metabasalt from large slab of metabasalt and metagabbro in the West Point melange at Marblehill, Ga. Light spots on rocks are lichen stains; holes are filled amygdules that have weathered out to resemble vesicles. Sample from outcrop between the southwestward-flowing tributary to the East Branch of Long Swamp Creek and the third unpaved road to the northeast from Georgia Highway 53, southeast of the town of Marblehill, in the Nelson, Ga. 7.5-min quadrangle. Knife is 6 cm long.



A

B

C

D

E

thrust sheets into very erosion-resistant rocks of the Great Smoky Group (Bill Arp thrust sheet) that underlie Brasstown Bald, the highest mountain in Georgia. In the window, contacts between the Great Smoky units (Copperhill and Wehutty Formations) trend northeast in contrast with the nearly north-south elongation of the map pattern of the West Point and Ropes Creek thrust sheets. Most of the Blue Ridge physiographic province is underlain by rocks that are extremely resistant to erosion; some of these same rocks make the Pine Mountain block physiographically more like the physiographic Blue Ridge than the physiographic Piedmont (Hack, 1982).

The matrix of the West Point melange in the Lake Chatuge area is highly sheared and deformed talc-actinolite-chlorite schist (with clumps of relict olivine) and highly deformed amphibolite (fig. 30); small anastomosing fault planes are ubiquitous and oriented in many directions (fig. 30). A wide variety of mafic and ultramafic rocks (including dunite, coronite troctolite, olivine gabbro, and wehrlite) occur as clasts (blocks) in the matrix. However, the most significant clasts are of eclogite (Kellberg, 1943; Hartley, 1973; Dallmeyer, 1974). In most localities knockers of eclogite and of well-foliated (locally mylonitic) amphibolite containing clasts of eclogite form low knobs above the surrounding, more easily eroded matrix, and locally it can be demonstrated that the eclogites are clasts surrounded by the matrix (fig. 31).

Dallmeyer's (1974) study of the eclogites in the West Point melange showed that (1) their chemical compositions fall in the range of eclogites from "alpine-type terranes (glaucophane schists)" on an F-M-A diagram; (2) the chemical compositions of cores of their garnets fall into the field of "glaucophane schists" on an (Al+Sp)–(Gr+And)–Py diagram; and (3) the primary cores of their pyroxenes fall well in the "eclogite field" as opposed to the "granulite field" on a plot of jadeite against CaTs and on a (Di+Hed+En)–(Jd)–(CaTs) diagram. Other aspects of Dallmeyer's study suggest that the eclogites have been slightly retrograded; however, he stated (1974, p. 372):

> The skeletal clinopyroxene inclusions in garnet led Hartley (1973) to infer that the garnet is secondary and developed during Middle Paleozoic metamorphism of the Lake Chatuge peridotite. The chemical data presented here are inconsistent with this interpretation, for both the inclusions and the cores of primary clinopyroxene grains are jadeitic. This implies a high pressure origin. Also, the configuration of core tie-lines suggests that garnet and clinopyroxene are cogenetic.

Dallmeyer (p. 373) concluded, on the basis of available experimental data, that the eclogites formed at pressures between 15 and 20 kbar and temperatures between 1,000 and 2,000 °C.

Jones and others' (1973) determinations of present-day $^{87}Sr/^{86}Sr$ ratios from rocks of the West Point melange and Ropes Creek Metabasalt in the Lake Chatuge area range from 0.7023 to 0.7047 indicating "upper-mantle" derivation (more likely oceanic crust derivation). More recently, analyses of Nd and Sr and Sm-Nd isotopes from Ropes Creek Metabasalt in the Lake Chatuge area and from the Chunky Gal Mountain "mafic-ultramafic complex" (of McElhaney and McSween, 1983) along strike in North Carolina (probably Ropes Creek and Soapstone Ridge thrust sheets; West Point melange does not appear to be present in the complex) led Shaw and Wasserburg (1984, p. 341) to conclude that "the Chunky Gal and Lake Chatuge amphibolites clearly have the isotopic signature of ancient oceanic crust."

The West Point melange is also preserved beneath Ropes Creek Metabasalt that has been considered Hillabee greenstone around Needmore, Ala. (pl. 1). In that area, knockers of pyroxene-garnet-chlorite rock (probably retrograded eclogite) form low knobs above the lowland underlain by the chloritic and talcose matrix. Metachert and a variety of mafic and ultramafic rocks are found as scattered float in the melange (also see Prouty, 1923).

With the exception of glaucophane schists (which probably would not have survived the amphibolite-grade metamorphism imposed on the West Point melange during its transport and emplacement; see Ernst, 1972), eclogites are generally regarded as the best indicators of subduction melange (for example Ernst, 1972; Hamilton, 1979). Their presence, along

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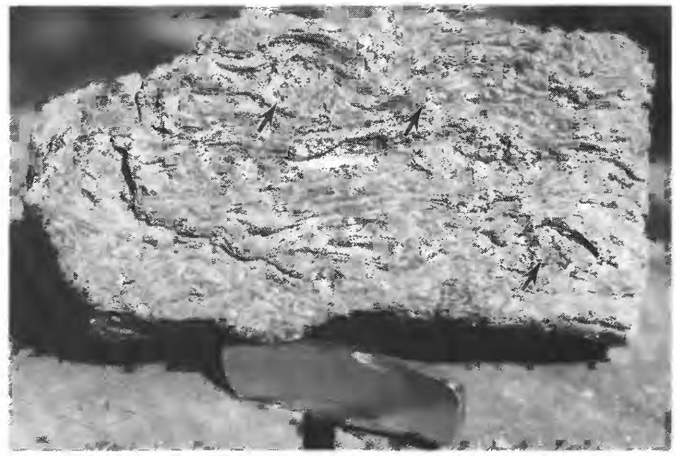
FIGURE 30.—The West Point melange. *A*, Block of eclogite-bearing amphibolite (under hammer handle) in highly sheared talcose and chloritic matrix, in outcrop along the northern shore of Lake Chatuge, just southeast of Lower Bell Creek Church, in the Hiawassee, Ga.-N.C. 7.5-min quadrangle. Hammer is 40 cm long. *B*, Highly deformed amphibolite containing small clasts of eclogite (arrows point to two of the eclogite clasts) along the northern shore of Lake Chatuge just south of Lower Bell Creek Church, in the Hiawassee, Ga.-N.C. 7.5-min quadrangle. Coin is 1.9 cm in diameter. *C*, Highly sheared talc-chlorite-actinolite schist matrix with small olivine grains. Note several shear-plane orientations. Same outcrop as *B*. Coin is 2.3 cm in diameter. *D*, Knockers of eclogite and ultramafic rocks in sheared amphibolite matrix in hillside just west of Lake Chatuge southwest of Lower Bell Creek Church in the Hiawassee, Ga.-N.C. 7.5-min quadrangle. Hammer is 40 cm long. *E*, Block of coarse-grained mafic rock in a chlorite-actinolite matrix along the eastern shore of West Point Lake, approximately 2 km northeast of West Point Dam ("type locality" of the West Point melange), in the Opelika, Ala.-Ga. 1° × 30′ quadrangle (the location is on the Lannett North, Ga.-Ala. 7.5-min quadrangle, but the dam was built after the 1964 Lannett North quadrangle map was published).

A



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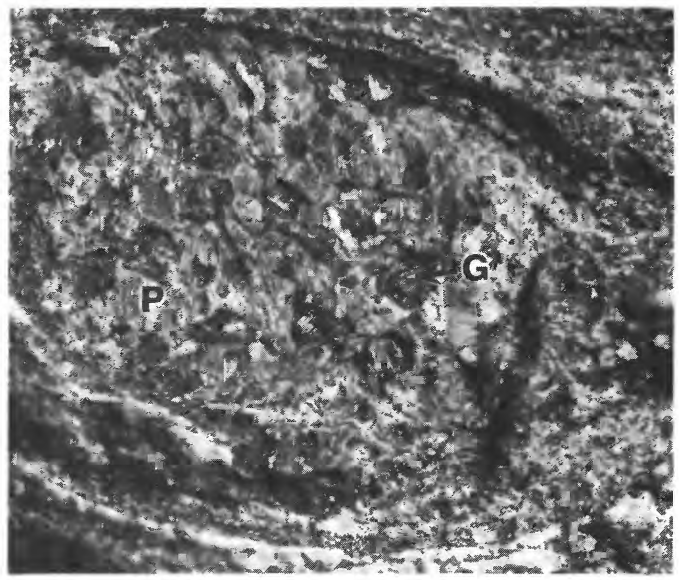


D

B

FIGURE 31.—Eclogite clasts in West Point melange. *A*, Large knocker of eclogite-bearing amphibolite in a highly sheared talc-actinolite-chlorite matrix. Arrow points to one of the abundant eclogite clasts or clots. Hammer is 40 cm long. Outcrop on small peninsula just southeast of Lower Bell Creek Church, in the Hiawassee, Ga.-N.C. 7.5-min quadrangle. *B*, Same outcrop as *A* showing sheared nature of the melange matrix. The eclogite-bearing knocker is labeled E. Hammer is 40 cm long. *C*, Block (from matrix of highly sheared talc-actinolite-chlorite schist) of highly deformed amphibolite containing clasts of eclogite; arrows point to three eclogite clasts. The amphibolite has the macrotexture of mylonite but is recrystallized in thin section. Knife is 6 cm long. *D*, Very close view of one of the larger eclogite clasts in the amphibolite block shown in *C*, showing "flow" of the amphibolite "layers" around the clast, light-colored pyroxenes (P), and darker garnets (G). See text and Dallmeyer (1974) for more details on the eclogites. (Photograph by Dean B. Radtke, U.S. Geological Survey.)

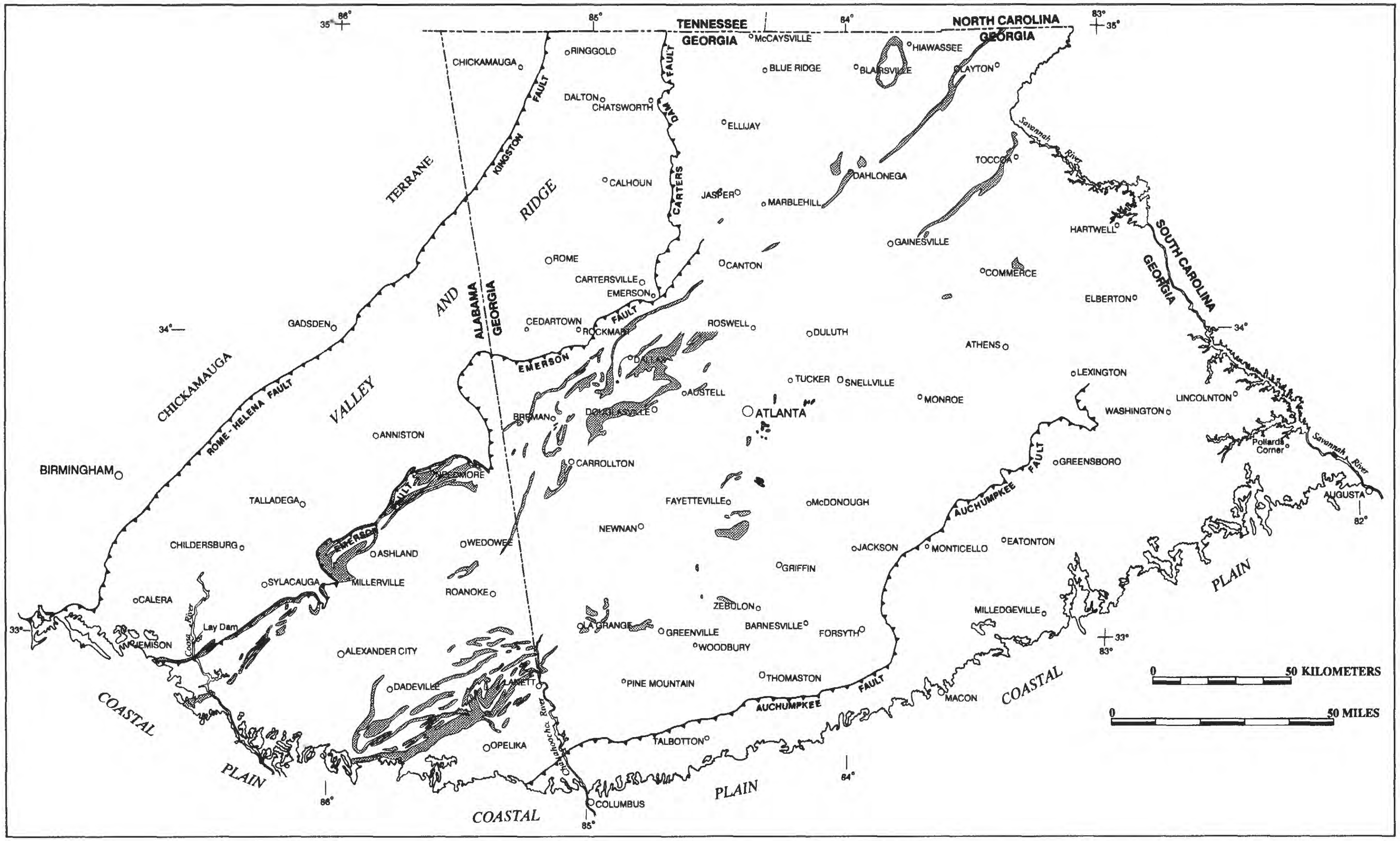


FIGURE 32.—Present known distribution of the Ropes Creek thrust sheet in the southernmost Appalachians. For greater detail, see plate 1.

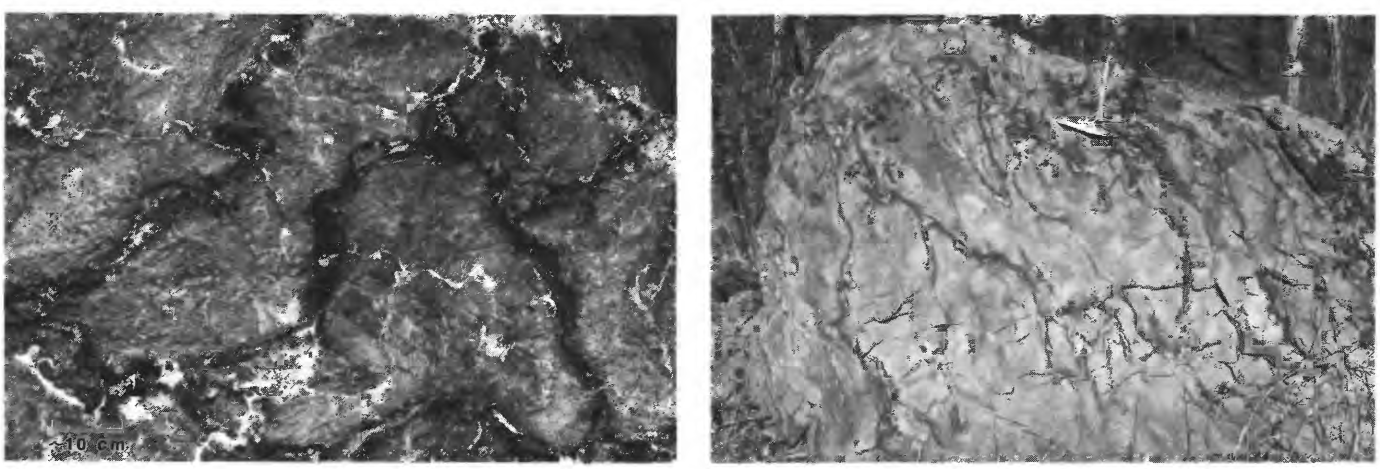
with a wide variety of oceanic-crust and mantle igneous rocks, in a scaly schist or sheared and altered mafic matrix in the West Point melange indicates quite strongly that the West Point is the remnant of an ancient subduction melange complex.

ROPES CREEK THRUST SHEET

Structurally above the West Point melange, or (more commonly) above the Paulding thrust sheet or lower units where the melange has been tectonically eliminated, is the Ropes Creek thrust sheet, composed of the Ropes Creek Metabasalt (Ropes Creek Amphibolite of Bentley and Neathery, 1970; see Appendix A) and its Cedar Lake Member; mostly unnamed, but mappable (fig. 2), volcanogenic alteration zones and iron formations, and the Cherokee alteration zone (an informally named zone of alteration and of pelagic manganiferous schists and metavolcanogenic chemical sediments). The present known distribution of the Ropes Creek sheet in the southernmost Appalachians is shown in figure 32. The Ropes Creek thrust sheet is essentially devoid of nonvolcanic clastic metasedimentary rocks, as also recognized by Fleming and others (1980), though pelagic manganiferous schists are locally present. Named units assigned to the Ropes Creek Metabasalt in Alabama include the Mitchell Dam, Ropes Creek, Beaverdam, and Ketchepedrakee amphibolites, part of the Doss Mountain amphibolite, the Slaughters metagabbro, and the upper part (nearly all) of the Hillabee greenstone (Bentley and Neathery, 1970; Neathery, 1975; Tull and others, 1982; Stow, 1982; Neilson, 1983; Stow and others, 1984; these names are considered informal; see Appendix A), and in Georgia, most of the Pumpkinvine Creek Formation (McConnell, 1980—name abandoned; see Appendix A), and the Lost Mountain Amphibolite Member of the Univeter Formation (McConnell and Abrams, 1984—names abandoned; see Appendix A).

The Ropes Creek Metabasalt is composed of ocher-weathering, massive to finely layered, locally laminated, locally pillowed (fig. 33), locally chloritic, commonly garnetiferous, locally magnetite-bearing, generally pyrite-bearing, green to greenish-black hornblende-plagioclase and plagioclase-hornblende amphibolites with insignificant amounts (generally less than a very small fraction of a percent) of fine- to medium-grained, generally amphibole-bearing granofels. The final weathering product of the amphibolites is a very characteristic dark-red clayey soil. The mafic rocks of this sheet are at least partially chloritized and epidotized; few areas larger than a few square kilometers have escaped some chloritization, epidotization, or uralitization. Many of the rocks in the Ropes Creek sheet contain disseminated pyrite, and locally, highly pyritiferous zones as much as 20 m wide can be followed for as much as 100 m along strike. The Ropes Creek thrust sheet also contains various K-feldspar-poor granitic rocks, including trondhjemites (Pate, 1980; Sanders, 1983), that are locally associated with gold-bearing quartz veins and alteration zones.

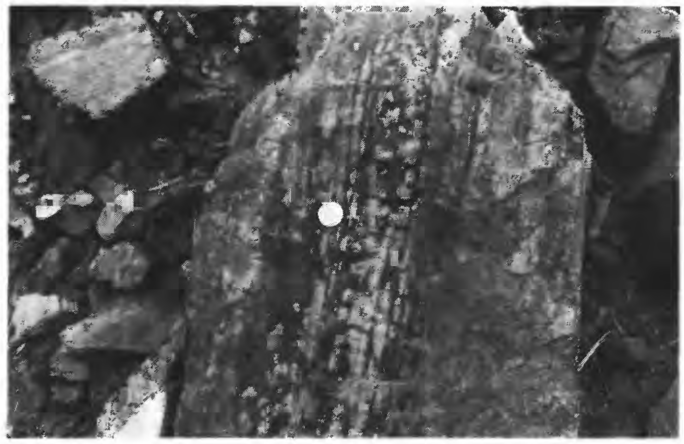
One of the more distinctive features of the Ropes Creek thrust sheet is its diverse suite of iron-rich, siliceous, and manganiferous metavolcanogenic, largely exhalative, chemical metasediments, divided (terminology modified from Stanton, 1976b) into banded iron formations (Abrams and McConnell, 1982; McConnell and Abrams, 1983, 1984; Abrams, 1985), ironstones, magnetite quartzites (Pate, 1980), mangan-



A *B*

FIGURE 33.—Pillow basalts in the Ropes Creek Metabasalt along the east side of the Flint River just upstream from Hampton Road, in the Fayetteville, Ga. 7.5-min quadrangle. Most of these blocks were moved a few meters during construction of water-treatment facilities nearby. Before they were disturbed, Y-shaped pillow junctions indicated they were right side up. The metabasalts are extensively epidotized and chloritized. *A*, Close-packed, essentially undeformed pillows. *B*, Deformed pillows.

A



C

B

FIGURE 34.—Iron formations in the Ropes Creek Metabasalt. *A*, Massive layered magnetite quartzite (banded iron formation, Q) interbedded with manganiferous banded iron formation (I) and manganiferous schists (M) and amphibolite (A) of the Cedar Lake Member of the Ropes Creek Metabasalt, in roadcut about 100 m north of where the powerlines cross the road running north-northwest from Ithaca, Ga., in the Villa Rica, Ga. 7.5-min quadrangle. *B*, Closer view of manganiferous banded iron formation in manganiferous schists. Same outcrop as *A*. Hammer is 40 cm long. *C*, Closer view of the layered magnetite quartzite. Dark layers are magnetite. Same outcrop as *A*. Coin is 2.3 cm in diameter.

iferous quartzites, and manganiferous schists (fig. 34). Some of the manganiferous rocks are similar to those found in the Zebulon and Atlanta thrust sheets, but the iron-rich rocks are so characteristic of the Ropes Creek thrust sheet that they can be used almost like index fossils to identify it. Locally associated with the iron-rich rocks are thin layers of fibrous tourmaline (generally dravite). In addition, as far as we know (except for sulfide deposits in the Little River allochthon [see Bell, 1982] and Ducktown-type deposits [see Slater and others, 1985]), all of the massive volcanogenic sulfide deposits in Georgia and Alabama are associated with alteration zones within the Ropes Creek thrust sheet. The alteration zones are mappable linear, siliceous and (or) aluminous, graphitic, magnetite-, garnet-, and pyrite-rich (fig. 35) zones (fig. 2, for example), locally as wide as several kilometers, that were probably closely associated with submarine exhalative vents (also see Carpenter and Allard, 1982, and Allard and others, 1985). The sulfide deposits are also closely associated with the iron formations (Pate, 1980; McConnell and Abrams, 1982, 1984; Abrams and McConnell, 1984) and tourmaline layers (or tourmalinite, also see Slack, 1982), generally within the alteration zones.

Geochemical studies (Stow and others, 1984; Appendix B) indicate that the amphibolites in the Ropes Creek thrust sheet probably originated as seafloor basalts in an ocean-ridge type of environment. Isotopic studies (Jones and others, 1973; Shaw and Wasserburg, 1984; see section above on West Point thrust sheet for further discussion) also indicate that the Ropes Creek amphibolites are ancient oceanic crust. These interpretations are supported by the fact that the rocks in the Ropes Creek thrust sheet are almost entirely mafic (though ultramafic rocks and insignificant amounts of intermediate to felsic rocks also occur), contain volcanogenic sulfide-rich alteration zones and deposits (probably "black-smoker" deposits), and are associated with metavolcanogenic chemical sediments (iron-rich and, to a slightly lesser extent, manganese-rich cherts) and minor amounts of manganiferous pelagic sediments. We suggest that most of the rocks in the Ropes Creek thrust sheet originated at the mid-Iapetus ridge.

HILLABEE GREENSTONE (INFORMAL)

"Hillabee greenstone" has been used for a sequence of metavolcanic and lesser metaplutonic rocks whose lower part belongs to the Paulding Volcanic-Plutonic Complex in the Paulding thrust sheet and whose upper part, which makes up almost all of its outcrop belt, belongs to the Ropes Creek Metabasalt in the Ropes

FIGURE 35.—Highly deformed magnetite-garnet-chlorite schist from the West Point melange in outcrop at Mill Creek and north-south-running road about 1.3 km southeast of where the Seaboard Railway crosses over the Southern Railway, in the Dallas, Ga. 7.5-min quadrangle (also see fig. 2). Knife is 9 cm long.

Creek thrust sheet; West Point melange is locally present beneath the Ropes Creek Metabasalt. The Hillabee has most recently been considered to rest stratigraphically and conformably upon the fossiliferous Lower and Middle Devonian Jemison Chert at the top of the Talladega Group (Tull and others, 1978; Tull and Stow, 1980a,b; Tull, 1982; Stow, 1982). (The Talladega Group is discussed in a later section.) We disagree with this interpretation for several reasons. (1) Everywhere we have examined the contact between the Hillabee and the Jemison, or between the Hillabee and Jemison equivalents, it appears to be a thrust fault (locally imbricate) that has placed the low-grade Hillabee upon the low-grade Talladega Group. In some places the Paulding Volcanic-Plutonic Complex rests upon the metasedimentary rocks, in others the West Point melange rests upon these rocks, and in most places the Ropes Creek Metabasalt rests upon them. (2) The upper part of (most of) the Hillabee has all of the distinctive characteristics that are unique to the Ropes Creek thrust sheet in Georgia and Alabama. It is an almost entirely metaigneous unit (but includes pelagic manganiferous sediments, volcanogenic chemical sediments, and volcanogenic alteration zones) that is lithologically identical to the Ropes Creek Metabasalt (including the Mitchell Dam amphibolite and Ketchepedrakee amphibolite, which are relatively near by to the south). The distinctive banded iron formations, ironstones, and magnetite quartzites that are unique to the Ropes Creek thrust sheet are widespread within the upper (Ropes Creek) part of the Hillabee. The Ropes Creek part of the Hillabee has the same type of massive volcanogenic sulfide deposits (Stow and Tull, 1982) that are confined to the Ropes Creek sheet. The mafic rocks of the Hillabee show the same chloritization, epidotization, and uralitization as mafic rocks in other parts of the Ropes Creek sheet, and many have the same disseminated pyrite (Tull and others, 1978, p. 19) and pyritiferous zones as mafic rocks in other parts of the Ropes Creek sheet. (3) The distinctive eclogite-bearing West Point melange is present beneath the Ropes Creek part of the Hillabee around Needmore, Ala. (pl. 1), and probably elsewhere (Prouty, 1923). (4) Comparison of the geochemical data in Stow and others (1984) from the Ropes Creek Metabasalt (including the Mitchell Dam and Beaverdam amphibolites, and most of the Ketchepedrakee amphibolite) and from the Paulding Volcanic-Plutonic Complex (including the Waresville Amphibolite) with the geochemical data in Tull and others (1978), Tull and Stow (1980a,b), and Stow (1982) from the Hillabee greenstone (mostly Ropes Creek Metabasalt, but locally including rocks of the Paulding Volcanic-Plutonic Complex in its lower parts, especially around Millerville, Ala.) clearly shows the identical chemical composition of the upper and lower parts of the Hillabee and the Ropes Creek Metabasalt and Paulding Complex (Appendix B). (5) The unpublished map of the crystalline rocks of Alabama (Alabama Geological Survey, 1973) and Tull and others' (1978) maps of the internal stratigraphy of the Hillabee suggest that part of the Hillabee section is locally cut out against Talladega Group units by the basal Paulding thrust fault. (6) Zircons from felsic units within the Paulding part of the Hillabee have yielded Ordovician ages of about 460 Ma (Russell, 1978; Russell and others, 1984); the zircon data are slightly discordant and the crystallization age could be older (but probably not younger—see Russell and others, 1984). (7) Variations in degree of deformation and metamorphism of the Jemison Chert in the vicinity of Jemison, Ala., were probably caused by overthrusting of the Hillabee upon the Jemison. West of the town of Jemison, where the Hillabee probably is not in contact with the Jemison Chert (Coastal Plain sediments obscure the relationship) but is located several kilometers south of the chert (also see Sutley, 1977), the Jemison is unsheared and unmetamorphosed and contains a diverse suite of undeformed fossils. In contrast, only a few kilometers to the east, the Jemison has been transformed into a sheared, strongly foliated, clearly metamorphosed micaceous quartzite and quartz-rich phyllonite (also see Tull, 1982, p. 11–12). A slight sedimentary facies change occurs in the Jemison through the same interval—microconglomerates with small chips of chert appear a short distance east of the town of Jemison, and the unit becomes more micaceous. The change in the Jemison Chert from an unsheared, unfoliated, unmetamorphosed chert with an interlocking mosaic texture of microquartz and chalcedony (also see Tull, 1982) to a well-developed tectonite with sheared and strongly foliated textures takes place a little farther to the east, almost exactly where the Hillabee first rests directly upon the Jemison, and becomes still more marked farther to the east. We suggest that the deformation and metamorphism of the Jemison Chert are directly related to and probably caused by thrust emplacement of the Hillabee greenstone upon the thin chert unit. (8) Original facies differences between the Hillabee metavolcanic rocks and the structurally underlying Jemison Chert strongly favor fault emplacement of the Hillabee. Geochemical and petrologic studies (Tull and others, 1978; Tull and Stow, 1980a,b; Stow, 1982) indicate that the dominantly mafic Hillabee has affinities with both low-K tholeiitic island-arc basalts (the lower part [around Millerville, Ala.], belonging to the Paulding Volcanic-Plutonic Complex) and ocean-floor basalts or "abyssal tholeiites" (the upper part, belonging to the Ropes Creek Metabasalt). According to Tull and Stow (1978), the data eliminate within-plate basalts as parental material for any part of the Hillabee. Stow (1982, p. 90) stated "the low K_2O content of Hillabee tholeiites compared with that of typical island arc tholeiites (0.25% versus 0.44%; Jakeš and White, 1973) can be interpreted to indicate minimal, continental crustal influence during volcanism." In sharp contrast, the lithologies and the faunal assemblage of the Jemison Chert indicate that it is a shallow-water deposit more akin to the continental Valley and Ridge rocks (in fact it is the Armuchee Chert–Frog Mountain Sandstone sequence) than to the rocks of the crystalline terrane; the Jemison must have been deposited on continental crust, and it has a faunal assemblage quite similar to that of nearby Valley and Ridge province rocks. Therefore, it seems highly improbable that island-arc and ocean-floor material with little or no evidence of continental crustal contribution, represented by the Hillabee greenstone, could have developed near to and been conformably deposited upon the thick pile of clastic metasedimentary rocks of the Talladega Group, which appear to be essentially devoid of volcanogenic material. (9) Finally, the general absence of volcanic material in the Upper Devonian Chattanooga Shale[8] and Lower Mississippian Maury Shale in the Valley and Ridge province less than 10 km north and northwest of the Hillabee and the Jemison Chert (Butts, 1926; Conant and Swanson, 1961; Thomas, 1979; Smith, 1979) is strong evidence against an island arc built stratigraphically above the Lower and Middle Devonian Jemison Chert.

[8]Conant and Swanson (1961, p. 30–34) reported a thin (1.5–4.3 cm) bentonite bed in the Chattanooga Shale in Tennessee but indicated that it is not present in Alabama.

Our work indicates that the Hillabee greenstone in the Alabama crystalline terrane is simply the northwesternmost infold of the Ropes Creek and Paulding thrust sheets (and locally the West Point sheet), that it originated a long way from its present position structurally atop the Talladega Group, and that its lower Paulding part is probably no younger than Middle Ordovician. Because evidence presented in later sections indicates that it was already emplaced upon lower sheets in the stack by the time of the unconformity that truncates part of the Upper Cambrian and Lower Ordovician Knox Group, we suggest that the Hillabee (and all of the Ropes Creek and Paulding thrust sheet rocks) is mostly Cambrian in age.

SOAPSTONE RIDGE THRUST SHEET

Structurally above the Ropes Creek thrust sheet is the Soapstone Ridge thrust sheet, the highest sheet in the Georgiabama thrust stack. It occurs as widely scattered remnants throughout the crystalline terrane northwest of the Macon melange (fig. 36), because of erosion or because the sheet may have broken up during transport and emplacement, or, more likely, both. Named units in the Soapstone Ridge thrust sheet in Alabama include the informal Goodwater and Boyds Creek ultramafic-mafic complexes, and part of the Doss Mountain amphibolite and Slaughters metagabbro (Bentley and Neathery, 1970; Reynolds, 1973; Neathery, 1975; Neilson, 1983), and in Georgia, the Soapstone Ridge and Laurel Creek Complexes (Higgins and others, 1980; Higgins and Atkins, 1981; Hatcher and others, 1984).

Like the Ropes Creek, Paulding, and Promised Land thrust sheets, the Soapstone Ridge is essentially an entirely igneous thrust sheet, but most of the rocks in this sheet are "metaplutonic" rather than metavolcanic. The Soapstone Ridge sheet is composed of ultramafic-mafic complexes and of small ultramafic and (less common) mafic slices. The ultramafic-mafic complexes commonly have a relatively thin basal unit of dunite or peridotite that has been sheared and altered to serpentinite and talc-chlorite schist. The basal unit is commonly overlain either by mixed units of altered ultramafic rocks and uralitized and chloritized metagabbroic rocks (including metagabbros, metatroctolites, meta-anorthosites, and so forth), or by uralitized and chloritized metapyroxenites, or by both assemblages.

One of the largest of the ultramafic-mafic complexes, the Soapstone Ridge Complex, has small sheeted-dike swarms (Higgins and others, 1980; H.E. Cofer, oral

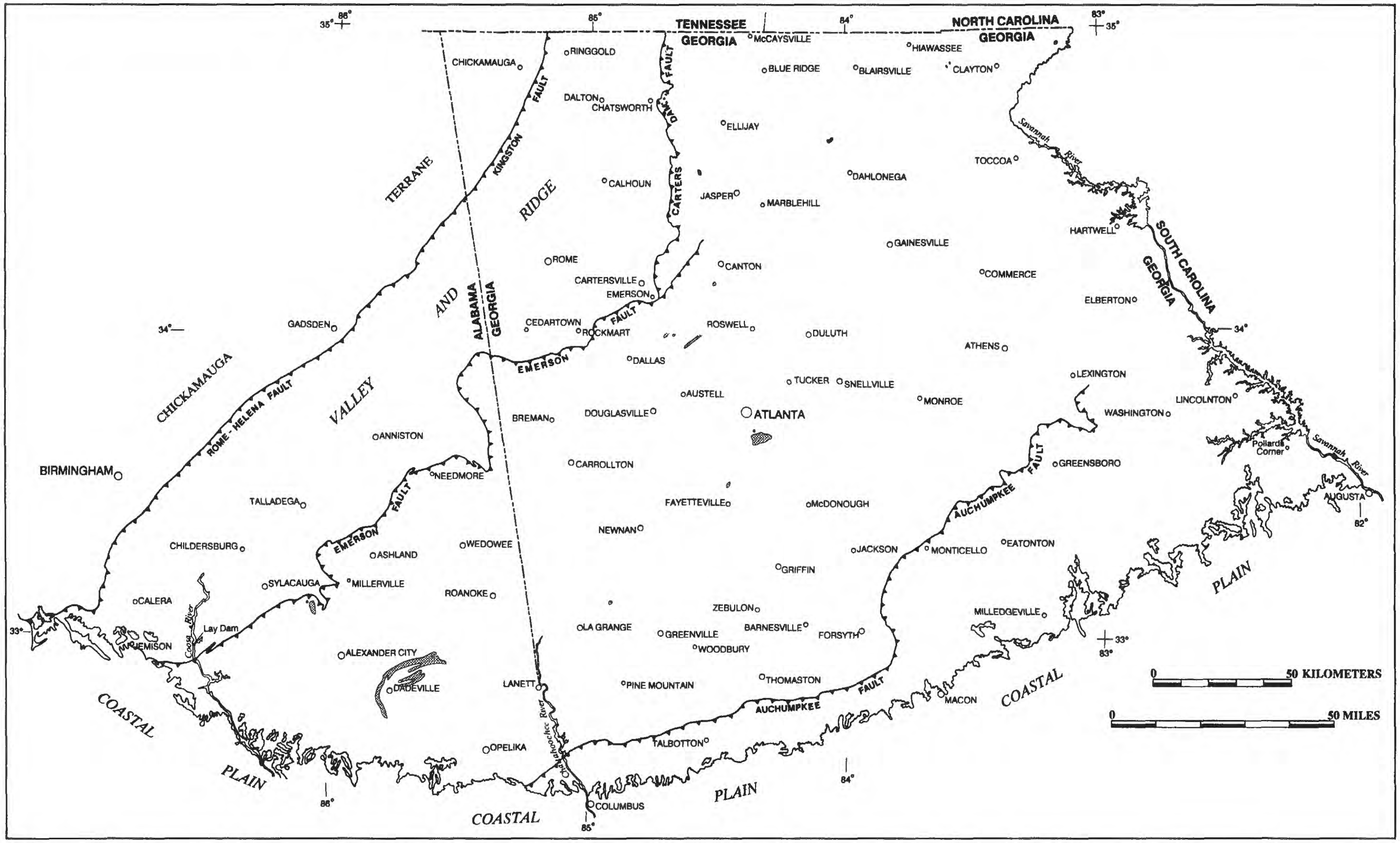


FIGURE 36.—Present known distribution of the Soapstone Ridge thrust sheet in the southernmost Appalachians. Some of the smaller occurrences have been exaggerated on this map. For greater detail, see plate 1.

commun., 1984) and locally rests upon thin slices of the Ropes Creek and Paulding thrust sheets (fig. 2). Its basal thrust fault is well exposed at several places (fig. 37), and where it rests upon rocks of the Promised Land thrust sheet it truncates folds, pegmatites, and quartz veins in the underlying rocks.

The work of Bluhm and Zimmerman (1977) and Dribus and others (1977) on small ultramafic-mafic complexes that are probably part of the Soapstone Ridge thrust sheet northwest of the Brevard Zone in North Carolina indicates that they have mantle-derived fabrics. Hatcher (1978a) and Hatcher and others (1981, 1984) recognized that some of the small ultramafic-mafic complexes in North Carolina and northern Georgia rest in thrust contact on the underlying rocks and are probably ophiolite-related.

We suggest that many of the small ultramafic and less common ultramafic-mafic bodies scattered through the crystalline terrane of the southernmost Appalachians are ophiolitic and part of the Soapstone Ridge thrust sheet. Some of these small bodies are clearly thrust-emplaced, but for most there is little evidence to indicate their mode of emplacement. However, the work of Prowell (1972) indicates that many of the small ultramafic bodies southeast of the Brevard Zone in Georgia were cold when emplaced in their present positions.

Numerous small altered ultramafic bodies that have been mined for talc in the vicinity of Fort Mountain in northwest Georgia (Hopkins, 1914; Furcron and others, 1947; Needham, 1972) are especially important because of their location (pl. 1) near the cratonward edge of the crystalline terrane (see section below on the Hayesville thrust fault). These bodies are now composed mainly of talc and serpentinite, but they contain chromite and pyrite, and some are intimately associated with greenstone. They occur imbricated with slices of sheared Corbin Gneiss and massive microconglomerates of the Pinelog Formation (fig. 38). These altered ultramafic rocks are possibly remnants of the Soapstone Ridge thrust sheet and, if they are, they are the most cratonward remnants of that sheet.

FIGURE 37.—Soapstone Ridge thrust fault at the base of the Soapstone Ridge thrust sheet in large cut behind Old Dominion Truck Lines Depot at Moreland Avenue and the South River in the Southeast Atlanta, Ga. 7.5-min quadrangle. Rocks above the thrust are altered metapyroxenites of the Soapstone Ridge Complex; there is a thin layer of highly sheared and altered dunite or peridotite (now talc-chlorite-actinolite schist) about 2 m thick at the base of the Soapstone Ridge sheet in this cut (not visible in this photograph). Rocks below the thrust fault are metamorphosed felsic tuffs with thin layers of amphibolite belonging to the Promised Land Formation. Folds and pegmatite dikes in the Promised Land rocks are cut off abruptly at the fault. View is approximately 20 m wide.

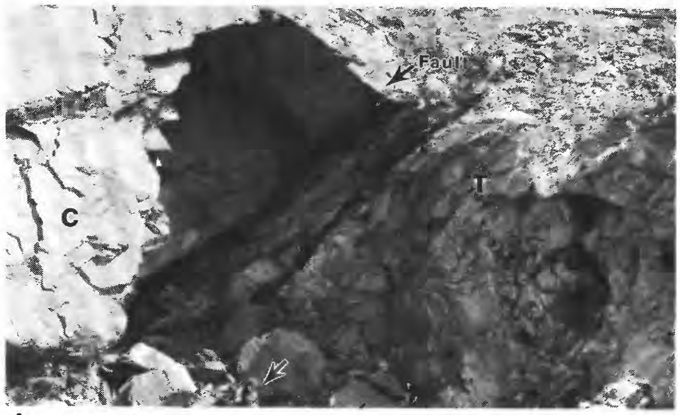
LITTLE RIVER THRUST STACK

Structurally above the Georgiabama thrust stack is the Little River thrust stack, composed (in ascending order) of the Macon melange, the Little River allochthon, and the Northern Florida platform sequence (figs. 1, 39; pl. 1; table 3). These sheets (which are all allochthogenetic to the North American craton) were apparently assembled from bottom to top as the "African" continent collided with the North American continent and were thrust upon the Georgiabama thrust stack. Because of its importance in interpretation of the other two units, the Little River allochthon is described first.

LITTLE RIVER ALLOCHTHON

Much of the southeasternmost part of the southern Appalachian orogen is underlain by thick sequences of mildly metamorphosed volcanic, volcaniclastic, volcanic-epiclastic, and intrusive rocks traditionally assigned to various "belts," including parts of the "Carolina slate," "Raleigh," "Belair," "Little River," "Kiokee," "Charlotte," and "Uchee" "belts" (Kish and Black, 1982, and references therein). These rocks are all part of the same volcanic arc assemblage, as implied by Cook (1983) and Secor and others (1983), and we assign them all to the (probably composite) Little River allochthon (pl. 1; figs. 1, 39).

Many of the rocks in the Little River allochthon have well-preserved igneous and sedimentary textures, and most have only been metamorphosed to the greenschist facies. Sedimentary features commonly indicate shallow-water or subaerial environments (Bramlett, 1980; Snoke and others, 1980; Green and others, 1982, and references therein). Metavolcanic and metavolcaniclastic rocks are generally more common in the



A

B

C

FIGURE 38.—Slices interpreted to belong to the Soapstone Ridge thrust sheet structurally emplaced with Corbin Gneiss in the Allatoona Complex of Grenville basement and the Pinelog Formation of the Ocoee Supergroup in the Fort Mountain area, Georgia. *A*, New talc prospect on the west face of Fort Mountain, in the Crandall, Ga. 7.5-min quadrangle. Corbin Gneiss (C) rests overturned in sharp fault contact upon talc and serpentinite (T). Arrow points to man for scale. Conglomerates of the Pinelog Formation crop out a few meters above the view in the photo. *B*, Massive greenstones in the same talc prospect; this view is adjacent on the right (south) to the view in *A*. It is not known whether these greenstones are metabasalts within the Soapstone Ridge thrust sheet or Ropes Creek Metabasalt in the Ropes Creek thrust sheet. *C*, Highly sheared Corbin Gneiss in entrance road to same prospect as *A* and *B*, about 50 m south of view in *B*. Arrows point to euhedral K-feldspars that have survived the shearing. Most K-feldspar crystals have been deformed into white streaks (compare with fig. 55). Coin is 2.3 cm in diameter.

lower parts of the sequences, and epiclastic rocks are more common in the upper parts (Sundelius, 1970; Whitney and others, 1978; Bell and others, 1980; Snoke and others, 1980; Green and others, 1982; Rogers, 1982), indicating that by Middle Cambrian time the arc was dying ("constructive" and "destructive" phases of Rogers, 1982). The metavolcanic and metavolcaniclastic rocks are bimodal and calc-alkaline, with characteristics indicative of a continental-margin arc environment (Rogers, 1982, and references therein).

Radiometric ages from metavolcanic rocks in the allochthon (see Kish and Black, 1982, for a summary) indicate latest Precambrian through Cambrian ages, and latest Precambrian (Ediacaran) and Cambrian fossils have been found at several localities (Gibson and others, 1984; Secor and others, 1983, and references therein). One of the latest finds of numerous trilobites near the top of the thick section in western South Carolina shows that these fossils are restricted to the upper two-thirds of the Middle Cambrian and are characteristic of the Atlantic faunal province (Secor and others, 1983). Thus, the sequences in the Little River allochthon probably span from latest Precambrian (Ediacaran) through Middle Cambrian time and were deposited in a volcanic arc (Little River arc) at the oceanward edge of the "African" continent. The sequences are probably slightly older in the northeastern parts of the allochthon and slightly younger in the southwestern parts (Green and others, 1982; Secor and others, 1983; D.T. Secor, Jr., oral commun., 1982). The lack of radiometric ages younger than Cambrian throughout the allochthon, the fact that Middle Cambrian trilobites occur near the top of what is probably one of the youngest of the sequences, and the suggestion that some of the younger radiometric ages are probably minimum ages (Kish and Black, 1982) imply that volcanism in the Little River arc ceased before or during the Late Cambrian.

MACON MELANGE[9]

Structurally beneath the Little River allochthon is the Macon melange (Higgins and others, 1984), more

[9]In this paper we use "melange" and "subduction melange" for the entire accretionary complex, following Hamilton's (1979) usage of "melange." Since this paper was written, we have changed the name of the accretionary complex from "Macon melange" to "Macon Complex" (Higgins and others, 1987). The overall concept is the same, but in the later paper, which will probably be published before this paper, we follow the usage of Berkland and others (1972) and Cowan (1985) for the Franciscan (accretionary) Complex, which we believe has many similarities to our "Macon melange," and rename the accretionary complex the Macon Complex. We agree with Berkland and others (1972) and Cowan (1974, 1985) that "melange" should be reserved for rock types (Greenly, 1919) and "accretionary complex" used for the accumulation of material, generally including broken formations and large packages of undisturbed sediments, as well as tectonic melanges and olistostromes, that forms between the trench and the magmatic part of an arc.

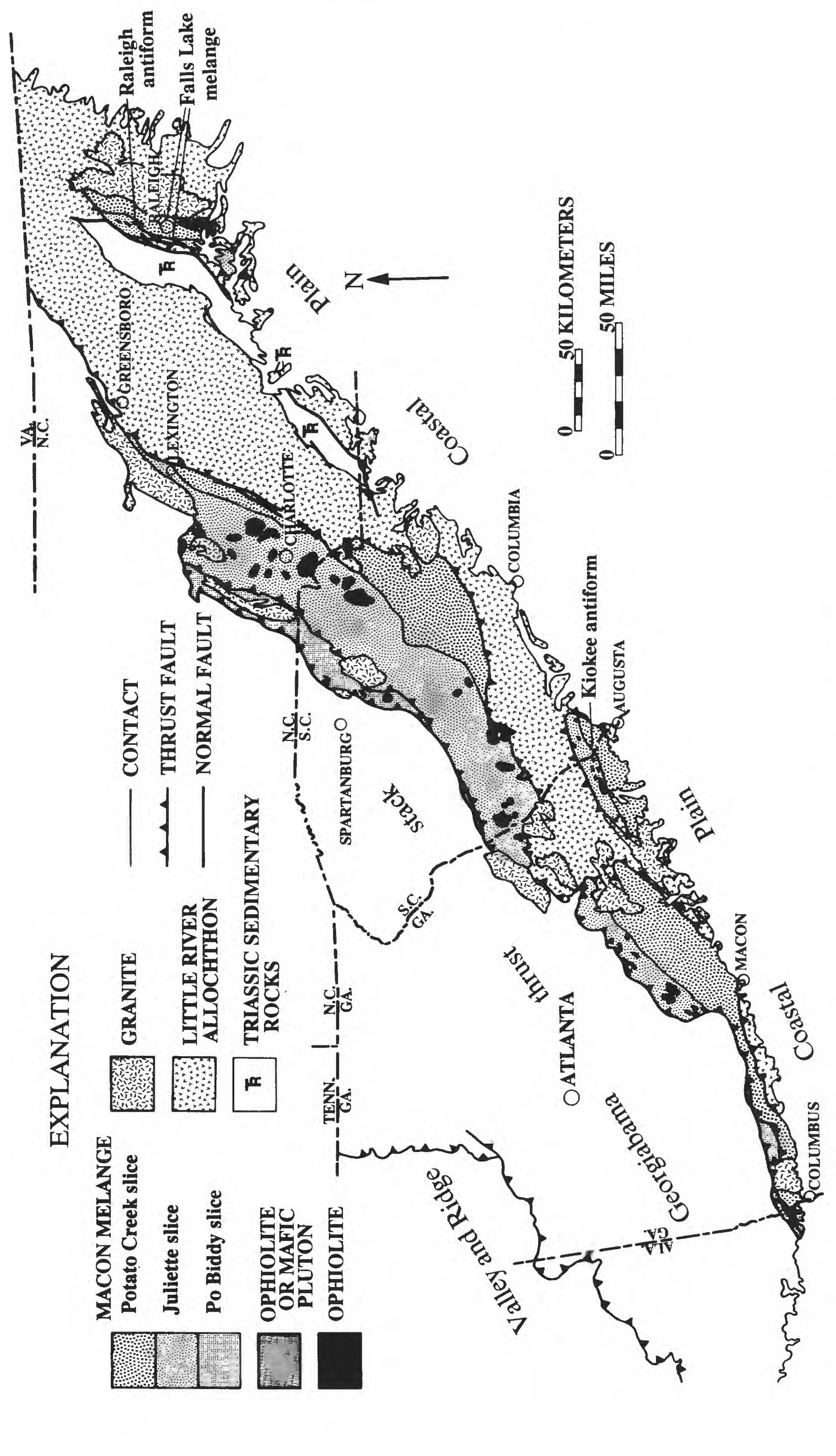


FIGURE 39.—Generalized geologic map of the Macon melange and Little River allochthon.

TABLE 3.—*Summaries of thrust sheets in the Little River thrust stack*

STRUCTURAL UNITS	STRATIGRAPHIC OR (AND) TECTONOSTRATIGRAPHIC UNITS	GENERAL CHARACTERISTICS	INTERPRETED ORIGIN
	NORTHERN FLORIDA PLATFORM SEQUENCE		
Northern Florida platform sequence	Unnamed Ordovician through Devonian sedimentary rocks beneath the Coastal Plain.	Unmetamorphosed, fossiliferous Lower Ordovician through Middle Devonian gray, red, and black siltstones, sandstones (locally crossbedded), quartz arenites, and micaceous shales. Clastic sequence apparently without volcanic components.	Platform (shelf) sequence deposited on African craton.
	LITTLE RIVER ALLOCHTHON		
Little River allochthon	"Little River series" of Crickmay (1952), Lincolnton Metadacite (Whitney and others, 1978), and parts of the "Little River," "Carolina slate," "Belair," "Kiokee," "Charlotte," "Raleigh," and "Uchee" "belts."	Felsic (~70-80%) and mafic (~20-30%) metavolcanic, metavolcaniclastic, and metavolcanic-epiclastic rocks, including metasubvolcanic rocks and hypabyssal plutonic rocks. Metavolcanic rocks are more common in lower parts of sequence, and metavolcanic-epiclastic rocks more common in upper parts. Atlantic faunal province trilobites of late Middle Cambrian age found in uppermost part of sequence in western South Carolina.	Continental-margin calc-alkaline arc deposits; formed in arc at edge of "African" microcontinent.

STRUCTURAL UNITS	STRATIGRAPHIC OR (AND) TECTONOSTRATIGRAPHIC UNITS	GENERAL CHARACTERISTICS	INTERPRETED ORIGIN
	MACON THRUST SHEET		
Potato Creek, Juliette, and Po Biddy slices	Uchee Complex (Bentley and Neathery, 1970), and parts of the "Charlotte," "Kiokee," "Uchee," "Inner Piedmont," "Kings Mountain," "Lowndesville," "Raleigh," "Pine Mountain," and "Carolina slate" "belts."	Po Biddy slice: matrix is an imbricate complex of mafic, intermediate, and (locally graphitic) felsic metavolcaniclastic rocks, graphitic schists, and manganiferous schists containing elongate clasts of rocks identical to the matrix, manganiferous quartzites, aluminous quartzites, metamorphosed thinly bedded and laminated chloritic and pyritiferous limestones, calc-silicate rocks, metaconglomerates, and various metagabbroic and serpentinized ultramafic rocks. Juliette slice: matrix is an imbricate complex of (most to least common) intershingled massive (but broken), coarse-grained quartzose, feldspathic, semischistose and schistose, generally amphibole-bearing, biotite-plagioclase metagraywackes, semischistose pebbly mudstones, semischists with thin broken metagraywacke beds, and thin tuffaceous metacherts interbedded with scaly schist composed of manganiferous mica, plagioclase, and amphiboles. Structural discontinuities and pervasive anastomosing shearplanes abound in the matrix at all scales; contains exotic clasts of metagabbroic rocks, metapyroxenites, amphibolites, metavolcanic and metavolcanic-epiclastic rocks, folded and unfolded tuffaceous metachert, fine-grained unmetamorphosed-appearing metadiabase, medium-grained garnet metadiabase, altered and unaltered or barely altered ultramafic rocks, contorted biotite gneisses, and high-grade schists; clasts range in size from tiny fragments to slabs tens of kilometers long and in shape from well-rounded to angular; slice contains abundant clasts of mafic and ultramafic rocks. Potato Creek slice: identical to the Juliette slice, but with less numerous clasts of mafic and ultramafic rocks.	Remnants of different parts of a subduction melange wedge (accretionary complex); Po Biddy - near toe of wedge where pelagic sediments, Iapetus Ocean crust, and sediments moving down the top of the wedge are imbricated together; Juliette - near bottom of wedge where more Iapetus Ocean crust was offscraped and imbricated into the wedge; Potato Creek - near top of wedge where more sediments moving down the top of the wedge were imbricated into the wedge.

than 100 km wide at its greatest preserved width and more than 500 km long (fig. 39). The Macon melange is comparable in size and complexity with the Franciscan melange of coastal California and Oregon (Cloos, 1982, and references therein) but is smaller than most active and fossil melanges in the Indonesian region (Hamilton, 1979, and references therein). Nevertheless, it is the largest melange known in the Appalachians and one of the largest Paleozoic melanges known in the world. Rocks of the Macon melange have previously been assigned to various "belts," including parts of the "Charlotte," "Kiokee," "Uchee," "Raleigh," "Kings Mountain," "Pine Mountain," "Inner Piedmont," "Lowndesville," and "Carolina slate" "belts."

The Macon melange is a tectonic, sedimentary, and metamorphic chaos, in which well-rounded to angular clasts of contrasting metamorphic grades, vastly different sizes, different igneous parentages, drastically different sedimentary facies, and different degrees of deformation "float" in highly imbricated and tectonized matrices (for example note the complex picture given by Glover and others, 1983, p. 231–233). The Macon melange locally has characteristics of Cowan's (1985) "type I" and "type II" melanges but most commonly would fit into Cowan's "type III" melange. The melange is divisible into three tectonostratigraphic slices that probably reflect different structural regimes (see Hamilton, 1979; Moore and others, 1985) within the accretionary melange wedge: (1) the Potato Creek slice, characterized by an abundance of clastic matrix rocks and the local presence of thin tuffaceous metacherts; (2) the Juliette slice, characterized by an abundance of mafic and ultramafic clasts; and (3) the Po Biddy slice, characterized by metamorphosed manganiferous sediments, metavolcaniclastic rocks, graphitic schists, and, locally, metamorphosed thinly bedded pyritiferous limestones, and with a wide variety of mineral deposits. Contacts between the slices are generally thrust faults, but locally they are so imbricated that they give the appearance of being broadly gradational.

POTATO CREEK AND JULIETTE SLICES

The Potato Creek and Juliette slices of the Macon melange have previously been assigned to parts of the "Charlotte," "Uchee," "Pine Mountain," "Kiokee," "Inner Piedmont," and "Carolina slate" "belts." The matrix of the Potato Creek and Juliette slices is an imbricate complex of (most to least common) intershingled massive (but broken), coarse-grained, quartzose, feldspathic, semischistose and schistose, generally amphibole-bearing, biotite metagraywackes; semischistose pebbly mudstones; semischists with thin, broken metagraywacke beds; and thin tuffaceous metacherts interbedded with scaly schist composed of manganiferous mica, plagioclase, and amphiboles (fig. 40). Structural discontinuities and pervasive anastomosing shear planes abound in the matrix at all scales (fig. 41).

All types of matrices in the Potato Creek and Juliette slices contain exotic clasts of metagabbroic rocks, amphibolites, metavolcanic and metavolcanic-epiclastic rocks identical with rocks of the overlying Little River allochthon, folded and unfolded tuffaceous metachert, fine-grained unmetamorphosed-appearing diabase, medium-grained garnet diabases, altered and unaltered or barely altered ultramafic rocks, contorted biotite gneisses, and high-grade schists (figs. 40, 42). Structures within the clasts do not pass into the matrix, which appears to have "shear-flowed" (Cowan, 1974) around the clasts. The clasts range in size from small fragments seen in thin sections to slabs tens of kilometers long and several kilometers wide, and in shape from well rounded to angular.

Some of the larger exotic mafic slabs and aggregates of mafic blocks and slabs in the Macon melange have been considered intrusions. These large clasts are concentrated in, but not confined to, the Juliette slice. Locally, mafic clasts are so abundant in the Juliette slice that the matrix is nearly obscured, and aggregates of clasts have been considered to be larger intrusive bodies. The Gladesville, Juliette, Berry Creek, and Holly Grove bodies (Matthews, 1967; Prather, 1971; Carpenter, 1971; Hatcher and others, 1984) in the Juliette slice in central Georgia (fig. 43) and the string of mafic and ultramafic bodies in the Pollards Corner area in eastern Georgia (McLemore, 1965; Crawford, 1968a,c; pl. 1) are examples of large slabs and aggregates of slabs and blocks that have been considered intrusions; Hatcher and others (1984, p. 491, 498) suggested some unspecified type of tectonic emplacement for the bodies in central Georgia.

The mafic bodies in central Georgia have been called norites (Matthews, 1967; Prather and Radcliffe, 1970; Prather, 1971; Carpenter and Prather, 1971). However, our mapping indicates that fine-grained metadiabase makes up 80–90 percent of the Gladesville body, or aggregate, and that the remaining 10–20 percent is mostly medium-grained metagabbro and amphibolite, with lesser amounts of coarse-grained metapyroxenite.

The body that has been called the "Gladesville norite" (Matthews, 1967; Radcliffe and Prather, 1970; Prather, 1971; Carpenter, 1971) is neither a single large body, nor a norite, but an aggregation of smaller bodies (fig. 44), of various sizes, of metadiabase and metamorphosed olivine gabbro, with lesser amounts of metapyroxenite in the melange matrix. The aggregation is neither as large as nor the same shape as the body shown in Matthews (1967), Prather (1971), Carpenter (1971), Georgia Geological Survey (1976), and Higgins and others (1984, 1986). Other relatively large bodies that have been called norites are mostly gabbros and are matched at all scales by smaller bodies that can be seen to be blocks or clasts in the melange matrix (fig. 45), providing evidence that the larger bodies are not intrusions but slabs in the melange.

Our work indicates that the attitude of igneous layering in the "Gladesville body" is not as regular as previous workers have depicted it and does not support the interpretation (based on structural measurements at three outcrops; Matthews, 1967; Carpenter and Hughes, 1970, p. 2) that the Gladesville body is an apophysis on a large stratiform body more than 15 km thick (Carpenter and Prather, 1971) that was intruded after metamorphism and then tilted 60 degrees (Matthews, 1967; Prather, 1971; Carpenter, 1971).

Most previous workers (Matthews, 1967; Prather, 1971; Carpenter, 1971) mapped continuous borders of "hornblende hornfels" and "pyroxene hornfels" around the mafic bodies in the Juliette slice (fig. 43), which they considered thermal aureoles resulting from contact metamorphism of the "country rocks" by intrusion of the mafic bodies. These borders, not nearly as continuous as depicted, are rather rare, and are composed entirely of altered mafic rocks; they are local alterations of the margins of the mafic slabs and blocks, rather than thermally metamorphosed "country rocks" (quartzofeldspathic clastic rocks of the melange matrix); the mafic bodies have no thermal aureoles. Ultramafic blocks and slabs in the melange also lack thermal aureoles (for example, see McLemore, 1965, p. 27) and must have been emplaced cold. Locally, some of the smaller mafic and ultramafic clasts in the melange have incomplete altered borders around unmetamorphosed-appearing interiors, thus mimicking the discontinuous borders of some of the larger slabs and blocks.

Low initial $^{87}Sr/^{86}Sr$ ratios (average 0.7035, but as low as 0.7025) from tholeiitic blocks in the melange in central Georgia (Jones and others, 1974) suggest oceanic derivation, as do ultramafic slabs (now mostly serpentinites and talc-chlorite schists, but originally peridotites and pyroxenites; McLemore, 1965; Whitney and Stormer, 1980, p. 122–123) in the melange. The ultramafic slabs contain chromite, magnetite, and sulfide minerals and have trace amounts of platinum and nickel (Worthington, 1964; McLemore, 1965). Centimeter-scale disrupted igneous layering is locally present in some of the mafic slabs and blocks (fig. 46), and cumulate textures have been described by Matthews (1967) and Prather (1971).

Wilson's (1981) magnetic and radioactivity surveys of the "Mecklenburg-Weddington" gabbro complex in the Juliette slice south of Charlotte, N.C., indicate that the gabbroic bodies have sharp contacts. His gravity models (1981, p. 35–36) indicate "lopolith-like" bodies only 3.5 to 4.5 km thick and a "sill-like" body about 2 km thick. Lawrence's (1985, and oral commun., 1985) detailed gravity survey of a large area in the melange in west-central South Carolina indicates that the mafic "plutons" there can be no more than a few kilometers thick, and some are as little as 1.6 km thick. The shapes and thicknesses are more compatible with large slabs in a melange than with large intrusive plutons, and certainly more compatible with slabs than with a mafic batholith as much as 7 km thick.

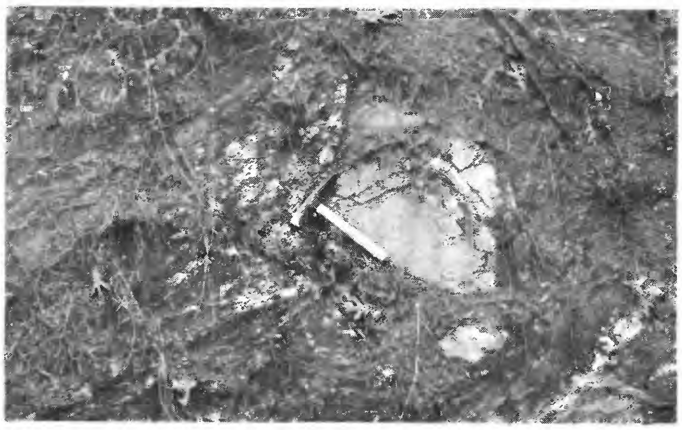
McSween and others (1984, p. 452–455) recently summarized data indicating that many of the gabbroic rocks in the Juliette slice were "emplaced" between 520 and 580 Ma and were probably metamorphosed about 400 Ma but that some were intruded about 400 Ma. The "emplacement" ages match well with our interpretation of the age of activity of the melange wedge and the Little River arc, and we suggest that the metamorphic ages represent the time of collision and of thrusting of the arc upon the melange and of the melange upon the Georgiabama thrust stack.

In addition to the clasts of mafic and mafic-ultramafic rocks in the melange, there are intrusive gabbroic bodies in the melange in the Carolinas (McSween and others, 1984, and references therein). These younger mafic bodies are locally associated with syenite; where the syenites have been dated they give radiometric ages of about 400 Ma (Fullagar, 1971, 1981, 1983; Butler and Fullagar, 1978; Eric Hund and A.K. Sinha, oral commun., 1985), matching the inferred age of the metamorphism. We have not separated the ~400-Ma intrusive bodies from the older clasts in the Carolinas.

In our opinion, the evidence indicates that many of the mafic and mafic-ultramafic bodies, and all of the ultramafic bodies, in the Macon melange are clasts of Iapetus Ocean crust and mantle (disrupted ophiolite) offscraped and incorporated into the melange; the tuffaceous ribbon metacherts and manganiferous scaly schists were probably pelagic sediments deposited on the Iapetus Ocean floor and offscraped (see Moore and others, 1981, 1985; Moore and Biju-Duval, 1984; Cowan, 1985) and incorporated into the melange along with semischist and semischistose metagraywacke trench sediments. The metamorphosed pebbly mudstones and associated quartzose metagraywackes probably represent continental clastic sediments deposited on top of the melange wedge and imbricated into it in the manner described by Hamilton (1979, p. 28–31).

A

B



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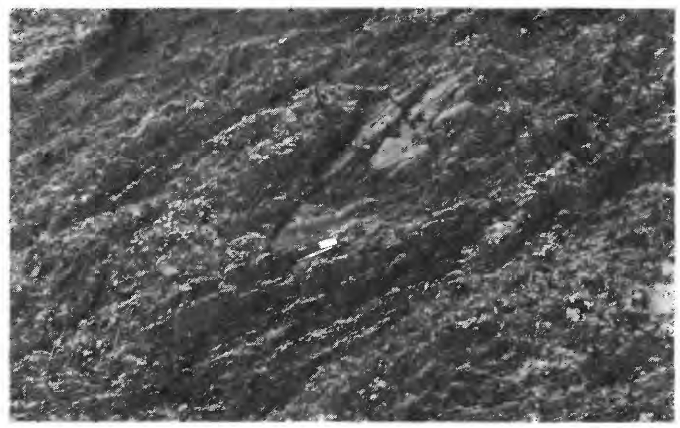

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FIGURE 40.—Matrices of the Potato Creek and Juliette slices of the Macon melange. *A*, Reddish-pink and white ribbon tuffaceous metacherts of the Potato Creek slice interbedded with scaly schist composed of manganiferous mica and amphiboles in a roadcut along Wesleyan Circle, 0.5 km from Wesleyan Drive in the Macon Northwest, Ga. 7.5-min quadrangle. Note numerous structural disruptions to bedding. Hand lens is 2.5 cm in diameter. *B*, Erratic structural features of the Juliette slice in metamorphosed pebbly mudstone and graywacke conglomerate in cut along unnamed road approximately 1 km south of Mt. Pleasant Church (S.C.), in the Chennault, Ga.-S.C. 7.5-min quadrangle. *C*, Scaly schist composed of manganiferous mica and amphiboles, with interbedded tuffaceous metacherts. Angular block and rounded clast below it are metagabbro. Same roadcut as *A*. *D*, Folded clast of tuffaceous metachert in matrix of scaly schist interbedded with tuffaceous metacherts. Same outcrop as *A*. Knife is 8 cm long. *E*, Metamorphosed pebbly mudstone in roadcut along Po Biddy Road just south of Potato Creek in the Lincoln Park, Ga. 7.5-min quadrangle. The isoclinal (elasticas) fold is discordant to the surrounding matrix. Knife is 8 cm long. *F*, Closeup of same fold as in *E*. Round, undeformed pebbles are quartz, quartzite, micaceous quartzite, and quartz-feldspar rock. Faint cleavage is not parallel to the axial plane of the fold. The highest grade minerals found in the matrix are biotite and garnet. Fold is interpreted to result from soft-sediment deformation during imbrication of the melange wedge. Knife is 8 cm long. *G*, Closeup of typical metamorphosed pebbly mudstone matrix in same outcrop as *E*. Hand lens is 1.9 cm in diameter.

The Juliette slice is probably a tectonostratigraphic horizon (see Moore and others, 1985; Cowan, 1985, p. 461, fig. 10) where concentrations of disrupted Iapetus ophiolite were imbricated into the melange wedge.

PO BIDDY SLICE

Rocks of the Po Biddy slice have previously been assigned to parts of the "Pine Mountain," "Uchee," "Lowndesville," "Kings Mountain," and "Raleigh" "belts" and to the "Avalon terrane." We interpret the Falls Lake melange in the Raleigh, N.C., area (Horton and others, 1985) as belonging to the Macon melange. We have interpreted these rocks as belonging to the Po Biddy slice of the Macon melange because they contain significant units of graphitic schist and metavolcanic rocks (also see Parker, 1979).

The matrix of the Po Biddy slice is an imbricate complex of mafic, intermediate, and (locally graphitic) siliceous and felsic metavolcaniclastic rocks, graphitic schists, and manganiferous schists. Large clasts in this slice are mostly elongate (some are continuous for tens of kilometers, but most are not), as shown by the mapping of Horton (1981a), Murphy and Butler (1981), Butler (1981), and Posey (1981) and our own work, and consist of rocks identical to the matrix, as well as manganiferous quartzites, aluminous quartzites, metamorphosed thinly bedded and laminated chloritic and pyritiferous limestones (fig. 47), calc-silicate rocks, metaconglomerates, and various metagabbroic and serpentinized ultramafic rocks. In many places the Po Biddy slice has deposits of barite, iron, sulfides, gold, lead, silver, and manganese (Parker, 1979; Sharp and Hornig, 1981; Posey, 1981, and references therein). Tin-spodumene pegmatites occur locally along the northwest edge of the slice (White, 1981, and references therein). The limestones, graphitic schists, and manganiferous schists were probably pelagic sediments, the metalliferous deposits were probably mostly oceanic volcanogenic exhalative deposits (also see Sharp and Hornig, 1981, and Posey, 1981), the manganiferous quartzites were probably volcanogenic chemical sediments (cherts), and the aluminous quartzites were probably volcanogenic alteration-zone deposits.

NORTHERN FLORIDA PLATFORM SEQUENCE

Much of the southeastern part of the Little River thrust stack is covered by Mesozoic and Cenozoic deposits of the Atlantic Coastal Plain. The terrane be-

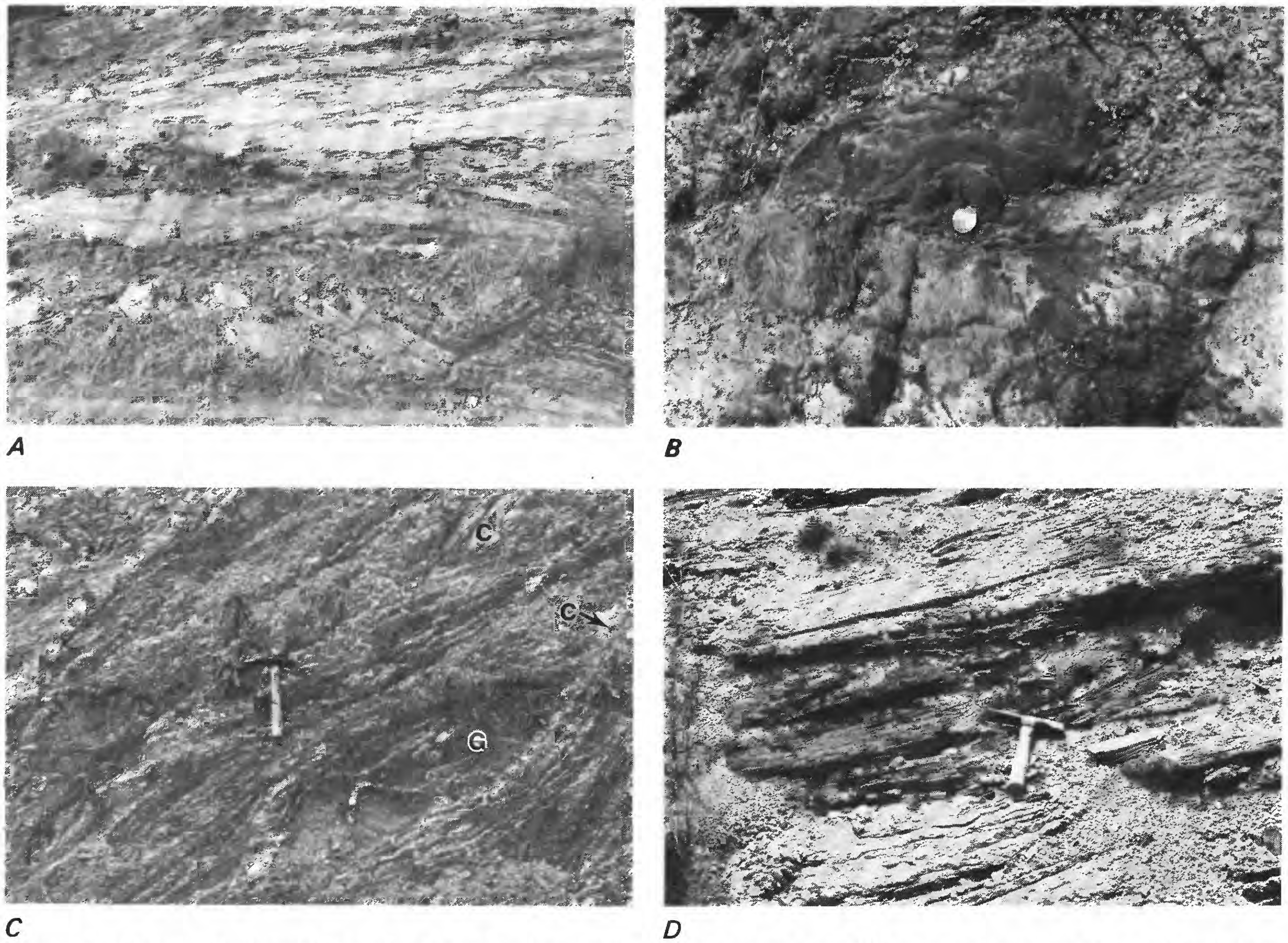

FIGURE 41.—Structural features of Potato Creek and Juliette slices of the Macon melange. *A*, Potato Creek slice. Same outcrop as figure 40*E*, showing numerous structural discontinuities common in the melange. Lighter rocks are metamorphosed pebbly mudstones; darker rocks are amphibolite blocks (clasts). *B*, Potato Creek slice. Same outcrop as figure 40*B*, showing erratic structural discontinuities. Clast of chloritic amphibolite is above coin. Coin is 1.9 cm in diameter. *C*, Potato Creek slice. Same outcrop as figure 40*A*, showing numerous structural discontinuities. Clasts are metatuffaceous chert (C) and metagabbro (G). *D*, Juliette slice. Structural discontinuities in metamorphosed pebbly mudstones and metagraywackes. Roadcut along first unpaved road to the west from U.S. Highway 23 north of St. Peters Rock Church on east side of the east fork of Rum Creek in the East Juliette, Ga. 7.5-min quadrangle.

neath the Coastal Plain deposits is known mainly from geophysical data and oil-well test holes; its geology has been recently synthesized by Chowns and Williams (1983). Their study showed that much of the subcrop of northern Florida and southeast Georgia consists of very mildly metamorphosed, mostly felsic, volcanic, volcaniclastic, volcanic-epiclastic, and intrusive rocks of probable latest Precambrian-Cambrian age, which we interpret as belonging to the Little River allochthon. Overlying this part of the Little River allochthon in northern Florida is a sequence of fossiliferous Ordovician through Devonian clastic sedimentary rocks, which Chowns and Williams (1983) referred to as the Northern Florida platform sequence. Fossils in these rocks belong to the Atlantic faunal province (Applin, 1951; Bridge and Berdan, 1952; Pojeta and others, 1976; Chowns and Williams, 1983, and references therein). Present data are insufficient to tell whether the Northern Florida platform sequence is thrust upon the Little River allochthon or not; the work of Arden (1974a,b) suggests that it is thrust upon the allochthon. In an earlier paper (Higgins and others, 1984), we suggested that the Northern Florida sequence might be a back-arc basin sequence deposited on the side of the Little River arc nearest the "African" continent. That interpretation is incorrect, because volcanic material is unknown in the sequence and the lithologies in the sequence (shales, siltstones, crossbedded sandstones, and quartz arenites) suggest a shelf environment (Chowns and Williams, 1983, p. L9–L10). Perhaps these rocks were deposited on the African continent (as suggested by Chowns and Williams, 1983) and thrust into their present position at the top of the Little River allochthon when that continent collided with the accreted allochthon.

STRUCTURE

The Macon melange structurally underlies the Little River allochthon. Southeast of its main outcrop belt, the melange crops out in antiforms that are essentially windows through the overlying allochthon; these antiforms and accompanying synforms verge northwest. Many of the folds in the melange are chaotic. Isoclinal folds in pebbly mudstones show no axial planar schistosity; both round and angular quartz pebbles and rock fragments are unflattened (figs. 40, 42), and deformational features consist of a cleavage that generally crosses the folds at an angle, anastomosing semischistosity planes that "flow" around the clasts, and numerous small thrust faults that are common even at outcrop scale. These minor folds are almost certainly the result of soft-sediment deformation caused by gravitational movement at the top and shear at the base of the wedge (see Hamilton, 1979). Other minor folds appear to be "metamorphic-tectonic," and the majority of these verge northwest, suggesting that they formed during transport of the Macon melange thrust sheet toward the North American craton.

In the Carolinas, the thrust fault at the base of the Macon melange (fig. 39) is marked by a narrow imbricate shear zone that has been called the Kings Mountain shear zone to the north (Horton, 1981b; Horton and Butler, 1981) and the Lowndesville shear zone to the south (Griffin, 1970, 1981; Nelson, 1981). Near the Georgia–South Carolina State line, the shear zone diverges from the fault at the base of the melange and continues to the southwest just southeast of the Elberton batholith, where it has been called the Middleton-Lowndesville shear zone (Rozen, 1978, 1981; Davis, 1980; Nelson, 1981). The fault at the base of the melange continues on a more westerly course to intersect the northeastern end of the Elberton batholith, which has intruded it. Previous workers have indicated (on the basis of aeromagnetic data) that the shear zone trends southwest to join the Towaliga fault in central Georgia. Our mapping shows that this is not the case, however; the Middleton-Lowndesville shear zone either dies out within, or becomes lost in, the tectonic chaos of the Juliette slice of the Macon melange southwest of Greensboro, Ga. (pl. 1, fig. 39). The Towaliga fault dies out within rocks of the Great Smoky Group in the Bill Arp thrust sheet north of Monticello, Ga. (pl. 1). The fault at the base of the Macon melange emerges from the southwest end of the Elberton batholith and trends southwest to locally coincide with what has previously been mapped as the Bartletts Ferry fault. In this course, it is locally coincident with what has been mapped as the Goat Rock fault. Thin mylonite zones are present along the "Bartletts Ferry" and "Goat Rock" "faults," and in rocks in between the faults, but most of the rocks that Bentley and Neathery (1970) and Higgins (1971) called blastomylonites in these areas are metamorphosed pebbly mudstones like some of the rocks in figure 40; they belong to the Macon melange. The Macon melange does form the southern boundary of the Pine Mountain anticlinorium, a major anticlinorium cored with Grenville basement rocks and overlain by metamorphosed clastic sedimentary rocks of the Pine Mountain Group of the Ocoee Supergroup that were deposited in rift basins associated with the opening of the Iapetus Ocean. Erosion of similar rocks from basins on the other side of the ocean probably contributed to much of the matrices of the Macon melange.

Because the fault at the base of the Macon melange does not everywhere coincide with the named shear zones (Kings Mountain, Middleton-Lowndesville, Lowndesville), nor with the "belt" boundaries, we (Higgins and others, 1984) called this fault the Macon melange thrust fault. Hooper and Hatcher (1986) have recently proposed the name "Ocmulgee fault" for this fault, based on their mapping of the area around Forsyth, Ga., and suggested that it is a fundamental tectonic boundary. We agree that it is a fundamental tectonic boundary (boundary between two thrust stacks). We proposed that in 1984 (Higgins and others, 1984), when we called the fault the Macon melange thrust fault. To avoid further confusion, we will call the fault at the base of the Little River thrust stack (figs. 1, 39) the Auchumpkee thrust fault for Auchumpkee Creek, which flows along the trace of the fault for a short distance in eastern Upson County, Ga. We suggest that the names Ocmulgee fault and Macon melange thrust fault should be abandoned.

The age of the Elberton Granite places constraints upon the time of final emplacement of the Macon melange and Little River allochthon (pl. 1, fig. 39), because the Elberton has intruded both units and the Auchumpkee thrust fault. However, in our opinion, the age of the Elberton is not well established. Zircons from the Elberton Granite yield discordant ages on a concordia plot that have an upper intercept of 320±20 Ma (Ross and Bickford, 1980), whereas rubidium-strontium analyses form two isochrons, one at 376±45 Ma and one at 350±11 Ma (Whitney and Hess, 1980). Whitney and Hess (1980) suggested that 320±20 Ma was the age of magmatic crystallization of the Elberton Granite. But what do the rubidium-strontium ages mean and why are they older than the zircon ages?

A

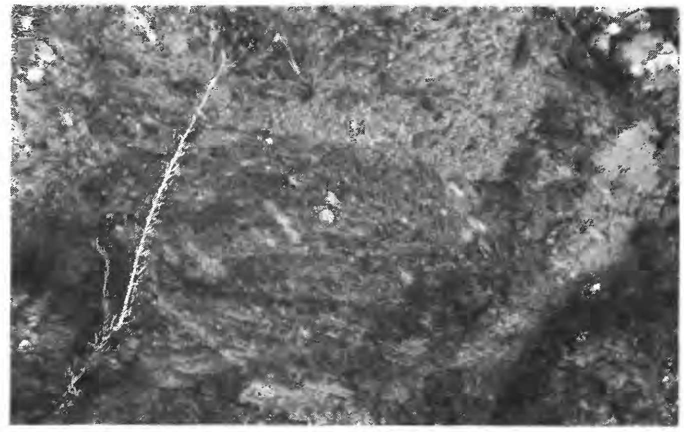

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FIGURE 42.—Exotic clasts in the Potato Creek and Juliette slices of the Macon melange. *A*, Block of metapyroxenite in pebbly mudstone matrix of the Juliette slice. Same outcrop as figure 41*D*. *B*, Pebbly mudstone of the Juliette slice in same outcrop as figure 40*B*. *C*, Closer view of *B*, showing undeformed, finely laminated, barely metamorphosed pebble of Little River allochthon argillite in scaly semischist matrix of pebbly mudstone. Clasts of various other rock types are also visible in this photograph. Same outcrop as *B*. Coin is 1.9 cm in diameter. *D*, Block of metachert in scaly semischist and metamorphosed pebbly mudstone. Same outcrop as *B*. *E*, Calc-silicate clasts in metamorphosed pebbly mudstone of the Juliette slice. Same outcrop as *B*. Lens cap is 5.5 cm in diameter. *F*, Large slab of high-grade metavolcanic gneisses in the Juliette slice in the Kiokee antiform. Roadcut along Georgia Highway 104, approximately 2.4 km southeast of Pollards Corner, in the Appling, Ga. 7.5-min quadrangle. *G*, Rounded clast of quartzite in the Juliette slice in the Kiokee antiform in cut along Interstate 20, approximately 6.5 km east of Georgia Highway 150, in the Winfield, Ga. 7.5-min quadrangle.

E

F

G

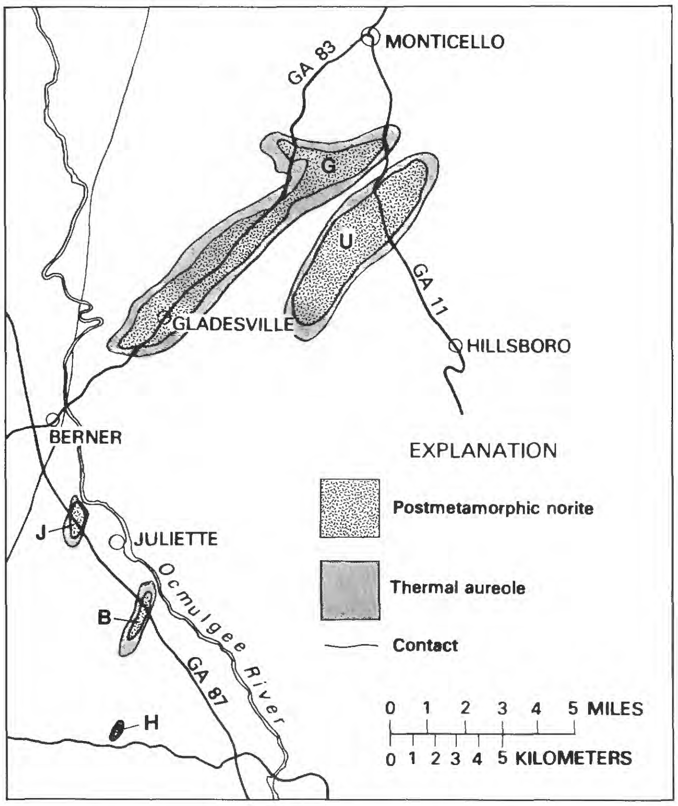


FIGURE 43.—Generalized geologic map of the Gladesville-Juliette area in central Georgia, showing the major mafic "bodies" as depicted by Matthews (1967), Prather (1971), Carpenter (1971), and Georgia Geological Survey (1976). B, Berry Creek norite body; G, Gladesville norite body; H, Holly Grove norite body; J, Juliette norite body; U, unnamed mafic body. Compare with figure 44.

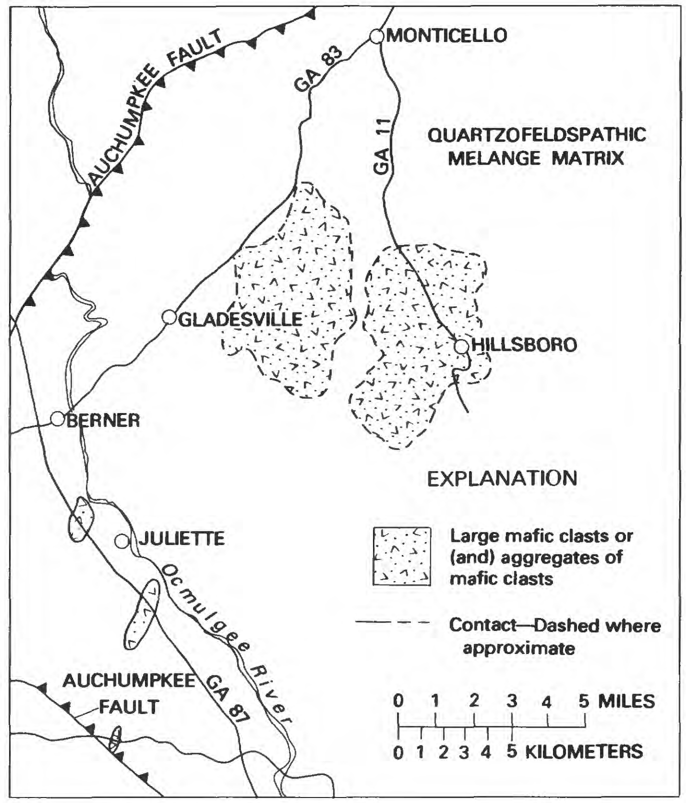


FIGURE 44.—Generalized geologic map of the Gladesville-Juliette area in central Georgia showing large mafic clasts and aggregates of mafic clasts as depicted by our mapping. Compare with figure 43.

FIGURE 45.—Rounded clast of metagabbro in the Macon melange in same outcrop as figure 40*A*. Melange matrix schistosity passes concordantly around the clast, whereas faint mineral alignment in the clast is oriented almost normal to the schistosity of the matrix, thus mimicking the structural relations between the melange matrix and large mafic and mafic-ultramafic clasts in the melange. Clast is approximately 20 cm long.

FIGURE 46.—Centimeter-scale, disrupted igneous layering in a mafic slab in the Juliette slice of the Macon melange. Roadcut along the east side of Georgia Highway 83, 1.4 km northeast of Gladesville, Ga., in the Berner, Ga. 7.5-min quadrangle. Hand lens is 2.5 cm in diameter.

MODOC ZONE

Howell and Pirkle (1976, p. 16) gave the name "Modock fault zone" to a 4- to 5-km-wide zone of button schists and mylonites that they considered to mark the boundary between the "Carolina slate belt" and the "Kiokee belt"; Hatcher and others (1977) shortened the name to "Modoc fault" and suggested (on the basis of aeromagnetic data) that it extends through North Carolina as part of their "Eastern Piedmont fault system." Subsequent workers have considered the fault to be the boundary between the "Carolina slate" and "Kiokee" "belts" (Secor and Snoke, 1978; Williams, 1978; Snoke and others, 1980; Maher and others, 1981; Secor and others, 1983; Price and Hatcher, 1983). Hatcher and Odom (1980, p. 324) showed the Modoc as a thrust with teeth on the northwestern side, which they stated indicates "direction of dip" of "probable or known thrust or reverse faults"; more recently, McConnell and Abrams (1984, p. 9) and Abrams and McConnell (1984, p. 1522) following Hatcher and Odom (1980), showed the Modoc as a fault with teeth on the northwest side but did not provide an explanation. Hatcher and Odom (1980), McConnell and Abrams (1984), and Abrams and McConnell (1984) show the Modoc fault cutting Coastal Plain sediments in east-central Georgia.

Our mapping (pl. 1) shows that the Modoc zone is a zone of extreme flattening and mylonitization (also see Hatcher and others, 1977) less than about 300 m wide and that it is located well within metavolcanic rocks of the Little River allochthon and does not form any major tectonic or lithologic boundary—it is not the fault (Little River thrust fault) that separates the Little River allochthon from the underlying Macon melange. It does not extend far enough to the southwest to intersect Coastal Plain sediments, and it does not cut those sediments.

METAMORPHISM

A major problem in the study of melanges is that the metamorphic grade of clasts in a melange is commonly different from that of the matrix (Hamilton, 1979; Drake and Morgan, 1981; Cloos, 1982, and references therein). Grade of metamorphism is generally determined from the highest grade mineral assemblages in a given area, and metamorphic isograds are determined by the first occurrence of index minerals. The metamorphic grade of clasts in a melange may be mistaken as indicating the ambient metamorphic grade of the melange.

The Potato Creek and Juliette slices of the Macon melange, which coincide in part with the "Charlotte," "Kiokee," and "Uchee" "belts," have generally been considered to be at high metamorphic grade. These slices do contain clasts of sillimanite-grade rocks, but the highest grade minerals thus far observed in the matrices are biotite, garnet, and amphiboles. Hence, these matrices may not be any higher in grade than the supposedly low-grade "Kings Mountain belt," which is the Po Biddy slice of the Macon melange (see Horton, 1981a; Horton and Butler, 1981; Gregory, 1981), and locally they appear to be at garnet grade.

PALEOGEOGRAPHIC RECONSTRUCTION

The structural position of the Macon melange beneath and also northwest of the Little River allochthon

A

B

FIGURE 47.—*A*, Finely laminated, chloritic, graphitic, and pyritic marble in the Po Biddy slice of the Macon melange. Hammer rests on chlorite schist lens; amphibolite lenses are also present in the marble. Vulcan Materials Grover quarry off frontage road for Interstate 85 in the Grover, N.C.-S.C. 7.5-min quadrangle. *B*, Closer view of slab of marble from the same quarry showing fine laminations. Knife is 8 cm long.

(pls. 1, 2), the presence of clasts of allochthon rocks in the melange, the northwest vergence of major and some minor folds in the melange, and the presence of Atlantic faunal province trilobites in the allochthon rocks indicate that the melange and the allochthon were thrust from the southeast (present direction) and that the subduction zone dipped toward the "African" continent (pl. 2). The cessation of volcanism in the Little River arc, apparently in the Late Cambrian, was probably caused by the Macon melange and the arc ("African" plate) overriding the mid-Iapetus ridge, just as part of western North America overrode the East Pacific Rise in the Miocene. Part of the Iapetus Ocean crust and mantle (welded [or underplated] to the bottom of the stack and metamorphosed and depleted) must have been thrust upon the North American continent along with the overlying Little River thrust stack, because the southern Appalachian gravity gradient coincides closely with the northern border of the melange (American Geophysical Union, 1964; Long, 1979), because ~400-Ma mafic plutons are probably derived from melting such depleted and metamorphosed material, and because Hercynian granitic plutons associated with the Little River stack have low initial $^{87}Sr/^{86}Sr$ ratios and low $\delta^{18}O$ ratios, which decrease to the southeast (Fullagar and Butler, 1979; Sinha and Zietz, 1982, and references therein), probably reflecting increasing thickness of the underplated sheet.

UNRESOLVED PROBLEMS

The northeastern end of the Macon melange is poorly known; our work in North Carolina was of a reconnaissance nature, and future work there will certainly modify the end of the melange as shown in figure 39. The boundaries of the melange and Little River allochthon in the Carolinas were field checked and taken from the maps and compilations of Overstreet and Bell (1965), Williams (1978), Secor and Snoke (1978), and Horton (1981). We have not done detailed petrologic work on either the matrix or the exotic clasts in the melange. To date, no glaucophane or other blueschist facies index minerals have been found in the rocks we have assigned to the Macon melange. However, we have only looked at a modest number of thin sections. Ernst (1972) has shown that blueschist minerals are rarely preserved in rocks of Paleozoic age or older.

ROME-KINGSTON THRUST STACK

Much of the Valley and Ridge province in northwest Georgia and northeast Alabama (pl. 1) is underlain by Paleozoic sedimentary rocks in three major thrust sheets (Butts, 1926; Allen and Lester, 1957; Cressler, 1963, 1964a,b, 1970, 1974; Chowns and McKinney, 1980; Thomas and Neathery, 1980; Chowns and Carter, 1983), which we, following Chowns and McKinney (1980) and Chowns and Carter (1983), call the Kingston, Clinchport, and Rome thrust sheets (tables 4, 5). These sheets make up the Rome-Kingston thrust stack. Each thrust sheet is composite because each is cut into slices by other thrust faults, and each contains some of the rock units found in the others. However, each sheet contains sedimentary facies not found in the other sheets, each appears to represent a slightly different paleotectonic environment, and each has had a slightly different deformational history. Underlying the Rome-Kingston thrust stack is a parautochthonous-autochthonous terrane, which we call the Chickamauga terrane (table 6).

CHICKAMAUGA TERRANE

The Chickamauga terrane, structurally underlying the Rome-Kingston thrust stack, is a parautochthonous-autochthonous terrane that is transitional (structurally and in paleodepositional environments) between the Valley and Ridge province and the "more stable" craton of the Cumberland (or Allegheny) Plateau province. Rocks in the Chickamauga terrane in Georgia and Alabama range in age from Early Cambrian through Early Pennsylvanian (Butts, 1926; Allen and Lester, 1957; Cressler, 1963, 1964a,b, 1970; Thomas and Cramer, 1979; Thomas, 1979; Smith, 1979; Chowns and McKinney, 1980; Thomas and Neathery, 1980; Chowns and Carter, 1983; Rich, 1983; Crawford, 1983; tables 4, 6). The lower part of the section is part of the Appalachian Cambrian-Ordovician carbonate shelf sequence (Rodgers, 1953, 1968, 1982; Cressler, 1970, 1974; Palmer, 1971; Thomas and Neathery, 1980; Chowns and McKinney, 1980). The carbonate shelf sequence in the Chickamauga terrane consists of the Lower Cambrian Rome Formation (the Shady Dolomite and rocks of the Chilhowee Group are apparently missing—Kidd and Neathery, 1976; Thomas and Neathery, 1980, p. 469), the Middle and Upper Cambrian Conasauga Formation, the Upper Cambrian and Lower Ordovician Knox Group (consisting of the Upper Cambrian Copper Ridge and Chepultepec Dolomites and Longview Limestone and the Lower Ordovician Newala Limestone), and the Middle Ordovician Lenoir Limestone (Butts, 1926; Cressler, 1970, 1974; Cressler and others, 1979; Thomas and Neathery, 1980; Chowns and McKinney, 1980; Chowns and Carter, 1983). Abundant evidence indicates that these rocks were deposited in shallow, warm water on the Cambrian-Ordovician carbonate shelf and that the clastic material within the sequence came from the North American craton (Rodgers, 1953, 1968, 1982; Palmer, 1971; Thomas and Neathery, 1980; Chowns and McKinney, 1980; Read, 1985a,b).

In the Chickamauga terrane, Lower Ordovician Knox Group rocks of the carbonate shelf sequence are overlain with marked disconformity by Middle Ordovician rocks of the Chickamauga Supergroup in Georgia (Milici and Smith, 1969; Chowns and McKinney, 1980; Chowns and Carter, 1983) and the Chickamauga Group in Alabama (Drahovzal and Neathery, 1971; Chowns and McKinney, 1980; Chowns and Carter, 1983). The disconformity locally has relief of as much as 13 m (Drahovzal and Neathery, 1971, p. 187; Chowns and McKinney, 1980), and depressions in the karstic surface are filled with basal Chickamauga conglomeratic beds of the Pond Spring Formation in Georgia (Jackson, 1951; Munyon, 1951; Milici and Smith, 1969; Chowns and McKinney, 1980) and the Attalla Chert Conglomerate Member of the Stones River Formation in Alabama (Butts, 1910; Drahovzal and Neathery, 1971; Neathery and Drahovzal, 1971). These basal beds are overlain by tidal-flat and lagoonal deposits composed of mottled grayish-red mudstone and silty limestone interbedded with micritic limestones (Pond Spring Formation in Georgia, Stones River Formation in Alabama), which are in turn overlain by Chickamauga Supergroup (Group in Alabama) shallow-water carbonate units (Murfreesboro, Ridley, Lebanon, Carters, Hermitage, Cannon, and Catheys formations in Georgia; Nashville, Inman, and Leipers formations in Alabama) as much as 440 m thick in Georgia but thinning to about 80 m thick in Alabama (Drahovzal and Neathery, 1971; Chowns and McKinney, 1980; Chowns and Carter, 1983). The carbonate sequence is overlain by the Sequatchie Formation, an alluvial red-bed sequence derived from the southeast (Thompson, 1971; Chowns, 1972; Milici and Wedow, 1977; Chowns and McKinney, 1980; Chowns and Carter, 1983). The alluvial red-bed sequence grades up into coarse-grained hematitic sandstones, conglomeratic sandstones, ironstones, red shales, and siltstones of the Lower Silurian (Llandoverian) Red Mountain Formation, also derived from the southeast (Chowns and McKinney, 1980, and references therein). Rindsberg (1982) and Chowns and Carter (1983) recently suggested that the coarse-grained sandstones traditionally placed in the Red Mountain Formation in northwest Georgia belong to the underlying Upper Ordovician Sequatchee Formation and that finer grained marine shales and turbidites of the Red Mountain unconformably overlie these coarser grained rocks.

In the Chickamauga terrane the Red Mountain Formation is unconformably overlain by thin, but persistent, Upper Devonian and Lower Mississippian shale units (Chattanooga and Maury Shales), which are in turn unconformably overlain by Mississippian shelf carbonates and marine shales, capped by Pennsylvanian clastic rocks (Butts, 1926; Allen and Lester, 1957; Conant and Swanson, 1961; Thomas and Cramer, 1979; Thomas, 1979; Smith, 1979; Chowns and McKinney, 1980; Thomas and Neathery, 1980; Chowns and Carter, 1983; Rich, 1983; Crawford, 1983).

KINGSTON THRUST SHEET

The Kingston thrust sheet, the lowest sheet in the Rome-Kingston thrust stack, is bounded at its base to the northwest by the Kingston thrust fault, and at its top by the Clinchport thrust fault (Chowns and Carter, 1983, and references therein) at the base of the Clinchport thrust sheet (pl. 1). Rocks in the Kingston thrust sheet range in age from the Early Cambrian Rome Formation through the Early Pennsylvanian Gizzard Formation in Georgia and Pottsville Formation in Alabama (Butts, 1926; Cressler, 1963, 1964a,b, 1970, 1974; Thomas and Cramer, 1979; Chowns and McKinney, 1980; Rich, 1983; Crawford, 1983; Chowns and Carter, 1983; table 4). The lowest sequence of rocks (up through the Upper Cambrian and Lower Ordovician Knox Group) in the Kingston sheet is the carbonate shelf sequence (see references above). In the Kingston sheet, the Middle Ordovician–Lower Silurian sequence records a northwest-to-southeast facies change (Chowns and Carter, 1983, and references therein). In northwestern outcrops in the sheet this sequence is nearly identical to that in the Chickamauga terrane, whereas, to the southeast, tongues of red beds increase within the Chickamauga Supergroup carbonate sequence and gradually thicken at the expense of the carbonate rocks from northwest to southeast. These tongues of clastic rocks have been assigned to the Greensport Formation in Georgia by Chowns and McKinney (1980) and Chowns and Carter (1983). In Alabama, the Greensport Formation occurs in the Kingston sheet and in what we interpret as the Clinchport sheet in a window through the Rome thrust sheet.

The mixed Middle and Upper Ordovician carbonate red-bed facies is overlain (probably unconformably) by the Lower Silurian Red Mountain Formation, which is unconformably overlain by the Lower and Middle Devonian Armuchee Chert and its Middle Devonian clastic facies, the Frog Mountain Sandstone (Butts, 1926; Allen and Lester, 1957; Cressler, 1963, 1964a,b, 1970, 1974; Thomas and Neathery, 1980; Chowns and

TABLE 4A.—*Stratigraphic units in the Chickamauga terrane and Rome-Kingston thrust stack in Georgia (modified from Cressler, 1963, 1964a,b, 1970, 1974; Cressler and others, 1979; Chowns and McKinney, 1980; Chowns and Carter, 1983; Rich, 1983; Crawford, 1983; Chowns, 1983)*

		Chickamauga terrane		Kingston thrust sheet		Clinchport thrust sheet		Rome thrust sheet
Pennsylvanian		Gizzard Formation		Gizzard Formation		Gizzard Formation		–
		Pennington Formation		Pennington Formation		Pennington Formation		–
		Bangor Limestone		Bangor Limestone		Bangor Limestone		–
Mississippian		Monteagle Limestone		Floyd Shale		Floyd Shale		Floyd Shale
		Tuscumbia Limestone		–		–		–
		Fort Payne Chert		Fort Payne Chert		Fort Payne Chert		Fort Payne Chert
		--unconformity--		--unconformity--		--unconformity--		--unconformity--
		Maury Shale		Maury Shale		Maury Shale		–
Devonian		Chattanooga Shale		Chattanooga Shale		Chattanooga Shale		–
		--unconformity--		--unconformity--		--unconformity--		–
		–		Armuchee Chert		Armuchee Chert		Frog Mountain Sandstone
		–		--unconformity--		--unconformity--		--unconformity--
Silurian		Red Mountain Formation		Red Mountain Formation		Red Mountain Formation		–
		--unconformity--		--unconformity--		--unconformity--		–
		Sequatchie Formation		–		–		–
	Chickamauga Supergroup: Nashville Group	Catheys Formation		Sequatchie Formation		Sequatchie Formation		–
		Cannon Limestone		(northwestern facies)		(southeastern facies)		–
		Hermitage Formation		–		–		–
	Stones River Group	Carters Limestone	Chickamauga Supergroup	Colvin Mountain Sandstone	Chickamauga Supergroup	Colvin Mountain Sandstone		Tellico and Chota Formations
		–		(northwestern facies)		(southeastern facies)		Rockmart Slate, Athens Shale
Ordovician		Lebanon Limestone		–		--unconformity--		--unconformity--
		Ridley Limestone		–		–		–
		Murfreesboro Limestone		Greensport Formation		Greensport Formation		–
		Pond Spring Formation		(northwestern facies)		(southeastern facies)		Lenoir Limestone
		--unconformity--		--unconformity--		--unconformity--		--unconformity--
	Knox Group	Newala Limestone	Knox Group	Newala Limestone	Knox Group	Newala Limestone	Knox Group	Newala Limestone
		Longview Limestone		Longview Limestone		Longview Limestone		Longview Limestone
		Chepultepec Dolomite		Chepultepec Dolomite		Chepultepec Dolomite		Chepultepec Dolomite
		Copper Ridge Dolomite		Copper Ridge Dolomite		Copper Ridge Dolomite		Copper Ridge Dolomite
		–		–		–	Conasauga Group	Maynardville Limestone
		–		–		–		Nolichucky Shale
Cambrian		Conasauga Formation		Conasauga Group		Conasauga Group		Maryville Limestone
		–		–		–		Rogersville Shale
		–		–		–		Honaker Dolomite
		Rome Formation		Rome Formation		Rome Formation		Rome Formation
		–		--Kingston fault--		--Clinchport fault--		Shady Dolomite
		–		–		–		Chilhowee Group
								--Rome fault--

TABLE 4B.—*Stratigraphic units in the Chickamauga terrane and Rome-Kingston thrust stack in Alabama (modified from Butts, 1926; Drahovzal and Neathery, 1971; Thomas and Neathery, 1980; Chowns and McKinney, 1983; Chowns and Carter, 1983)*

		Chickamauga terrane		Kingston thrust sheet		Clinchport thrust sheet		Rome thrust sheet
Pennsylvanian		Pottsville Formation		Pottsville Formation		Pottsville Formation		--
Mississippian		Pennington Formation		Parkwood Formation		Parkwood Formation		--
		Bangor Limestone		Bangor Limestone		Bangor Limestone		--
		Monteagle Limestone		Floyd Shale		Floyd Shale		Floyd Shale
		Hartselle Sandstone		--		--		--
		Pride Mountain Formation		--		--		--
		Tuscumbia Limestone		--		--		--
		Fort Payne Chert		Fort Payne Chert		Fort Payne Chert		Fort Payne Chert
		--unconformity--		--unconformity--		--unconformity--		--unconformity--
Devonian		Maury Shale		Maury Shale		Maury Shale		--
		Chattanooga Shale		Chattanooga Shale		Chattanooga Shale		--
		--unconformity--		--unconformity--		--unconformity--		--
		--		Frog Mountain Sandstone		Frog Mountain Sandstone		Frog Mountain Sandstone
		--		--unconformity--		--unconformity--		Jemison Chert
Silurian		Red Mountain Formation		Red Mountain Formation		Red Mountain Formation		--unconformity--
		--unconformity--		--unconformity--		--unconformity--		--
Ordovician		Sequatchie Formation		Sequatchie Formation		Sequatchie Formation	Talladega Group	Butting Ram Sandstone
		--		(northwestern facies)		(southeastern facies)		Lay Dam Formation
	Chickamauga Group	Liepers Limestone		--		--		--unconformity--
		Inman Formation		--		--		--
		Nashville Formation	Chickamauga Group	Colvin Mountain Sandstone	Chickamauga Group	Colvin Mountain Sandstone		Athens Shale, Rockmart Slate
		Stones River Formation		(northwestern facies)		(southeastern facies)		--unconformity--
		Attalla Chert Con-		Greensport Formation		Greensport Formation		--
		glomerate Member		(northwestern facies)		(southeastern facies)		--
		--unconformity--		--unconformity--		--unconformity--		--
		Lenoir Limestone		Lenoir Limestone		Lenoir Limestone		Lenoir Limestone
		--unconformity--		--unconformity--		--unconformity--		--unconformity--
	Knox Group	Newala Limestone	Knox Group	Newala Limestone	Knox Group	Newala Limestone	Knox Group	Newala Limestone
		Longview Limestone		Longview Limestone		Longview Limestone		Longview Limestone
		Chepultepec Dolomite		Chepultepec Dolomite		Chepultepec Dolomite		Chepultepec Dolomite
		Copper Ridge Dolomite		Copper Ridge Dolomite		Copper Ridge Dolomite		Copper Ridge Dolomite
Cambrian		--		--		--	Conasauga Group	Maynardville Limestone
		--		--		--		Nolichucky Shale
		Conasauga Formation		Conasauga Formation		Conasauga Formation		Maryville Limestone
		--		--		--		Rogersville Shale
		--		--		--		Honaker Dolomite
		Rome Formation		Rome Formation		Rome Formation		Rome Formation
		--		--Kingston fault--		--Clinchport fault--		Shady Dolomite
		--		--		--		Chilhowee Group
								--Helena fault--

TABLE 5.—*Summaries of thrust sheets in the Rome-Kingston thrust stack*

STRUCTURAL UNITS	STRATIGRAPHIC UNITS	GENERAL CHARACTERISTICS	INTERPRETED ORIGIN
	ROME THRUST SHEET		
Valley and Ridge province Cambrian-Ordovician carbonate shelf sequence, Middle Ordovician dark pelites, Lower and Middle Devonian chert, and Mississippian marine shale.	Chilhowee Group (Cochran, Nichols, Wilson Ridge, and Weisner Formations), Shady Dolomite, Rome Formation, Conasauga Group (Honaker Dolomite, Rogersville Shale, Maryville Limestone, Nolichucky Shale, Maynardville Limestone), Knox Group (Copper Ridge Dolomite, Chepultepec Dolomite, Longview Limestone, Newala Limestone), Lenoir Limestone, Rockmart Slate, Athens Shale, Tellico Formation, Chota Formation, Talladega Group (Lay Dam Formation and its Cheaha Quartzite Member, Butting Ram Sandstone, Jemison Chert), Frog Mountain Sandstone, Fort Payne Chert, Floyd Shale.	Basin-fill clastic deposits overlain by Cambrian through Middle Ordovician carbonate shelf (platform) sequence, overlain unconformably (and in many places overthrust) by Middle Ordovician dark pelites, overlain unconformably by Lower and Middle Devonian chert, overlain unconformably by Mississippian marine shale.	Basin-fill clastic deposist overlain by carbonate shelf sequence built at edge of North American craton, overlain by deep-water graptolitic Middle Ordovician dark pelites, overlain by most proximal parts of a clastic wedge derived from erosion of thrust sheets arriving from present southeast and later chert and marine shale and clastic sequences.
	CLINCHPORT THRUST SHEET		
Valley and Ridge province Cambrian-Ordovician carbonate shelf sequence, Middle Ordovician-Lower Silurian red-bed molassic sequence, Lower and Middle Devonian cherts, Upper Devonian-Lower Mississippian dark shales, Middle-Upper Mississippian carbonate and marine shale sequence, and Pennsylvanian clastic sequence.	Rome Formation, Conasauga Formation, Knox Group (Copper Ridge Dolomite, Chepultepec Dolomite, Longview Limestone, Newala Limestone), Lenoir Limestone, Chickamauga Group - Alabama; Chickamauga Supergroup - Georgia (Greensport Formation - southeastern facies, Colvin Mountain Sandstone - southeastern facies), Sequatchie Formation, Red Mountain Formation, Armuchee Chert, Frog Mountain Sandstone, Chattanooga Shale, Maury Shale, Fort Payne Chert, Floyd Shale, Bangor Limestone, Pennington Formation, Parkwood Formation, Pottsville Formation, Gizzard Formation.	Cambrian through Lower Ordovician carbonate shelf (platform) sequence, overlain unconformably by Middle Ordovician through Lower Silurian molassic red-bed sequence, overlain unconformably by Lower and Middle Devonian cherts, overlain by thin but persistent Upper Devonian and Lower Mississippian chert, overlain by Mississippian carbonate and marine sand and shale sequence, overlain by Pennsylvanian clastic sequence.	Carbonate shelf sequence built at edge of North American craton overlain by proximal parts of a clastic wedge derived from erosion of thrust sheets arriving from the present southeast and later chert, carbonate, and marine shale and clastic sequences.

STRUCTURAL UNITS	STRATIGRAPHIC UNITS	GENERAL CHARACTERISTICS	INTERPRETED ORIGIN
KINGSTON THRUST SHEET			
Valley and Ridge province Cambrian-Ordovician carbonate shelf sequence, Lower Silurian red-bed clastic sequence, Upper Devonian-Lower Mississippian black shales, Middle-Upper Mississippian shelf carbonate and marine shale sequence, and Pennsylvanian clastic sequence.	Rome Formation, Conasauga Formation, Conasauga Group, Knox Group (Copper Ridge Dolomite, Chepultepec Dolomite, Longview Limestone, Newala Limestone), Lenoir Limestone, Chickamauga Group - Alabama; Chickamauga Supergroup - Georgia (Greensport Formation - northwestern facies, Colvin Mountain Sandstone - northwestern facies), Sequatchie Formation, Red Mountain Formation, Armuchee Chert, Frog Mountain Sandstone, Chattanooga Shale, Maury Shale, Fort Payne Chert, Floyd Shale, Bangor Limestone, Pennington Formation, Parkwood Formation, Pottsville Formation, Gizzard Formation.	Cambrian through Middle Ordovician carbonate shelf (platform) sequence, overlain unconformably by Middle Ordovician through Lower Silurian red-bed clastic sequence, overlain by Lower and Middle Devonian cherts, overlain unconformably by thin but persistent Upper Devonian and Lower Mississippian dark shales, overlain by Mississippian carbonate and marine sandstone and shale sequence, overlain by Pennsylvanian clastic sequence.	Shelf (platform) sequences at cratonward edge of most cratonward basin mixed with clastic molassic basin-fill deposits from thrust sheets to the present southeast and later chert, carbonate, marine shale, and clastic sequences.

TABLE 6.—*Summary of the Chickamauga terrane*

STRUCTURAL UNITS	STRATIGRAPHIC UNITS	GENERAL CHARACTERISTICS	INTERPRETED ORIGIN
Valley and Ridge province-Cumberland Plateau province Cambrian-Ordovician carbonate shelf (platform) sequence, Lower Silurian red-bed clastic sequence, Upper Devonian-Lower Mississippian black shales, Middle-Upper Mississippian shelf carbonate and marine shale sequence, and Pennsylvanian clastic sequence.	Rome Formation, Conasauga Formation, Knox Group (Copper Ridge Dolomite, Chepultepec Dolomite, Longview Limestone, Newala Limestone), Chickamauga Group (Alabama - Attala Chert Conglomerate Member of the Stones River Formation, Nashville Formation, Inman Formation, Leipers Limestone), Chickamauga Supergroup (Georgia - Stones River Group: Pond Spring Formation, Murfreesboro Limestone, Ridley Limestone, Lebanon Limestone, Carters Limestone; Nashville Group: Hermitage Formation, Cannon Limestone, Catheys Formation), Sequatchie Formation, Red Mountain Formation, Chattanooga Shale, Maury Shale, Fort Payne Chert, Tuscumbia Limestone, Pride Mountain Formation, Hartselle Sandstone, Monteagle Limestone, Bangor Limestone, Pennington Formation, Pottsville Formation, Gizzard Formation.	Cambrian through lower Middle Ordovician carbonate shelf (platform) sequence, overlain unconformably by Middle Ordovician carbonate shelf (platform) sequence, overlain unconformably by Lower Silurian red-bed sequence, overlain unconformably by thin but persistent Upper Devonian and Lower Mississippian chert, overlain by Mississippian carbonate shelf (platform) sequence, overlain by Mississippian marine shale, overlain by Pennsylvanian clastic sequence.	Shelf (platform) carbonate sequences and platform clastic sequences that are transitional between the North American craton and the Valley and Ridge basin.

Carter, 1983), thus filling part of the hiatus in the Chickamauga terrane between the Red Mountain Formation and Chattanooga and Maury Shales. The sequence overlying the Armuchee Chert is similar to that in the Chickamauga terrane, except that more of the Mississippian sequence is composed of shale at the expense of carbonate rocks.

CLINCHPORT THRUST SHEET

The Clinchport thrust sheet is bounded at its base by the Clinchport thrust fault and at its top by the Rome thrust fault. In this sheet the Cambrian-Ordovician carbonate shelf sequence is disconformably overlain by a Middle and Upper Ordovician sequence composed predominantly of clastic sedimentary rocks; the tongues of red beds have increased at the expense of Chickamauga Supergroup carbonate rocks to the extent that carbonate rocks are found as tongues in the red beds only in the northwestern edge of the sheet (Chowns and Carter, 1983, and references therein; table 4). The red-bed sequence reaches its maximum thickness (about 700 m) in the southeastern part of the Clinchport sheet. In this area the sequence is composed of the Greensport Formation, Colvin Mountain Sandstone, and Sequatchie Formation (Drahovzal and Neathery, 1971; Chowns and McKinney, 1980; Chowns and Carter, 1983). The overlying Lower Silurian Red Mountain Formation also reaches its greatest thickness (about 400 m) in the southeastern part of the Clinchport sheet (Cressler, 1970; Drahovzal and Neathery, 1971; Chowns and McKinney, 1980). The sequence above the Red Mountain Formation is essentially the same in the Clinchport sheet as in the underlying Kingston sheet.

ROME THRUST SHEET

The Rome thrust sheet is bounded below by the Rome-Helena thrust fault system (Hayes, 1891; Butts, 1926; Butts and Gildersleeve, 1948; Cressler, 1970, 1974; Thomas and Neathery, 1980; Chowns and McKinney, 1980; Chowns and Carter, 1983).[10] Most of the Rome thrust sheet is made up of the Cambrian-Ordovician carbonate shelf sequence, which here includes at its base the Lower Cambrian Shady Dolomite, underlain by rocks of the Chilhowee Group (table 4). The thick Middle-Upper Ordovician red-bed sequence is absent in the Rome Sheet, its lower parts taken by the lower Middle Ordovician Lenoir Limestone and the Middle Ordovician Rockmart Slate and Athens Shale (see below). The Lower Silurian Red Mountain Formation is also absent in the eastern part of this sheet, and the Middle Ordovician slates and shales are overlain with angular unconformity by the Lower and Middle Devonian Armuchee Chert–Frog Mountain Sandstone sequence. The Armuchee–Frog Mountain sequence is unconformably overlain by the Lower Mississippian Fort Payne Chert and Upper Mississippian Floyd Shale. The Mississippian carbonate sequence is absent in the Rome sheet and was probably never deposited there, its place being partially taken by the Fort Payne and Floyd.

ROCKMART SLATE, ATHENS SHALE, TELLICO FORMATION, AND TALLADEGA GROUP

Middle Ordovician shales, slaty shales, and slates crop out discontinuously along the eastern and southeastern edge of the Rome thrust sheet (pl. 1). These rocks are of special interest, because their age and structural and stratigraphic position relative to the craton is approximately the same as those of similar shales and slates in the complex Taconic allochthon of the northern (western New England) Appalachians (Zen, 1961, 1967, 1968; Ratcliffe, 1975, 1979; Fisher, 1969, 1979; Ratcliffe and Hatch, 1979; Stanley and Ratcliffe, 1980; Rowley and Kidd, 1981; Bosworth and Rowley, 1984).

ROCKMART SLATE, ATHENS SHALE, AND TELLICO FORMATION

The Rockmart Slate (Hayes, 1891) is a relatively thin (about 180 m thick) sequence of slate and siltstone of Middle Ordovician age (and younger?) that crops out immediately north and northwest of the Emerson thrust fault in the Valley and Ridge province in northwestern Georgia and northeastern Alabama (pl. 1). It rests either in thrust contact or unconformably (or both) upon Valley and Ridge carbonate-shelf-facies rocks as young as the Deaton Member of the lower Middle Ordovician Lenoir Limestone (Cressler, 1970). The lower part (roughly half) of the Rockmart is a dark-gray to nearly black, calcareous slate containing well-developed folds and cleavages and a rich Middle Ordovician graptolite fauna (Cressler, 1970). The upper part of the Rockmart is composed of siltstone and slate with some feldspathic sandstone and with lenses of spectacular polymictic conglomerate made up of angu-

[10]The Rome fault and Helena fault are probably the same fault, as implied by Chowns and McKinney (1980) and Chowns and Carter (1983); they are separated by only a few kilometers by the flood plain of the Coosa River near Gadsden, Ala.

lar to subrounded fragments, chips, pebbles, and cobbles of (in order of abundance) limestone, dolomite, slate, sandstone, chert, and quartzite in a matrix of feldspathic sandstone, sandy slate, graywacke, clay slate, or rarely dolomite or limestone (fig. 48). As Cressler (1970), Chowns and McKinney (1980), and Sibley (1983) recognized, some of the quartzite clasts were metamorphosed before deposition. Some of the slate clasts in the conglomerates lithically match rocks of the lower part of the Rockmart, some of the sandstone clasts lithically match sandstone beds in the lower part of the upper part of the Rockmart, and some of the carbonate clasts lithically match rocks of the carbonate shelf sequence below the Rockmart (Cressler, 1970, p. 25). Cressler suggested that the slate and sandstone clasts are reworked Rockmart. Conglomerates like those in the upper sequence of the Rockmart have been described in units (Chota and Tellico Formations) in similar stratigraphic and structural positions as far northeast along strike as Fincastle, Va. (Kellberg and Grant, 1956). No fossils have been found above the lower, dark-slate sequence in the Rockmart Slate.

Like the lower part of the Rockmart Slate, the Athens Shale, which occupies a similar stratigraphic and structural position in Alabama (Butts, 1926; not shown in pl. 1), is a dark-gray to nearly black, calcareous, strongly cleaved and folded slaty shale containing a rich graptolite fauna of Middle Ordovician age (Butts, 1926; Bergström and Drahovzal, 1972;

FIGURE 48.—Polymictic conglomerate from the Tellico Formation above the Rockmart Slate, from cut of the Seaboard Coast Line Railroad east of the overpass on U.S. Highway 278, in the Rockmart South, Ga. 7.5-min quadrangle. Photograph by C.W. Cressler, U.S. Geological Survey.

Bergström, 1973; Finney, 1978, 1980) that rests either in thrust contact or unconformably (or both) upon carbonate-shelf-facies rocks as young as the Middle Ordovician Lenoir Limestone. Conglomerates like those in the upper part of the Rockmart Slate have not been reported in the Athens Shale in Alabama.

Another outcrop area of Athens Shale is north of Chatsworth in north Georgia (pl. 1). The basal parts of the Athens here, which rest in sharp contact upon the Newala or Lenoir Limestones, are dark-gray to olive-gray, calcareous clayey and silty shale containing interbedded tan, brown, or olive-gray siltstones and sandstones (Butts and Gildersleeve, 1948; Munyon, 1951; Jackson, 1951; Cressler, 1974), unlike the dark slates and shales in the basal parts of the Rockmart Slate and Athens Shale to the southwest in Georgia and Alabama. These northern Georgia rocks also appear to be less deformed and less metamorphosed than their counterparts (or near counterparts) to the southwest. However, they also contain a Middle Ordovician graptolite fauna (Cressler, 1974). In this northern Georgia outcrop belt, the Athens Shale is overlain by the Tellico Formation as mapped by Butts and Gildersleeve (1948) or the Chota Formation (Neuman, 1955) as mapped by Salisbury (1961). The Chota (or Tellico?) is composed of crossbedded sandy limestone, calcareous sandstone, and minor amounts of quartz-free limestone, as well as beds and lenses of polymictic conglomerate identical to that in the upper part of the Rockmart Slate (Munyon, 1951; Jackson, 1951; Kellberg and Grant, 1956; Cressler, 1974). According to Mack (1985) the provenance of sandstones in the Athens Shale and Chota Formation in northern Georgia was K-feldspar-rich granitic rocks or high-grade metamorphic rocks (Grenville basement) and low-grade metapelitic slates and phyllites.

The upper, unfossiliferous part of the Rockmart Slate is probably an entirely different unit (Cressler, 1970, and oral commun., 1984) from the lower, graptolitic part. This is suggested by the lithologic differences between the two, by the absence of the upper part in some areas where thick sections of the lower part are present, by the presence of what appear to be clasts of the lower slates in the conglomerates in the upper part, and by the lithologic similarities (especially the polymictic conglomerates) of the upper part with the Chota or (and) Tellico Formations. We suggest (as did Cressler, 1970, p. 30) that the upper part of the Rockmart Slate may represent depositional equivalents of both the Tellico Formation and overlying Chota Formation (as defined by Neuman, 1955) in Tennessee. Because it most resembles the Tellico, we here assign this unit to the Tellico Formation.

The Tellico Formation overlying the Rockmart Slate appears to have been derived from the east (or southeast) rather than from the craton or the carbonate shelf. This source is indicated (Cressler, 1970) by the size and angularity of some of the noncarbonate clasts in the conglomerates, by the presence of clasts that were metamorphosed before sedimentation, by the fact that grain size in sandstone beds increases from west to east and bedding thickens toward the east, and by the fact that "the conglomerate lenses in the southeasternmost outcrops are thickest and have the widest lateral extent. They also contain the coarsest and the least rounded pebbles and cobbles, apparently having been deposited nearest the source area" (Cressler, 1970, p. 27). Cressler (1970, p. 30) described the distribution of the sequence above the dark slates as follows: "The lower, predominately slaty part of the Rockmart, beginning near Cedartown in Polk County, is overlain by an eastward thickening wedge of clastics, composed largely of sandstone, conglomerate, and conglomeratic slate."

Both the Athens Shale in Alabama and the Rockmart Slate in Alabama and Georgia are unconformably overlain by the Lower and Middle Devonian Frog Mountain Sandstone, or by its equivalent chert facies the Armuchee Chert (Butts, 1926; Cressler, 1970; Thomas and Drahovzal, 1973). Neither the Frog Mountain nor its equivalents are present in the north Georgia Athens Shale outcrop belt. It may have been overridden by Bill Arp thrust sheet rocks on the Carters Dam fault (pl. 1), but it is far more likely that it was never deposited in northern Georgia (also Cressler, oral commun., 1985), its principal development being to the southwest in western Georgia and Alabama. The Frog Mountain Sandstone–Armuchee Chert is unconformably overlain by the Lower Mississippian (Osagean) Fort Payne Chert (Butts, 1926; Cressler, 1970).

Both Cressler (1970) and Sibley (1983) have shown that the Rockmart Slate was deformed before deposition of the Frog Mountain Sandstone. For example, Cressler stated (1970, p. 30):

> At Etna, where the Rockmart re-enters Polk County from Alabama, it is between 200 and 300 feet thick, but it thins toward the east, diminishing to about 20 feet at Oremont, and it is absent a quarter of a mile southeast of there, apparently having been eroded off an anticline that formed prior to deposition of the Frog Mountain Sandstone of Early and Middle Devonian age.

Sibley (1983, p. 34–37) reported that some of the larger pebbles and cobbles in the conglomerates in the Tellico overlying the Rockmart "have a well-developed cleavage that is sharply divergent from the matrix cleavage and appears to have been present prior to deposition."

The contact between the Rockmart Slate and Athens Shale and the underlying rocks of the carbonate shelf sequence (Lenoir and Newala Limestones) is either an unconformity or a thrust fault, or perhaps locally both. According to Bergström and Drahovzal (1972), Bergström (1973), and Finney (1980), the base of the Athens Shale in Alabama is diachronous. Graptolite data given by Cressler (1970, p. 26–30) and Bergström (1973) suggest that the lower part of the Rockmart Slate may also be diachronous. All available paleontological evidence indicates a striking similarity in age between the dark, graptolitic slaty shales and slates and the youngest underlying shallow-water shelf carbonates. Where the contact between the two facies is exposed, it is always seen to be knife-sharp (fig. 49). The drastic difference in sedimentary facies between the underlying warm, shallow-water shelf carbonates with their shelly faunas (Cressler, 1970), and warm, shallow-water conodonts (A.G. Harris and J.E. Repetski, written commun., 1984), and the overlying deeper water dark shales with their graptolite faunas (Cressler, 1970; Bergström and Drahovzal, 1973; Finney, 1980) is also striking. Moreover, the pelitic rocks appear to be more deformed than the underlying carbonate rocks, and they are clearly more metamorphosed than are shales in the Rome and Conasauga Formations in the same structural position only a short distance away. The relations between the Rockmart Slate and Athens Shale and the underlying carbonate-shelf-sequence rocks suggest to us that the contact between them is at least locally (particularly around Rockmart, Ga.) a thrust fault.

Bergström and Drahovzal (1972) and Bergström (1973) have shown that the base of the Athens Shale in the Cahaba Valley region (Rome thrust sheet) in Alabama becomes progressively older to the southeast, and is the same age, within the same narrow conodont zone, as equivalent units in the clastic wedges in eastern Tennessee, but that the carbonate units underlying the shale at Calera are older than those in the Tellico-Sevier belt in eastern Tennessee. Bergström (1973, p. 289) stated,

> Recently collected samples from rocks mapped as the Lenoir Limestone immediately beneath the Rockmart Slate at Rockmart have yielded exactly the same Whiterockian-type of conodont fauna as that present in the calcarenites in the lower portion of the Lenoir Limestone at Calera. The fact that in the sections studied this fauna evidently ranges up to the very base of the Rockmart Slate without any intervening unit with North Atlantic province conodonts of the *Eoplacognathus foliaceous* Subzone suggests that the base of the Rockmart Slate at Rockmart is older than the base of the Athens in the Calera area. This conclusion is supported by graptolites collected from the Rockmart; at least at some localities they represent the *Didymograptus murchisoni* Zone (Jaanusson and Bergström, in preparation) and are therefore older than those collected from any other Middle Ordovician section in the southern Appalachians. The incomplete data so far available from the Rockmart region suggest the presence there of a shale wedge which is partly older than those in other areas in the southern Appalachians. This may be taken as an indication that this shale originally was deposited further away from the Midcontinent platform than, for instance, the Athens Shale at Calera and the Blockhouse Formation of the Tellico-Sevier belt.

TALLADEGA GROUP

In the northernmost part of the Alabama crystalline terrane (pl. 1), the Talladega Group (Tull, 1982) is sandwiched between rocks of the Cambrian-Ordovician carbonate shelf sequence in the Rome thrust sheet, on the north, and the Hillabee greenstone in the Paulding,

A

B

FIGURE 49.—Dark graptolitic Middle Ordovician Rockmart Slate resting in sharp contact upon Middle Ordovician Lenoir Limestone. *A*, In abandoned quarry 0.6 km north-northeast of Portland, Ga., in the Rockmart North, Ga. 7.5-min quadrangle. Quarry face is approximately 30 m high. *B*, In cuts leading to abandoned quarry about 400 m northeast of where Marquette Road crosses the Seaboard Coast Line Railroad east of Georgia Highway 101, in the Rockmart North, Ga. 7.5-min quadrangle.

West Point, and Ropes Creek thrust sheets (or rocks of the Zebulon thrust sheet where the Hillabee is absent), on the south. The Talladega Group consists of the Lay Dam Formation with its Cheaha Quartzite Member, the Butting Ram Sandstone, the Jemison Chert, and in eastern outcrops the Frog Mountain Sandstone. The Talladega Group is bounded below by a structurally discordant contact where different clastic metasedimentary rocks of the group rest upon different units of the "Sylacauga marbles" (including the lowermost unit, the Jumbo Dolomite), which are now known to be mildly metamorphosed lower Paleozoic (mostly Knox Group) rocks of the carbonate shelf sequence in the Rome thrust sheet (Harris and others, 1984), including Chilhowee Group rocks that Tull (1982, 1985) and Guthrie (1985) have placed in the Kahatchee Mountain Group. Since the early 1960's this discordant contact has generally been interpreted as an unconformity (Shaw and Rodgers, 1963; Shaw, 1970, 1973; Gilbert, 1970, 1973; Carrington, 1973; Tull, 1978, 1979, 1982, 1984; Cook, 1982; Pendexter, 1982; Harris and others, 1984), the "pre-Lay Dam Formation unconformity" (Tull, 1982); early workers interpreted it as a thrust fault (McCalley, 1897; Prouty, 1916; Butts, 1926). We suggest that the evidence is equivocal but that the relations of the Talladega Group to underlying rocks are remarkably similar to those of the Rockmart Slate. We interpret the Talladega Group to belong with the Valley and Ridge province rocks in a thrust slice in the Rome thrust sheet and to have been overthrust by the Bill Arp and higher thrust sheets. The nearly north-south thrust contact (extension of the Emerson fault) between the Talladega Group of the Valley and Ridge province in the Talladega thrust slice and Great Smoky Group (Ocoee Supergroup) rocks in the Bill Arp sheet in eastern Alabama just west of the Georgia-Alabama State line is shown dashed and queried in plate 1. We have not yet done enough detailed mapping in that part of Alabama to revise the map relations between the Ocoee rocks and the Talladega Group; however, somewhere in the vicinity of the dashed and queried extension of the Emerson fault, the Talladega Group rocks of the Valley and Ridge province must become covered by the Bill Arp and higher sheets, just as their counterparts the Rockmart Slate and Tellico and Chota Formations are to the northeast.

The Talladega Group, like the Great Smoky Group in the Bill Arp thrust sheet that locally overlies it, is composed entirely of metasedimentary rocks, so that in many places the two are difficult to distinguish (this has been part of the "Talladega problem"). The basal unit of the Talladega Group in Alabama is the Lay Dam Formation (Carrington, 1973; Tull, 1982), a thick sequence of slates, phyllites, metagraywackes, and metasiltstones (graded bedding is locally well preserved). In the type area around Lay Dam on the Coosa River, the basal part of the Lay Dam Formation is a diamictite (Carrington, 1973; Telle and others, 1979; Telle, 1981; Tull, 1982) with fragments, chips, cobbles, and boulders of phyllite, quartzite, chert, granitic gneiss, and various metacarbonate rocks floating in a somewhat scaly, slightly arkosic phyllitic matrix. Many of the clasts have foliations or S-surfaces that terminate abruptly against the surrounding matrix. According to Tull (1982, p. 10) and Cook (1982, p. 50), the diamictites occupy higher positions in the Lay Dam Formation to the northeast.

Granitic gneiss clasts are fairly common in the Lay Dam diamictite near Lay Dam, and zircons from some of these clasts have yielded radiometric ages of about 1.1 Ga (Telle and others, 1979). The zircon age and the size and angularity of some of the clasts led Telle and others (1979) and Tull (1982) to suggest that the granitic gneiss clasts were derived from nearby Grenville-age basement. Telle and others (1979) suggested that this source lay to the northwest of the present outcrop belt of the Lay Dam Formation and that the basement rocks were exposed in fault blocks. There are problems with this interpretation. So far as we know, there is nothing in the preserved sedimentary record in the Valley and Ridge sequences to the northwest to suggest that Grenville-age basement was exposed in fault blocks during the time of sedimentation (see below) of the Lay Dam Formation (Thomas and Neathery, 1980; Chowns and McKinney, 1980). Aeromagnetic data (Higgins and Zietz, 1975) indicate that the basement is relatively deep under the Valley and Ridge at the present time. However, Grenville basement (Allatoona Complex) is present beneath the Ocoee Supergroup rocks in the Bill Arp sheet to the southeast, and granitic gneisses are also present. We suggest that the granitic gneiss clasts in the Lay Dam diamictite were derived from the southeast as debris shed from granitic rocks in the thrust-up leading edge of the Bill Arp thrust sheet during sedimentation of the Lay Dam. We also suggest that the carbonate clasts in the Lay Dam were shed either from a shoved-up part of the shelf in front of the thrust-up edge of the Bill Arp sheet or, more likely, from parts of the carbonate shelf sequence on top of the Bill Arp thrust sheet (pl. 2). Mack (1985) has shown that most of the clastic sedimentary rocks in the southeasterly derived Middle Ordovician clastic wedge ("Blount clastic wedge" in Tennessee; Tellico-Talladega clastic wedge of this paper) are rich in K-feldspar, probably from Grenville basement rocks, and that their source was mostly sedimentary rocks and low-grade metapelitic slates and phyllites, thus supporting their derivation from thrust-up Bill Arp sheet rocks.

Harris and others (1984) recently reported the discovery of conodont elements of Silurian to Pennsylvanian morphotypes from laminated lower greenschist facies metasiltstone in the upper one-third of the Lay Dam Formation 5 km west of Jemison, Ala. Fossils of probable Silurian or Early Devonian age have been reported from the Butting Ram Sandstone, which overlies the Lay Dam Formation (Carrington, 1973). An Early and Middle Devonian age has long been established for the Jemison Chert and has since been confirmed by fossils that we collected from the Jemison both west and east of the town of Jemison. On the basis of these fossils and the earlier collections, J.T. Dutro, Jr., and E.L. Yochelson (written report, 7/13/83) assigned an Oriskany age to the Jemison. Butts (1926) and Thomas and Neathery (1980) correlated the Jemison Chert with the Lower and Middle Devonian Frog Mountain Sandstone and Armuchee Chert. We agree and suggest that the sedimentary facies change east of Jemison, Ala., is the same as the facies change from chert to a clastic facies between the Armuchee and Frog Mountain in Georgia (Cressler, 1970). Everywhere but in the Talladega section, the Lower and Middle Devonian chert-sandstone sequence (Armuchee–Frog Mountain) is above a post-Silurian or post-Ordovician unconformity (Cressler, 1970; Drahovzal and Thomas, 1977; Thomas and Neathery, 1980). The Silurian-Pennsylvanian conodont elements (Harris and others, 1984) from the upper third of the Lay Dam Formation pose a problem, because they indicate that the upper part of the Lay Dam must be Silurian. Silurian rocks were previously unproven this far south or southeast in the Valley and Ridge province in Georgia and Alabama (Butts, 1926; Cressler, 1970; Drahovzal and Thomas, 1977; Chowns and McKinney, 1980; Thomas and Neathery, 1980). Part of the answer may lie in the undated Tellico and (or) Chota Formation equivalents at the top of the Rockmart Slate. The diamictite horizon containing carbonate clasts in the Lay Dam Formation may represent the same depositional environment as the Middle Ordovician Tellico and Chota Formations in Tennessee (Neuman, 1955), as the Chota and (or) Tellico Formations on top of the Athens Shale north of Chatsworth in northern Georgia, and as the Tellico Formation at the top of the Rockmart Slate (fig. 50). The Silurian-Pennsylvanian conodont elements (Harris and others, 1984) are from the upper third of the Lay Dam Formation, whereas the diamictite horizon is at or near the base of the ~4.5-km-thick section at the Coosa River and is not present in the 1- to 1.5-km-thick section west of Jemison that contained the conodonts (Tull, 1982, p. 10). Regardless of whether the basal contact of the Lay Dam Formation with the Lower Ordovician (lower to middle Arenigian) Knox Group near Sylacauga ("Sylacauga Marble Group" of Tull, 1982) is an unconformity or a thrust (or both), the basal part of the Lay Dam there must be post-Early Ordovician. According to Cook (1982, p. 50, fig. 3), the diamictite horizon is more than 3 km above the base of the Lay Dam Formation near Sylacauga, in a total Lay Dam section that is approximately 4.6 km thick. It is thus probable that the basal part of the Lay Dam Formation near Sylacauga may be as old as Middle Ordovician and perhaps roughly equivalent in age to (or only slightly younger than) the Rockmart Slate and Athens Shale (fig. 50). If the interpretation that the base of the Lay Dam Formation everywhere overlies an unconformity is valid (whether the Lay Dam has been thrust upon that unconformity or not), and if the diamictites mark a distinct horizon of deposition (depositional "event"), then the base of that horizon is probably diachronous, becoming progressively younger to the southwest. The hiatus between the base of the Lay Dam and the underlying carbonate rocks must also become greater to the southwest, because the unconformity apparently truncates progressively older carbonate units to the southwest: Middle Ordovician Lenoir Limestone near Rockmart, Ga. (Cressler, 1970), Lower Ordovician Knox Group rocks near Sylacauga, Ala. (Cook, 1982; Tull, 1982; Harris and others, 1984), and Jumbo Dolomite (probably Lower Cambrian Shady Dolomite) beneath the Knox Group west of Sylacauga (Pendexter, 1982; Tull, 1982; fig. 50). A similar case can be made for the unconformity beneath the Armuchee Chert–Frog Mountain Sandstone horizon. The age of the upper part of the Rockmart Slate is unknown, but the Armuchee Chert–Frog Mountain Sandstone clearly rests in angular unconformity upon it, whereas near Jemison, roughly 150 km along strike, there appears to be a thick section of Silurian rocks that probably represent a depositional environment similar to that of the Tellico below the Jemison Chert; though an unconformity beneath the Jemison is likely, probably neither the hiatus nor any angularity is as great as it is to the northeast (fig. 50). The apparent absence of the Frog Mountain Sandstone in northern Georgia also indicates diachronous depositional differences from northeast to southwest.

As early as 1956, Lochman had shown that the Middle Ordovician pelitic rocks in the western part of the northern Appalachians are contemporaneous with the Middle Ordovician carbonate shelf rocks there. Rodgers (1968) pointed out that similar relationships between Middle Ordovician deep-water dark shales and slates and Middle Ordovician shallow-water carbonate rocks of the carbonate shelf (or bank) exist along the eastern margin of the Valley and Ridge

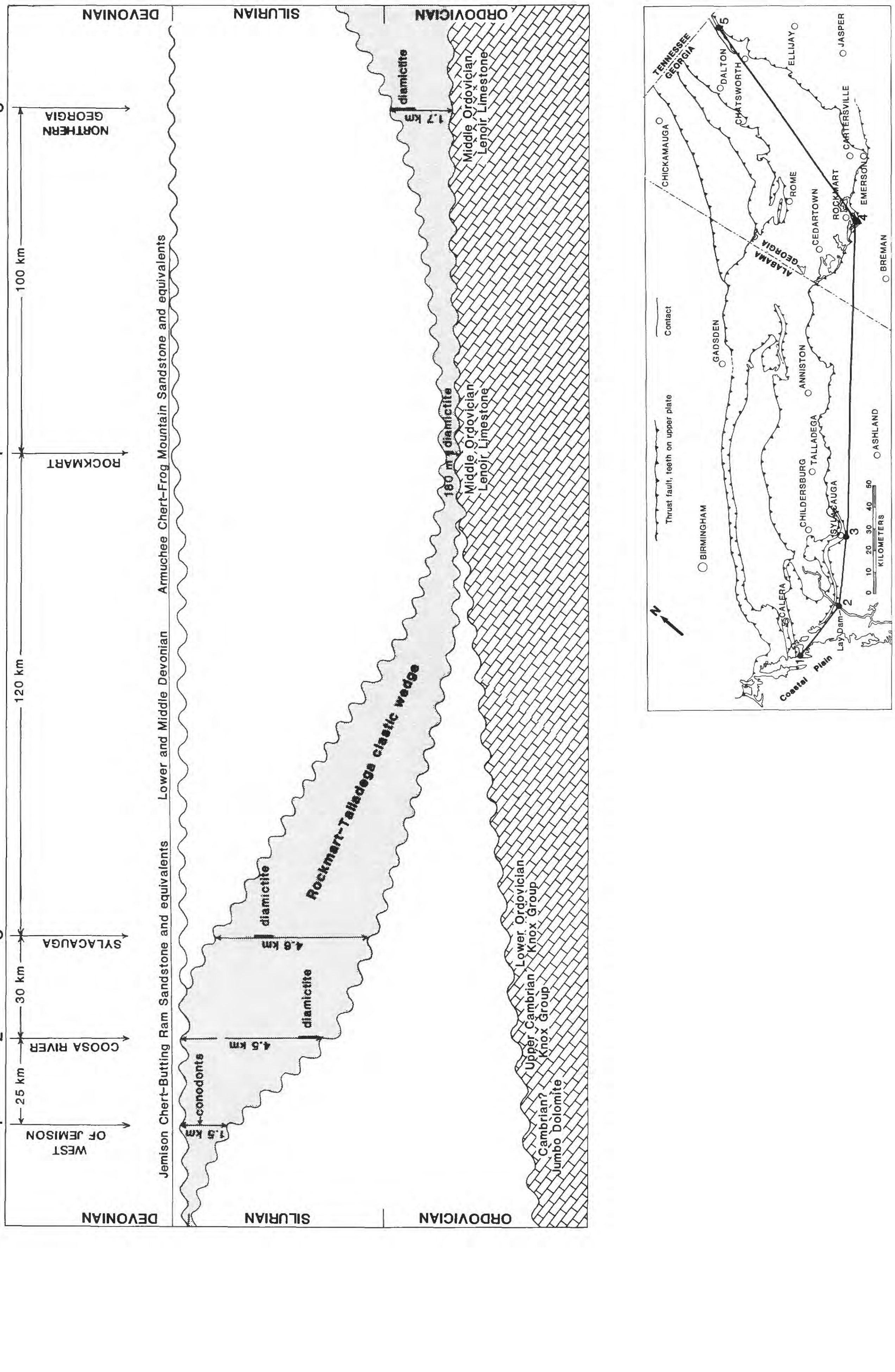


FIGURE 50.—Diagram illustrating interpreted, approximately along-strike changes in the Tellico-Talladega clastic wedge (see text for further explanation).

province throughout the Appalachians. He suggested that the carbonate shelf had subsided rapidly during the Middle Ordovician and that deposition of the deep-water pelites had transgressed over the edge of the shelf. Rodgers (1968, p. 146) stated,

> The outlying masses [of slates and shales] may be allochthonous, having slid into their present location during the Middle Ordovician, when this part of the carbonate bank sank—we know it did, relatively at least, because the carbonate rocks there are overlain by Middle Ordovician black shale and then by eastward-derived graywacke turbidites. Uplifted source areas from which the masses could have slid are indicated both by these sediments and by erosional unconformities beneath Middle Ordovician rocks to the east (Zen, 1967, and this volume).

Rodgers (1968, p. 145) considered that the polymictic conglomerates (his "lime-breccias" and "lime conglomerates"), limey beds, and argillaceous limestone lenses were derived through "slumps from the edge of the carbonate bank, still not far away" and that the areas where the dark pelites are juxtaposed against the carbonate shelf sequence marked the oceanward edge of the carbonate bank and approximately "what was then the eastern edge of sialic crust." However, in the southern Appalachians the polymictic conglomerates contain clasts that were clearly metamorphosed before sedimentation, as recognized by Cressler (1970), Chowns and McKinney (1980), and Sibley (1983), and sandstone layers and lenses in the sequences that contain the conglomerates are feldspathic, suggesting that they were derived from crystalline rocks. Moreover, there is abundant evidence that the clastic sequences (clastic wedges) were derived from a source to the southeast (see above). We interpret the clastic rocks in the sequences to be derived from the shoved-up edge of the Bill Arp thrust sheet during early stages of its cratonward movement (pl. 2). The initiation of thrusting probably uplifted the leading edge of the sheet enough to form a land mass that isolated the starved (probably partly stagnant) basin where the dark, calcareous pelites were deposited. The polymictic conglomerates containing clasts representing most units of the carbonate shelf sequence and probably parts of the Chilhowee Group (Cressler, 1970), as well as metamorphic clasts from the Bill Arp sheet, and the conglomeratic sandstones were most likely derived from erosion of part of the carbonate shelf on top of the Bill Arp sheet that was thrust up with the Bill Arp thrust sheet (pl. 2). The clasts of reworked slate suggest that mildly metamorphosed basinward parts of the dark pelites were also buckled up, or more likely thrust up, and were eroded to supply material to the coarser sequences now above the dark pelites. As the thrust sheet encroached upon the carbonate shelf, the clastic wedges transgressed farther toward the craton, but, at least locally (as appears to us to be the case with the Rockmart Slate), the incompetent shales (with the clastic wedges on top—in fact sedimentation was probably taking place on top of the wedges even as they were being thrust) detached and were shoved up the gentle slope of the shelf to become thrusts over the unconformity at the top of the Middle Ordovician shelf carbonate rocks. Continued movement folded the shelf carbonate sequence along with the parautochthonous and autochthonous sequences, and at the same time clastic wedges of molasse (Greensport, Colvin Mountain, Sequatchee) spread cratonward far beyond the limit of the dark pelites. The former edge of the carbonate shelf (Rodgers' carbonate bank edge) in the southern Appalachians must have been located far oceanward from the present location of the dark pelites. Late Paleozoic movement on the Emerson and Carters Dam faults has probably covered much of the sequences in the southernmost Appalachians.

The southwestward younging of the depositional environment of the polymictic conglomerate and diamictite horizons in the clastic sequences, from probably Upper Ordovician or Lower Silurian in the Rockmart, Ga., area to Silurian in western outcrops of the Talladega Group, and the apparent decrease in age of rocks immediately below the unconformity underneath the clastic sequences, from the Middle Ordovician Lenoir Limestone near Rockmart, Ga., to the Upper Cambrian–Lower Ordovician Knox Group near Sylacauga, Ala., to the pre-Upper Cambrian (probably Lower Cambrian Shady Dolomite or its equivalent) Jumbo Dolomite farther west in Alabama, suggest that the initiation and advancement of thrusting of the Bill Arp sheet was diachronous and progressed like a triple junction from northeast to southwest (fig. 50).

PREVIOUS THRUST CONCEPTS

The classic thrust faults in the Valley and Ridge province have been known for many years (Hayes, 1891; Willis, 1893), and for nearly as many years debate raged over the mechanics of their formation and whether the Grenville-age basement was a passive or active participant in the process (Bucher, 1933; Rich, 1934; Cooper, 1964; Rodgers, 1964; Gwinn, 1970). The "no-basement" hypothesis for Valley and Ridge structure (Rodgers, 1964; Gwinn, 1970) now seems fairly well established, especially in light of recent geophysical evidence (for example Cook and others, 1979; Harris and Bayer, 1979). Yet most of the geophysical methods, including deep seismic reflection profiling, are not designed to distinguish shallow structures very well, and though flat reflectors that have been interpreted as deep decollements (whatever their significance and whatever the underlying strata may be) can be detected, such features as folded thrust sheets may go undetected. Thus, the tendency among many geologists has been to depict thrusts in the crystalline terrane of the southern Appalachians as long, continuous, southeastward-dipping features that must root somewhere in the substrate or along the "master decollement." Some of these features have been elevated to such importance that they have begun to dominate interpretations of the structure and evolution of the southern part of the orogen. On the other hand, when flatter features are discovered, there has been a tendency to assume that they represent distinct allochthons rather than representing the "normal" situation in the crystalline terrane. An example of one of these is Hatcher's (1978b) "Alto allochthon" (also Hopson and others, 1985, and Dallmeyer and Hatcher, 1985), which probably doesn't exist as a separate allochthon but is simply part of the Zebulon thrust sheet and smaller slices of the Bill Arp and Sandy Springs sheets outlined by a slice of the Ropes Creek thrust sheet on the southeast and by juxtaposition against retrograded Brevard Zone rocks (mostly Bill Arp sheet rocks; pl. 1).

THE "HAYESVILLE THRUST FAULT"

Hadley (*in* Hadley and Nelson, 1971) mapped (but did not name) a fault that passes through Hayesville, N.C., and separates "biotite gneiss and schist" from the "Great Smoky Group undivided." Hatcher, who considered the "Blue Ridge" to be divided into "belts" (or "docked" entities), stated (1978a, p. 284–285),

> An important distinction between the western and eastern belts of the Blue Ridge is that the western is largely volcanic free, except for the Mount Rogers Formation volcanics and those in the lower Chilhowee (Unicoi Formation) in northeastern Tennessee and southwestern Virginia. The eastern belt contains abundant metavolcanic rocks.
>
> The eastern subdivision is bounded by the Fries fault from the Grandfather Mountain window northeastward. Rankin (1975) has suggested that the Fries fault extends southwestward into Georgia from the Grandfather Mountain window. The new "Geologic Map of Georgia" (Pickering, 1976) [sic; cited herein as Georgia Geological Survey, 1976] does not show a fault in this area, except the Allatoona fault near Cartersville. But one particular contact in the Georgia Blue Ridge is probably a major fault, which can be traced into the boundary between the Ashland-Wedowee belt and the Talladega belt, and is probably also a major fault across Alabama (Neathery and Tull, 1975) [sic; refers to "Geologic profiles of the Northern Alabama Piedmont," Neathery, T.L., and Tull, J.F., eds.: Guidebook for thirteenth annual field trip of the Alabama Geological Society, 1975]. I propose that this segment be called the Hayesville fault and the entire system the Hayesville-Fries thrust sheet. If the Hayesville-Fries thrust sheet extends to the Coastal Plain overlap, it is as extensive as the Blue Ridge thrust farther west and probably tectonically just as important.
>
> Several other lines of evidence point toward a major thrust sheet in the eastern Blue Ridge. Most of the ultramafic rocks occur in this belt (as first pointed out by Rankin, 1975, p. 323), along with all the Paleozoic granitic plutons. Throughout most of this belt, there is also a paucity of "Grenville" basement orthogneisses.

On the basis of the geologic map of Georgia (Georgia Geological Survey, 1976), one might generalize broadly and say that most of the metavolcanic and ultramafic rocks and nearly all of the Paleozoic granitic plutons (transported in thrust sheets above the Bill Arp thrust sheet) occur in this eastern terrane, and a likely boundary from which to extrapolate would be the minor fault that Hadley (Hadley and Nelson, 1971) mapped in Hayesville, N.C.

Hatcher's (1978a) Hayesville fault has been widely accepted without much additional mapping. It is shown, just as he depicted it, on Williams' (1978) "Tectonic lithofacies map of the Appalachian orogen" and in numerous subsequent publications dealing with the southern Appalachians. In Georgia, McConnell and Costello (1980), following Hatcher's depiction of the "Hayesville fault," renamed Hurst's (1973) Allatoona fault "the Allatoona-Hayesville fault," though they did not show how it connected with the fault at Hayesville, N.C. More recently, McConnell and Abrams (1984, p. 9) depicted the "Allatoona fault" and the "Hayesville fault" as different faults, whereas Abrams and McConnell (1984, p. 1522) depicted the "Allatoona-Hayesville fault" as the same fault, much as Hatcher (1978a, 1981) and Williams and Hatcher (1982, 1983) had depicted it.

In 1978, Dallmeyer and others showed that distinctive formations of the Great Smoky Group map directly across the trace of the "Hayesville fault" as depicted by Hatcher (1978a). Despite Dallmeyer and others' work, Hatcher and Odom (1980, p. 322) suggested that the fault is a "cryptic suture," and in 1981, Hatcher (p. 493) stated, "The Hayesville fault is a fundamental boundary which separates a terrane of mafic volcanic and ultramafic rocks, metasedimentary rocks, granite plutons and rare continental basement rocks to the east from a metasedimentary nonvolcanic terrane which is easily tied to continental basement (Hatcher, 1978)." Williams and Hatcher (1982, 1983) shifted the depicted position of the Hayesville fault to the east in western Georgia and eastern Alabama and depicted all of the terrane to the west of it (including part of the Ocoee Supergroup) as the "Appalachian Miogeocline."

Our work confirms the conclusion of Dallmeyer and others (1978, p. 31) that the Hayesville fault as defined and depicted by Hatcher (1978a, 1981), Williams (1978), Hatcher and Odom (1980), and Williams and

Hatcher (1982, 1983) does not exist in Georgia and Alabama (and, as they define it, probably not to the northeast in North Carolina). Mafic metavolcanic rocks of the Zebulon Formation in the Zebulon thrust sheet, mafic metavolcanic rocks of the Ropes Creek Metabasalt (locally with the distinctive iron formations) in the Ropes Creek thrust sheet, and mafic and ultramafic plutonic rocks of the Soapstone Ridge thrust sheet are present as infolded slices both east and west of the proposed trace of Hatcher's Hayesville fault—to the west, they are present almost to the border of the crystalline terrane (pl. 1). Mafic metavolcanic rocks and ultramafic rocks in the West Point melange are present in the Murphy syncline. In the complex area east of Blairsville, Ga., mafic metavolcanic rocks in the Zebulon thrust sheet underlie the West Point melange and Ropes Creek Metabasalt (see section above on West Point thrust sheet); the areas to the east and west are mostly underlain by rocks of the Bill Arp thrust sheet, which (including the Richard Russell thrust slice) lack volcanic components, but scattered infolded slices of higher thrust sheets containing mafic volcanic components occur throughout. The faults that have been called the "Hayesville" or "Allatoona-Hayesville fault" to the southwest in Georgia and Alabama are simply the northwesternmost infolds of the Ropes Creek or (and) Paulding thrust sheets (±West Point thrust sheet). We therefore suggest that the names Hayesville fault, Allatoona-Hayesville fault, and Hayesville or Hayesville-Fries thrust sheet should not be used in Georgia and Alabama.

THRUSTING

Major thrusting in the southernmost Appalachians in Georgia and Alabama appears to have taken place almost continuously from about Middle Ordovician to Permian time. The youngest major thrust faults are those in the Valley and Ridge province (Rome, Clinchport, Kingston); the Rome thrust fault serves as an example. The Rome fault (pl. 1, fig. 1) has thrust the Cambrian-Ordovician carbonate shelf sequence upon rocks as young as Late Mississippian but has been folded along with Lower Pennsylvanian rocks. There is evidence (Cressler, 1970) that thrusting on the Rome fault took place during formation of the major folds in the underlying rocks. Cressler (1974, p. 31) estimated a minimum of 5–10 miles (8.5–17 km) of displacement on the Rome fault, on the basis of remnants of the Rome thrust sheet found west and northwest of the present trace of the fault. Actual displacement on the fault is probably on the order of many tens of kilometers. Where shale has been thrust upon shale the Rome fault is marked by a zone of claylike gouge generally less than 6 cm thick, but where harder rocks such as siltstone or limestone are in contact there is generally a zone (tectonic melange) about 2–4 m thick that is a mixture of rocks from above and below (Cressler, 1970, p. 52; 1974, p. 31). Cressler (1974, p. 31) described the fault as follows:

> The Rome Fault is a flat-lying bedding-plane thrust that originated in shale of the Conasauga or Rome Formations. The fault developed a frontal prow that angled steeply upward, cutting through the overlying formations until it reached the Floyd Shale. There it flattened out and continued its westward slide. The Conasauga, having been uplifted 7,000 feet along the frontal prow of the fault, continued to push westward as a flat thrust sheet. Even with all this movement, the fault zone in most places consists of only 1 or 2 inches of claylike gouge.

Probably about the same age as or only slightly older than the Rome fault, the Emerson thrust fault (pl. 1) has emplaced the metamorphic rocks in the Georgiabama thrust stack upon the Rome thrust sheet. The Emerson fault has emplaced rocks as old as the late Precambrian Great Smoky Group upon rocks as young as the Lower Mississippian (Chesterian) Floyd Shale. The amount of displacement on the Emerson fault is unknown but is probably on the order of many tens of kilometers rather than hundreds of kilometers (also see Tull, 1984). The Emerson fault is locally marked by a thin silicified breccia; mylonitic rocks have not been found along the fault.

The major fault that forms the boundary between the crystalline terrane and the Valley and Ridge province north of Emerson, Ga. (pl. 1), has generally been called the Great Smoky fault (McConnell and Costello, 1982; Crawford and Cressler, 1982; and references in both) and has been assumed to be the same as the Great Smoky fault in eastern Tennessee. Moreover, with the exception of Kesler (1950) and Hurst (1973), most workers have considered the Great Smoky and Emerson (formerly Cartersville) faults the same fault (McConnell and Costello, 1982, and references therein). Rocent detailed work by Crawford and Cressler (1982; Cressler and others, 1979) has shown that the east-northeast-trending Emerson fault has overridden the nearly north-south Great Smoky fault and other structures and rock units with the same general trend near Emerson, Ga., thereby precluding the equality of the two faults. More recently, Costello and McConnell (1983) suggested that the nearly north-south fault that has generally been called the Great Smoky fault in Georgia is correlative with the Miller Cove thrust fault in Tennessee, rather than with the Great Smoky fault. McConnell and Costello (1984, p. 264) depicted the fault as the "Blue Ridge thrust" but stated in a footnote that "the major fault separating Ocoee Supergroup rocks from Chilhowee Group rocks is now interpreted to be only the Cartersville fault." Still more recently, McConnell and Abrams (1984, p. 9, fig. 2) and Abrams and McConnell (1984, p. 1522) depicted the "Cartersville fault" as the boundary between the Valley and Ridge and Blue Ridge from eastern Alabama through most of Tennessee, and they used the name "Great Smoky fault" for the Johnson Mountain fault of Cressler and others (1979), which is located entirely in the Valley and Ridge province and has thrust the Cambrian Rome Formation over the Cambrian Conasauga Formation. King (1964, p. 100) pointed out the difficulties in identifying the Great Smoky fault outside of its type area in eastern Tennessee. In light of all of this confusion, we feel that the fault in northwest Georgia can be correlated directly with neither the Great Smoky fault nor the Miller Cove fault with any confidence at the present time, and we suggest that the fault in Georgia, where we have some control, be called the Carters Dam fault for Carters Dam (pl. 1) where it is well exposed in the spillway cuts (fig. 51).

The exposures at Carters Dam show that the Carters Dam fault is marked by a zone of tectonic melange as much as 30 m wide. The lower 2 m of this melange is a scaly "gouge" containing clasts of sheared Great Smoky Group rocks from above and of Conasauga Formation rocks from below (fig. 51); the matrix also appears to be derived from a mixture of rocks from above and below (Cressler, 1974, p. 33). The bulk of the melange above this zone consists of intensely sheared and disrupted (fig. 51) quartz-granule metaconglomerate of the Great Smoky Group exposed around the top of the dam.

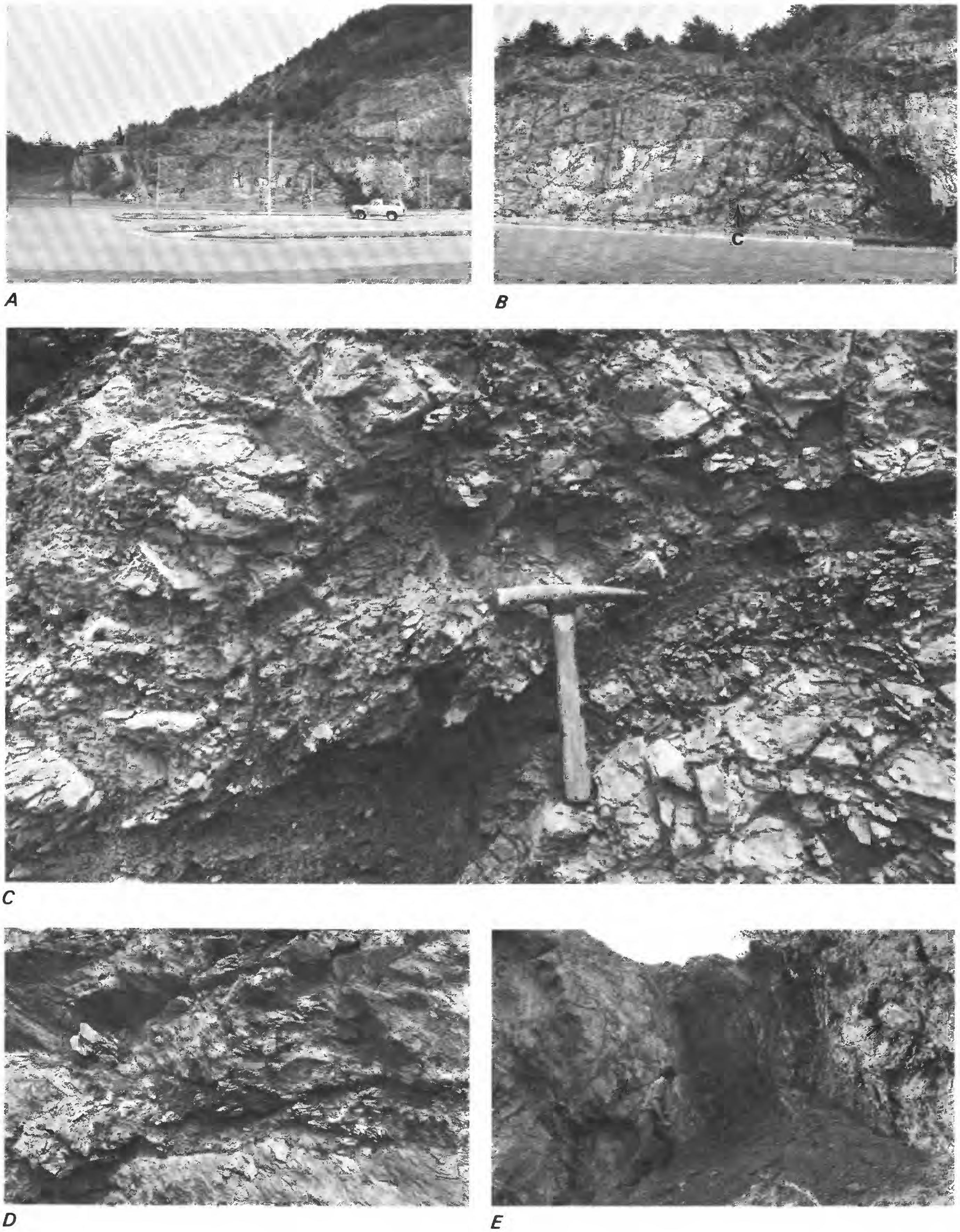
The amount of displacement on the Carters Dam fault is unknown. However, it has transported late Precambrian Ocoee Supergroup rocks onto the Cambrian-Ordovician carbonate shelf sequence and younger rocks in the Rome thrust sheet, suggesting at least many tens of kilometers of displacement. Regardless of the amount of displacement, the Emerson and Carters Dam faults have accounted for final emplacement of the Georgiabama thrust stack upon the Rome thrust sheet in the Rome-Kingston thrust stack through Georgia and Alabama.

THRUSTING WITHIN THE GEORGIABAMA THRUST STACK

The Georgiabama thrust stack appears to be divisible into three main sequences of sheets by differences in metamorphic and deformational histories and also by differences in deformation of the sheets northwest and southeast of the Brevard Zone. The autochthogenetic Bill Arp thrust sheet has apparently had a different history from that of the overlying Zebulon, Clairmont, Wahoo Creek, Atlanta, and Promised Land thrust sheets, and these five sheets differ from the overlying Sandy Springs, Paulding, West Point, Ropes Creek, and Soapstone Ridge thrust sheets. The most striking differences occur at or just southeast of the Brevard Zone and the line of large synforms that are perhaps best represented by the Newnan-Tucker synform (fig. 2). Northwest of the synforms and the Brevard Zone, the Sandy Springs and higher sheets, as well as the underlying Zebulon and Bill Arp sheets, are tightly folded in generally northeast-trending, northwest-verging isoclines with axial traces that are, in general, nearly parallel to the axial trace of the Newnan-Tucker synform. However, to the southeast (fig. 2), the Sandy Springs and higher sheets rest discordantly athwart contacts of units involved in the northeast-trending synforms and appear to have been involved in fewer folding events than the underlying rocks. These relations strongly suggest that the Newnan-Tucker and other cogenetic synforms along strike formed (or partly formed) before arrival of the Sandy Springs and higher sheets and before final development of the major northeast-trending folds to the northwest. Thus, there appears to be a fundamental tectonic change at, or more likely just southeast of, the Brevard Zone.

Despite their position at the bottom of the Georgiabama thrust stack, rocks of the Bill Arp thrust sheet northwest of the Brevard Zone are apparently less deformed than the rocks of the overlying Zebulon, Sandy Springs, Paulding, Ropes Creek, and Soapstone Ridge sheets; rocks of the Bill Arp sheet northwest of the Brevard apparently have at least one fewer fold generation than the five next overlying thrust sheets. Therefore, we suggest that the rocks of the Bill Arp sheet were neither intensely folded nor much metamorphosed when the overlying sheets were emplaced upon them, whereas the rocks of the Zebulon through Promised Land sheets were already metamorphosed and intensely folded before emplacement upon the Bill Arp sheet.

We have found no firm criteria to indicate whether the Zebulon, Clairmont, Wahoo Creek, Atlanta, and Promised Land thrust sheets were emplaced upon the Bill Arp sheet as an assembled five-sheet stack or separately in sequence. The fact that the Zebulon thrust sheet extends almost as far to the north and northwest as the Bill Arp thrust sheet (pl. 1), and locally almost to the Valley and Ridge province, seems to suggest that it may have arrived slightly ahead of, and separately from, the Clairmont and higher sheets. Moreover, the fact that the Clairmont, Wahoo Creek, Atlanta, and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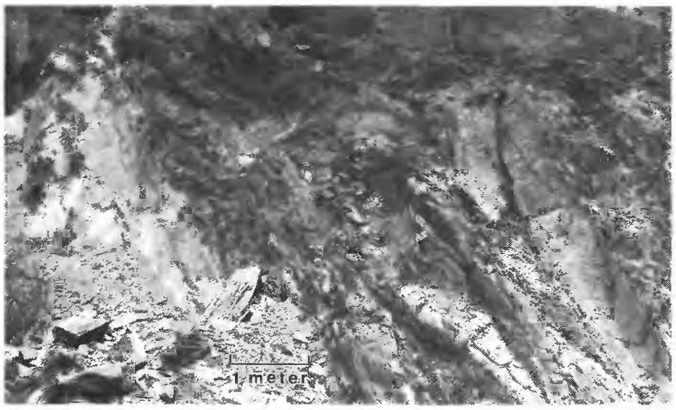

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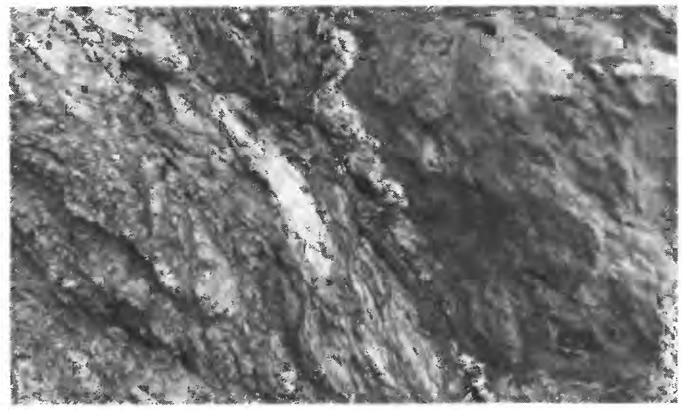

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FIGURE 51.—Fault zone of the Carters Dam fault in construction cuts for the spillway below Carters Dam, in the Oakman, Ga. 7.5-min quadrangle. *A*, Arrow points to main tectonic melange gouge zone. Entire cut east (right) of main gouge zone is tectonic melange formed from massive blue-quartz-bearing Ocoee metagraywackes with lesser amounts of graphitic schists. *B*, Closer view of faults. C points to faults within melange. *C*, Closer view of highly sheared nature of the tectonic melange at C in *B*. *D*, Scaly melange about 5 m east (right) of main gouge zone. Knife is 9 cm long. *E*, The main tectonic melange gouge zone (dark zone to right of man). Light rocks to left of man belong to the Cambrian Conasauga Formation (trilobites have been collected from the Conasauga a few meters from this view); rocks to right of dark zone are an autoclastic melange composed of clasts of widely varying size of Ocoee Supergroup metaconglomerates. Arrows point to native blocks in tectonic melange zones on both sides of the main tectonic melange gouge. *F*, Closer view of imbricated dark and light rocks in tectonic melange. View is at right side of *E*. *G*, Closer view of block of light rock (Conasauga?) in scaly tectonic melange in eastern edge of main gouge zone. Knife handle is 6 cm long.

Promised Land sheets are only present southeast of the Brevard Zone, as much as 50 km south and southeast of the present northernmost and northwesternmost extent of the Zebulon thrust sheet, suggests their arrival upon the Zebulon as a separate four-sheet thrust stack.

The presence of the upper Precambrian Great Smoky Group in the Bill Arp thrust sheet places a lower constraint on the time of emplacement of the overlying Zebulon, Clairmont, Wahoo Creek, Atlanta, and Promised Land sheets. Lack of debris from the overlying thrust sheets in the Great Smoky metasedimentary sequences and the widespread preservation of graded bedding and other more delicate sedimentary structures in the rocks (Hurst, 1955; Mellen, 1956; Webb, 1958; Hurst and Schlee, 1962; fig. 6, this paper) suggest that these Ocoee rocks were well consolidated before final emplacement of the Zebulon, Clairmont, Wahoo Creek, Atlanta, and Promised Land thrust sheets. Therefore, these five sheets were probably emplaced upon the Bill Arp sheet after the Precambrian, and probably after the Early Cambrian (see below).

Because it rests in discordant thrust contact upon the rocks of the Bill Arp, Zebulon, Clairmont, Wahoo Creek, Atlanta, and Promised Land thrust sheets but has been folded along with the Bill Arp and Zebulon sheets northwest of the Brevard Zone, the Sandy Springs thrust sheet must have been emplaced after the folding that produced the Newnan-Tucker synform but before the completion of the northeast-trending folds northwest of the synform. Thus, the Sandy Springs and higher thrust sheets must have overridden the leading edge of the Clairmont through Promised Land sheets.

The upper limit for time of emplacement of the Zebulon, Clairmont, Wahoo Creek, Atlanta, and Promised Land sheets upon the Bill Arp sheet, and emplacement of the overlying Sandy Springs sheet, is best set by the time of emplacement of the overlying Paulding, West Point, Ropes Creek, and Soapstone Ridge thrust sheets. In Alabama (pl. 1), rocks in the leading edge of the Paulding, West Point, and Ropes Creek sheets (Hillabee greenstone) rest in thrust contact upon the Lower and Middle Devonian (Ozarkian-Onandagan) Jemison Chert and some of its equivalents (Armuchee Chert–Frog Mountain Sandstone equivalents), clearly establishing that these sheets were emplaced in their present tectonostratigraphic positions after the Middle Devonian and that the underlying (Zebulon through Sandy Springs) sheets were emplaced earlier.

Thus, there is evidence that the lower sheets in the Georgiabama stack were emplaced upon the lowest (Bill Arp) sheet between Middle Ordovician and Middle Devonian time. The Athens Shale, Rockmart Slate, Chota and Tellico Formations, the Talladega Group, and the rocks in the Rome-Kingston thrust stack provide further clues for interpreting the time of emplacement of the Zebulon through Sandy Springs sheets.

The Cambrian-Ordovician carbonate shelf sequence in the Rome-Kingston thrust stack provides evidence of the time of thrusting in the Georgiabama thrust stack.

There is abundant evidence that this sequence represents the building of an enormous carbonate bank that grew essentially uninterrupted, except for periodic influxes of mostly fine-grained clastic material from the craton (such as that in the Rome and Conasauga Formations), from the time of deposition of the Lower Cambrian Shady Dolomite (itself deposited on top of tidal flat and beach-barrier island deposits of the Chilhowee Group; Mack, 1980) through the time of deposition of the Upper Cambrian and Lower Ordovician Knox Group (Butts, 1926; Rodgers, 1953, 1968, 1982; Cressler, 1970, 1974; Palmer, 1971; Thomas and Neathery, 1980; Read, 1985a,b). A regional unconformity truncates the top of the Knox Group (Colton, 1970; Thomas and Neathery, 1980) and records a major regression that marked the beginning of instability of the shelf and signaled the first movement of the Bill Arp thrust sheet, probably in response to arrival of higher sheets in the Georgiabama stack upon the oceanward parts of that sheet. From Middle Ordovician to Early Devonian time, the shelf was unstable and was alternately receiving clastic material from the southeast and being buckled up and eroded. The end of deposition on the southeastern part of the shelf was established with the arrival of the Paulding and Ropes Creek thrust sheets upon the Lower and Middle Devonian Jemison Chert (Armuchee Chert–Frog Mountain Sandstone equivalent).

METAMORPHISM AND DEFORMATION

As Rodgers (1982, p. 237–238) recognized, the movement of the great stacks of mostly crystalline thrust sheets[11] "was what compressed and deformed the rocks of the folded belt [Valley and Ridge of this paper], producing all of the folds and thrust sheets observed there." We suggest that the slow but relentless collisional impact and the continuously cratonward-advancing thrust sheets also produced all of the deformation and metamorphism in the crystalline terrane and that the metamorphism was the result of the overpressures and depths of burial caused by the thick stack of moving thrust sheets, enhanced by the blanketing effect of the stack (see Waldbaum, 1971, especially p. 546). In general, then, metamorphic effects should decrease toward the leading edges of thrust sheets or thrust stacks and towards the top of the thrust stack sequence, whereas tight folds with axes approximately normal to the direction of movement of the thrust sheets and thrust stacks should increase towards the leading edges, especially if these leading edges were relatively thin. This picture is oversimplified, given the complexities of the southern Appalachians, but fits well in a general way with the metamorphic and structural relations in Georgia and Alabama.

One of the most intriguing metamorphic features of the Georgia and Alabama crystalline terrane is the difference in metamorphic grade between many of the rocks in the Paulding, Ropes Creek, and Soapstone Ridge thrust sheets and the rocks in the thrust sheets that underlie them. Metamorphosed mafic rocks in the Paulding, Ropes Creek, and Soapstone Ridge sheets are commonly chloritic to some extent, are epidote-rich in many outcrops, and locally have tremolite or actinolite as their principal ferromagnesian mineral (Hurst and Crawford, 1970; Bentley and Neathery, 1970; Neathery, 1975; Stow and others, 1984). Metamorphosed mafic rocks in the underlying Zebulon, Clairmont, Wahoo Creek, Atlanta, Promised Land, and Sandy Springs thrust sheets are unchloritic, generally less rich in epidote, and almost invariably have hornblende as their principal ferromagnesian mineral. Most workers have attributed the lower grade of rocks in the Paulding, Ropes Creek, and Soapstone Ridge sheets to retrogressive chloritization because these sheets also have rocks that appear to be at amphibolite grade (although many of these have small amounts of chlorite in the mode) and some contain pyroxenes. It is often difficult to distinguish between mafic rocks that have been prograded to amphibolite grade and later retrograded to chlorite grade and mafic rocks that have been prograded or partly prograded only to chlorite grade. The mafic rocks of the Paulding, Ropes Creek, and Soapstone Ridge sheets have some of the characteristics of both. In many parts of the sheets, rocks with greenschist-facies mineral assemblages, rocks with amphibolite-facies assemblages, and rocks with assemblages belonging to both facies appear to be randomly intermixed, suggesting retrogression of rocks originally metamorphosed to the amphibolite facies. Even the lowest grade mafic rocks near the leading edge of the Paulding and Ropes Creek thrust sheets (including the Hillabee greenstone, according to Griffin, 1951, and Carrington and Wigley, 1967) locally contain hornblende and metamorphosed felsic and silicic volcaniclastic rocks within the predominantly mafic sequences and have large, locally euhedral hornblende crystals which Tull and others (1978, p. 20–22) interpreted as porphyroclasts of "relict phenocrysts from the original igneous rock." However, most of these hornblende crystals, and particularly the subhedral and euhedral ones,

[11]Rodgers (1982, p. 237), following the COCORP interpretations of what was previously known of the geology of the crystalline part of the southern Appalachians, considered the crystalline rocks to have moved as a single block on the "major fault at the northwest front of the Blue Ridge" for as much as 200 km.

are not porphyroclasts. They may originally have been igneous phenocrysts, but the fact that some of them appear to have grown and pushed apart the enclosing foliation planes, forming pressure shadows (Tull and others, 1978, p. 23, fig. 8), strongly suggests that they are porphyroblasts formed during amphibolite-facies metamorphism.

The bulk of evidence indicates that most of the rocks in the Paulding, Ropes Creek, and Soapstone Ridge thrust sheets were metamorphosed to amphibolite grade and later partly retrograded to chlorite grade. We suggest that rapid and incomplete prograde metamorphism of these rocks took place during early stages of plate collision near their original tectonic settings and was followed fairly rapidly by generally incomplete retrogressive metamorphism during transport.

Also generally at chlorite grade and not intensely deformed are the metavolcanic and metasedimentary rocks in the Little River allochthon. The overlying Northern Florida platform sequence is unmetamorphosed. These sheets were probably the last stack of rocks to arrive in their present position on top of the Georgiabama thrust stack before collision ceased. Their high structural position and the waning pressure of collision probably account for their generally low grade and lack of strong deformational features.

The thrust sheets in the lower part of the Georgiabama thrust stack (Bill Arp through Sandy Springs) southeast of the Brevard Zone are everywhere at sillimanite grade. Northwest of the Brevard, in the Austell-Frolona anticlinorium (pls. 1, 2), the Frolona Formation, which underlies the Bill Arp Formation in the Bill Arp thrust sheet, is at kyanite grade, and the Bill Arp Formation is presumed to be at kyanite grade, although aluminosilicate index minerals are unknown. About 25 km to the northwest, where Bill Arp thrust sheet rocks (Great Smoky Group undivided) reappear from beneath the Zebulon, Paulding, Ropes Creek, and Soapstone Ridge thrust sheets (fig. 2), they are mostly at biotite grade, and the grade appears to decrease to the northwest until chlorite-grade rocks are present just southeast of the Emerson fault (also see Webb, 1958). Southwest of the area of figure 2, where wider outcrop belts of Bill Arp thrust sheet rocks occur (pl. 1) between the Emerson fault and the leading edges of the Zebulon, Paulding, Ropes Creek, and Soapstone Ridge thrust sheets, the zone of chlorite-grade rocks is also wider; still farther to the southwest, where the Talladega Group intervenes between the Talladega thrust fault and the leading edges of the higher thrust sheets, the zone of chlorite-grade rocks is wider still. A wider zone of chlorite- and biotite-grade rocks of the Bill Arp thrust sheet also occurs west of the last erosional remnants of the Zebulon thrust sheet in northern Georgia (pl. 1; also J.W. Smith and others, 1969, and Hurst, 1973), west of the Murphy syncline.

Rocks of the Zebulon thrust sheet maintain kyanite-grade, and locally staurolite-grade, assemblages from where they emerge from beneath the leading edge of the Clairmont melange and higher sheets to the present leading edge of the Zebulon sheet (pl. 1). Throughout this extent the Zebulon sheet was structurally overlain by the Paulding, Ropes Creek, and Soapstone Ridge thrust sheets. Thus, again there appears to be a relation between the presence and thickness of overlying thrust sheets and degree of metamorphism; where the Zebulon sheet was overlain by the thick Clairmont, Wahoo Creek, Atlanta, and Promised Land thrust sheets it is at sillimanite grade, but where it was overlain only by the Sandy Springs, Paulding, Ropes Creek, and Soapstone Ridge thrust sheets or by just the Paulding, Ropes Creek, and Soapstone Ridge sheets it is at kyanite or staurolite grade.

Perhaps the most dramatic evidence suggesting a relation between overlying thrust sheets and degree of metamorphism lies in the Jemison Chert and "Sylacauga marbles" near the northwestern edge of the crystalline terrane in Alabama (pl. 1). We have already described how the Jemison Chert can be traced from an unmetamorphosed rock to a metamorphic tectonite, with the change taking place almost exactly where the Hillabee greenstone first rests in thrust contact upon it. A similar situation exists in the "Sylacauga marbles." These "Sylacauga Marble group" rocks are now known to belong to the Valley and Ridge province Cambrian-Ordovician carbonate shelf sequence, yet they appear to have been mildly metamorphosed because they were once structurally overlain by the Talladega Group.

The thrust sheets and their emplacement also affected the style and intensity of deformation. Southeast of the leading edges of the Clairmont melange and Wahoo Creek thrust sheets (pls. 1, 2), rocks of the Zebulon, Clairmont melange, Wahoo Creek, Atlanta, and Promised Land thrust sheets have at least five generations of folds (Atkins and Higgins, 1980) and have been folded into large, northwest-verging, tight to isoclinal, moderately to steeply inclined (Fleuty, 1964) synforms, such as the Newnan-Tucker synform, that must have formed slightly before or during the later stages of emplacement of the overlying Sandy Springs, Paulding, Ropes Creek, and Soapstone Ridge thrust sheets, which discordantly overlie the synforms and the earlier folds (pls. 1, 2). Southeast of the Newnan-Tucker synform and similar synforms roughly along strike, other large synforms, such as the Griffin synform containing the Zebulon and Atlanta thrust sheets, and large antiforms, such as the Ola anticlinorium containing the

Zebulon and Bill Arp thrust sheets, become more open and more upright (pl. 2*O*). We attribute the differences to a rumpling effect in the leading edge of the moving stack of thrust sheets (much as a pushed carpet becomes more tightly folded at its leading edge), an effect that naturally decreases away from the front. The cause and effects are thus quite similar to the thrust-caused folds in the Valley and Ridge province (Cressler, 1970; Rodgers, 1982).

Northwest of the leading edge of the Clairmont or Wahoo Creek thrust sheet (pls. 1, 2), the Sandy Springs, Paulding, Ropes Creek, and Soapstone Ridge thrust sheets, which hardly participated in the northeast-southwest folding that produced the Newnan-Tucker line of synforms to the southeast, and to a slightly lesser extent the Bill Arp and Zebulon sheets as well, are folded into northwest-verging, tight to isoclinal, gently to steeply inclined folds that become closer spaced to the northwest toward the leading edges of the sheets. Here again the pushed-carpet analogy seems to apply, with the thick, already folded (Newnan-Tucker and similar synforms) Promised Land and underlying sheets forming the more solid pushing block. As with the metamorphic scenario, this picture is oversimplified, chiefly because the folding probably took place continuously, with formation of folds in one sector of the stack overlapping and overtaking the formation of folds in another sector, as appears to have happened in the Valley and Ridge province (Cressler, 1970, 1974).

Variations in metamorphic effects upon K-Ar and ^{40}Ar-^{39}Ar ages of micas also appear to be related to the thickness of overlying thrust sheets and stacks. As Hurst (1970, p. 394, fig. 5) recognized, K-Ar dates of biotite and muscovite are, in general, older to the northwest and younger to the southeast across the crystalline terrane in Georgia, Alabama, South Carolina, and parts of Tennessee and North Carolina, until older ages reappear in the Little River allochthon. Hurst (1973, p. 664) stated, "An areal plot of available radiometric ages for the southeastern United States shows a well defined pattern. For micas the older ages are along the west side of the Blue Ridge belt. Eastward the ages are progressively though erratically younger toward the zone characterized by 250 Ma ages, which extends northeast-southwest through Raleigh, North Carolina, and Elberton, Georgia." Thus, in a general way, it appears that where the rocks were covered by numerous thick thrust sheets, the metamorphic effect has been a lowering of K-Ar ages of micas, and where the rocks were covered only by a few sheets or by the thinner leading edges of sheets older K-Ar ages of micas have been retained.

^{40}Ar-^{39}Ar plateau ages of hornblende and muscovite (Dallmeyer and Hatcher, 1985) from rocks of the Zebulon thrust sheet and the Ropes Creek thrust sheet in northeast Georgia (in the area of the so-called "Alto allochthon," see above) also support a relation between the thickness of overlying thrust sheets and the ages. The oldest ages are from the Ropes Creek Metabasalt in the Ropes Creek thrust sheet ("Chauga belt" of Dallmeyer and Hatcher, 1985) near the top of the Georgiabama thrust stack, and younger ages are from the Zebulon Formation in the Zebulon thrust sheet (rocks of the "Alto allochthon" of Dallmeyer and Hatcher, 1985) near the bottom of the Georgiabama thrust stack. In addition, a comparison of the ages from the Zebulon rocks in northeast Georgia with those obtained by Dallmeyer (1978) from the Atlanta, Ga., area also supports a relation between thickness of thrust sheets and ^{40}Ar-^{39}Ar plateau ages. The Zebulon rocks in northeast Georgia have older plateau ages than the rocks in the Atlanta area (Dallmeyer, 1978; Dallmeyer and Hatcher, 1985). The Zebulon rocks dated in northeast Georgia were probably never covered by the thick Clairmont, Wahoo Creek, Atlanta, and Promised Land thrust sheets (pl. 1), whereas the rocks dated in the Atlanta area were covered by one or more of these sheets.

THE BREVARD ZONE

The Brevard Zone is a narrow zone of sheared and low-grade-appearing rocks that extends from beneath the Coastal Plain in Alabama to southern Virginia. There have been more than twenty different interpretations and combinations of interpretations of the nature of this controversial zone (see reviews and discussions in Medlin and Crawford, 1973; Roper and Justus, 1973; Rankin, 1975; and references in all three). Many of these interpretations have invoked thrust faulting or strike-slip faulting, or some combination of the two, to explain the zone, but nearly as many have emphasized the stratigraphic nature of the zone. Still other interpretations involve some form of root zone, or a "Caledonide-like Abscherung-zone," or a paleosubduction zone, or a complicated polytectonic zone in which isoclinal folds are formed and then sheared out during plate collision(s), or the suture zone between a Piedmont island arc and the North American continent, which was also the root zone for Blue Ridge thrust sheets, or the transported suture along which the proto-Atlantic Ocean finally closed.

Perhaps not surprisingly, our work indicates that the Brevard Zone is probably a combination of many of the previous interpretations in one sense or another, except for the root zone, Abscherungzone, transported suture, and paleosubduction zone interpretations. Our work shows that throughout Georgia and Alabama at least, identical stratigraphic sequences in the Bill Arp, Zebulon, Sandy Springs, Paulding, Ropes Creek, and Soapstone Ridge thrust sheets are found on both sides of the Brevard Zone (pls. 1, 2), and that the only major sequences found on one side of the zone but not on the other are those in the Clairmont, Wahoo Creek, Atlanta, and Promised Land thrust sheets and in the Little River thrust stack (excluding of course rocks in the Valley and Ridge province, including the Talladega Group, Rockmart Slate, and Athens Shale). This precludes the Brevard Zone being a fault of great magnitude, as predicted by Hurst (1970, 1973). It also nullifies the concept that the Blue Ridge and Piedmont are separate geologic belts, as pointed out earlier by Medlin and Crawford (1973) and Crawford and Medlin (1973). Our work shows that no major thrust sheets in Georgia and Alabama are rooted in the Brevard Zone or anywhere near it.

The works of Hurst and Crawford (1964), Hatcher (1969), Hurst (1973), Medlin and Crawford (1973), Crawford and Medlin (1973, 1974), and Kline (1980), and our own work, clearly show that mappable stratigraphic sequences are present in the traditional Brevard Zone. We further suggest that different sequences within the zone are different thrust sheets in the Georgiabama thrust stack that have been sheared and generally incompletely retrograded. The rocks of the Brevard Zone were considered low-grade (and prograde) phyllites and schists by Keith (1905, 1907b), and Hatcher (1969, 1970). Our work confirms the conclusions of Jonas (1932) and Reed and Bryant (1964) that the low-grade appearance of the Brevard Zone rocks is due to retrogressive metamorphism. Relict staurolite, kyanite, and sillimanite have been found in the low-grade-appearing rocks virtually throughout the length of the Brevard Zone, from Alabama to northern North Carolina (Keith, 1905, p. 8; Reed and Bryant, 1964, p. 1181, 1183; Butler and Dunn, 1968, p. 43; Bentley and Neathery, 1970, p. 23–24; Hurst, 1970, p. 389; Roper and Dunn, 1971, 1973; Crawford and Medlin, 1973, p. 714, 719; 1974, p. 1–4; Medlin and Crawford, 1973, p. 99; Roper and Justus, 1973, p. 115).

In Georgia and Alabama rocks in the Brevard Zone are identifiable as belonging to several different thrust sheets in the Georgiabama thrust stack. Near Atlanta, Ga. (pls. 1, 2), the rocks in the Brevard are retrograded (locally graphitic) schists and phyllonites that are devoid of volcanogenic components and that belong to the Bill Arp thrust sheet. Just southwest of Atlanta, these rocks are structurally overlain by the Zebulon thrust sheet, and the shearing and retrogression typical of the zone have affected schists, amphibolites, and gneisses of the Zebulon Formation in the Zebulon thrust sheet. A short distance farther to the southwest, the Zebulon sheet in the Brevard Zone is structurally overlain by the Sandy Springs thrust sheet and locally by slices of the Paulding thrust sheet, so that the shearing and retrogression have affected rocks of the Sandy Springs Group and locally the Paulding Volcanic-Plutonic Complex. The shearing and retrogressive effects appear to stay within the Sandy Springs Group and the part of the Jacksons Gap Group (Bentley and Neathery, 1970) that belongs to the Sandy Springs thrust sheet all the way to the Coastal Plain overlap in Alabama (pl. 1). Northeast of Atlanta, the Brevard is mostly composed of rocks of the Bill Arp and Zebulon thrust sheets so closely folded together that we have not yet been able to divide them. Locally, rocks of the Sandy Springs sheet occur in the zone northeast of Atlanta.

The marbles in the Brevard Zone have most recently been considered to be Valley and Ridge carbonate-shelf-sequence rocks (Shady Dolomite or Knox Group rocks) brought to the level of the present surface by thrust faulting (Hatcher, 1971a; Hatcher and others, 1973; Hatcher, 1978a). Where we have seen these marbles they are always infolded with sequences of sheared pelitic rocks and sheared metagraywacke that lack amphibolites and appear to belong to the Bill Arp thrust sheet. We interpret the Brevard Zone metacarbonate rocks as representing the same depositional environments as the Murphy and Chewacla Marbles, though probably in a different Ocoee basin. Thus, the Brevard marbles may be roughly the same age as Valley and Ridge carbonate-shelf-sequence rocks, but they are probably not directly correlative with any of the carbonate-shelf-sequence units.

Our work has also demonstrated approximately 35 km of late right-lateral displacement along the Brevard Zone between Gainesville, Ga., and Suwanee, Ga. (pl. 1). Tightly folded stratigraphic sequences of Sandy Springs Group rocks in the Sandy Springs thrust sheet are present on both sides of the Brevard Zone in this stretch between Gainesville and Suwanee, as first suggested by Hurst (1973) and later shown by the detailed work of Kline (1980, 1981). Narrow, parallel, tight to isoclinal, northeast-trending anticlines and synclines, involving the distinctive Sandy Springs stratigraphic sequence, can be followed for many kilometers to the southwest; in the vicinity of Gainesville, they bend abruptly southeastward and terminate within (probably structurally above) a narrow outcrop belt of Bill Arp thrust sheet rocks that marks the center of the sheared and retrograded Brevard Zone there. Identical tight folds of the Sandy Springs Group on the southeast side of the Brevard trend southwest to the vicinity of Suwanee and then bend abruptly northwestward to terminate within the Brevard. The bending of the folds and the stratigraphic sequence on both sides of the Brevard Zone are interpreted to be the result of drag folding caused by right-lateral strike-slip faulting along an unseen fault or faults within the narrow zone. The measured displacement is approximately 35 km. Because the offset and drag affect the folds in the Sandy Springs thrust sheet, and because these folds probably formed after the Early Silurian (see above), strike-slip faulting is considered post-Early Silurian. The Carboniferous Ben Hill and Palmetto Granites near Atlanta, Ga., place further constraints on the age of the strike-slip faulting along the Brevard Zone in Georgia. Right-lateral faulting along the Brevard is suggested by the northeast-trending "tails" of the granites (pls. 1, 2), but no offset of stratigraphic sequences or other features has been found anywhere but in the stretch between Gainesville and Suwanee. The strike-slip faulting along the Brevard is probably post-Carboniferous and local.

There is also evidence of late normal faulting along part of the northwestern border of the Brevard Zone (W.A. White, 1950; Butler and Dunn, 1968; Roper and Dunn, 1971; Stonebraker and Harper, 1973; Roper and Justus, 1973), in which the southeastern side is downthrown relative to the northwestern side. Like the strike-slip faulting, this normal faulting is probably post-Carboniferous.

Our interpretation of the pre-Carboniferous Brevard in Georgia and Alabama is akin to the interpretation of Roper and Justus (1973), but with some modifications. We suggest that the Brevard is a complex polytectonic zone of extreme flattening, isoclinal to elasticas (Fleuty, 1964) folding, and shearing that formed continuously in parts of the thrust sheets beneath and in front of the advancing Clairmont and higher sheets in the Georgiabama thrust stack, and that the Brevard was transported cratonward along with the stack. It probably started forming far from its present position as the Clairmont thrust sheet moved onto the underlying Zebulon thrust sheet causing isoclinal folding and shearing of the Zebulon sheet and underlying Bill Arp sheet immediately in front of and beneath the leading edge of the Clairmont and the thick stack of sheets above the Clairmont. As the stack of moving thrust sheets continued to advance, rocks in the zone were continuously refolded, flattened, mylonitized, and remylonitized. Isoclinal folds were almost continuously being formed and then sheared out in different parts of the zone (Roper and Justus, 1973), but vestiges of the original stratigraphic sequences survived in many places, especially in upfolded parts of the Bill Arp sheet and in the Sandy Springs, Paulding, Ropes Creek, and Soapstone Ridge thrust sheets, which only became involved and infolded in the Brevard Zone after their leading edges had overridden the leading edge of the Atlanta and Promised Land sheets but while the greater parts of these sheets were still on top of and moving with the Promised Land and lower sheets (pl. 2).

Thus, the Brevard Zone is a kind of suture zone only in the sense that it is the frontal "suture" of the far-travelled, allochthogenetic Clairmont, Wahoo Creek, Atlanta, and Promised Land thrust sheets. It could also be considered a kind of very complicated tectonic melange formed in front of and beneath a thick stack of thrust sheets.

PLUTONISM

Granitic plutonic rocks underlie large areas in the crystalline terrane of Georgia and Alabama (pl. 1; not all are shown in pl. 1). At present, the number of radiometrically dated plutons is small, but available radiometric data coupled with geologic data indicate three major groups of granitic plutons (fig. 52): (1) Cambrian (and Early Ordovician?) plutons that have intruded consanguineous ocean-ridge, ocean-floor, and island-arc rocks and have been transported with these rocks in the Zebulon and higher thrust sheets; (2) Silurian-Devonian plutons that have intruded Bill Arp or Bill Arp and Zebulon thrust sheet rocks but have been overthrust by higher thrust sheets; and (3) Carboniferous plutons that have intruded all of the thrust sheets in the Georgiabama and Little River thrust stacks. The Cambrian plutons appear to have been the result of island-arc or ocean-ridge volcanism, whereas the younger plutons appear to have been derived through anatexis of lower thrust sheets (perhaps including Grenville basement in the Bill Arp thrust sheet), in the Georgiabama thrust stack, and of depleted oceanic lithosphere at the base of the Little River thrust stack. The heat necessary to achieve the melting was caused by the insulating effect of the overlying stack of thrust sheets (see Buck and Toksoz, 1983). Thus, granitic plutonism appears to have taken place when the pile of thrust sheets and stacks was thickest, from Silurian through Carboniferous time (pl. 2). Waldbaum (1971) and Wood and Spera (1984) have shown that adiabatic decompression can cause temperature rises in the crust, and Sinha and others (1985) suggested that such decompression may result from isostatic adjustment following loading by the thrust stacks. They (Sinha and others, 1985) suggested that granitic magmas are produced through anatectic melting caused by this decompression and that the melting takes place about 30 to 50 m.y. after the extreme stackup of thrust sheets. We

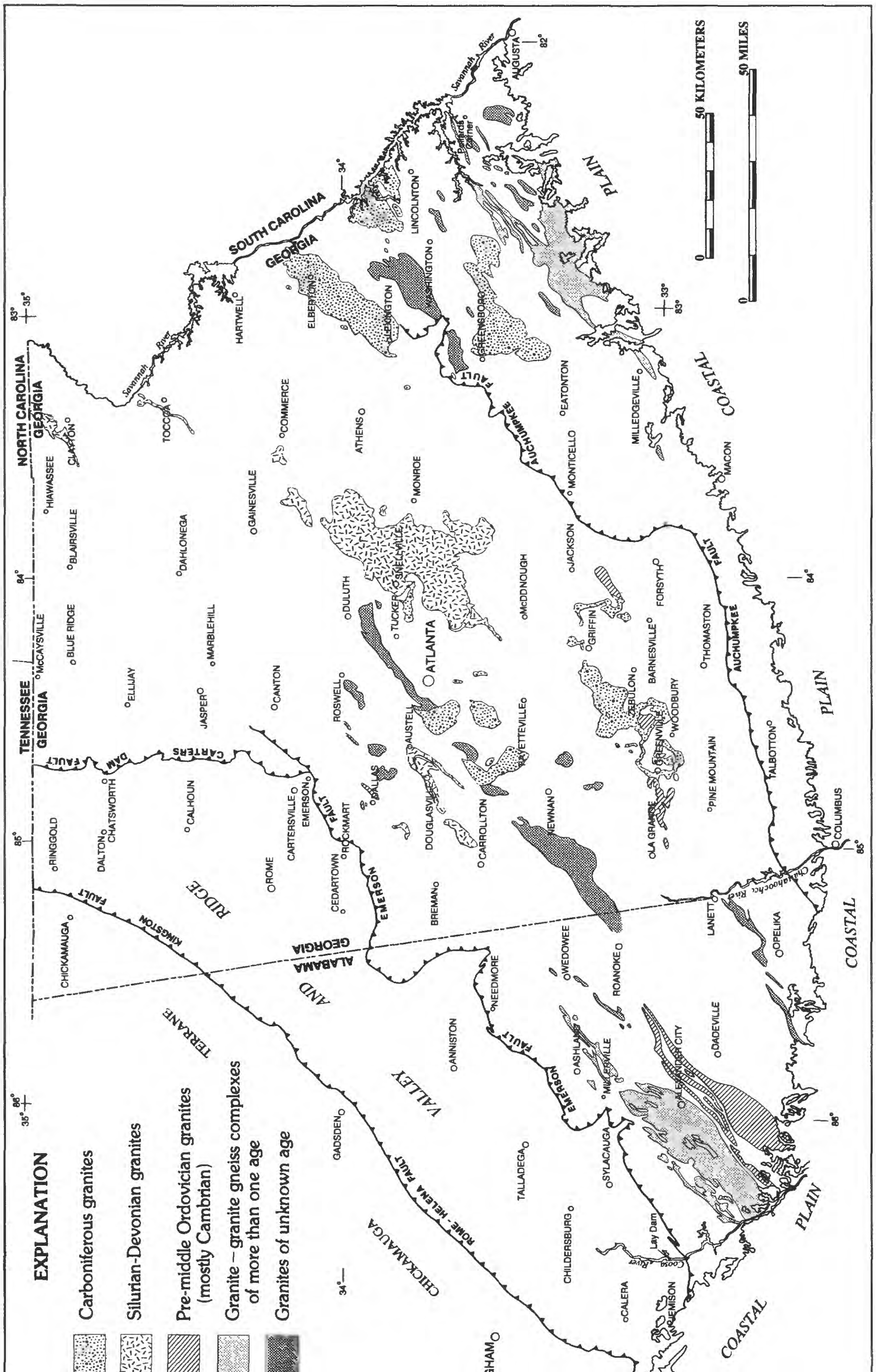


FIGURE 52.—Major groups of granitic plutons in the southernmost Appalachians. For greater detail, see plate 1.

believe that magma production is more continuous than periodic but that the stackup of thrust sheets and thrust stacks causes the plutonism, probably by a combination of their blanketing effects (Buck and Toksoz, 1983) and the effects of decompression (Waldbaum, 1971; Wood and Spera, 1984; Sinha and others, 1985); this mechanism also applies to the ~400-Ma mafic plutons in the Macon melange.

CAMBRIAN (AND ORDOVICIAN?) PLUTONS

The oldest group of deformed and metamorphosed pre-Carboniferous Paleozoic granitic plutons in the southern Appalachians are K-feldspar-poor granitic plutons that have intruded the Ropes Creek Metabasalt in the Ropes Creek thrust sheet and similar plutons that are part of the Paulding Volcanic-Plutonic Complex in the Paulding thrust sheet (pl. 1, fig. 52). Field relations indicate that these plutons have been transported with the thrust sheets and are locally truncated against the basal thrust faults. Therefore, their minimum age, on the basis of geologic relations and sparse geochronologic data, is Middle Ordovician, but their actual age is probably Cambrian. Some of the plutons, such as the Villa Rica Gneiss in western Georgia (Appendix A), are trondhjemitic (Pate, 1980; Sanders, 1983). Abrams and McConnell (1981) and McConnell and Abrams (1984) considered the Villa Rica Gneiss to be of volcanic origin and called it a "metadacite." However, the Villa Rica is mostly massive, and xenoliths of Ropes Creek Metabasalt are common in the gneiss indicating a plutonic origin, as recognized by Pate (1980). The mineralogic and chemical composition of the Villa Rica (Pate, 1980; Sanders, 1983) is similar to the composition of some of the thin felsic laminae in the Ropes Creek Metabasalt. The K-feldspar-poor plutons are considered essentially consanguineous with the metavolcanic rocks they have intruded, and most (including the Villa Rica Gneiss) are probably hypabyssal plutons.

SILURIAN-DEVONIAN PLUTONS

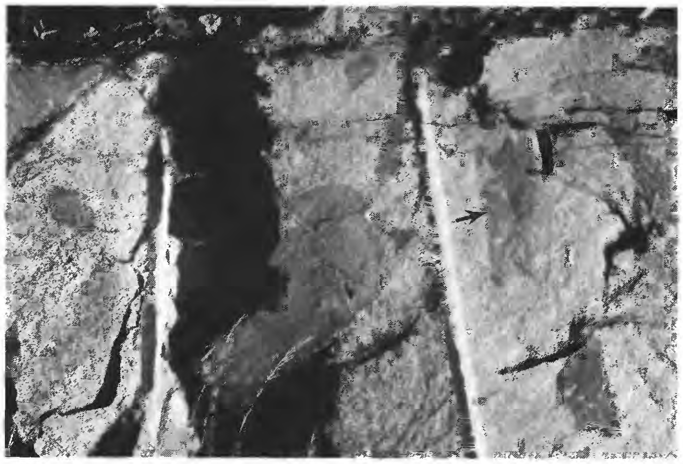
The Austell Gneiss (Appendix A) serves as an example of a second group of metamorphosed and deformed plutons. The northeastern "nose" of the Austell-Frolona anticlinorium (fig. 2*B*) is occupied by a coarsely porphyritic or blastoporphyritic biotite-oligoclase-quartz-microcline quartz monzonite gneiss (Coleman and others, 1973; Crawford and Medlin, 1974; Abrams and McConnell, 1981) that Hayes (1901) named the Austell Granite and Medlin and Crawford (1973) renamed the Austell Gneiss (the name Austell Gneiss is here adopted). The gneiss is at best only a semiconcordant intrusion whose original shape has been considerably modified, especially along its southeast side by thrusting on the Chattahoochee fault (Hurst, 1973)[12] and along parts of its northwest side by the Sandy Springs and Ropes Creek thrust faults. The Austell has intruded the Bill Arp Formation, of which it contains xenoliths (fig. 53), and is interpreted to have intruded the Zebulon Formation because coarse micas have grown across the foliation in Zebulon schists near their contact with the gneiss. The Austell Gneiss has been overthrust by the Sandy Springs and higher thrust sheets, which are also folded with the gneiss.

Our mapping shows abundant graded beds in the Bill Arp Formation in the northeastern part of the Austell-Frolona anticlinorium, which indicate clearly that it is an anticlinorium and that the axial trace of the anticlinorium is truncated at an angle by the Austell Gneiss (fig. 2). Nevertheless, despite the discordancy between the gneiss and the Bill Arp Formation, there are indications that the gneiss has been folded.

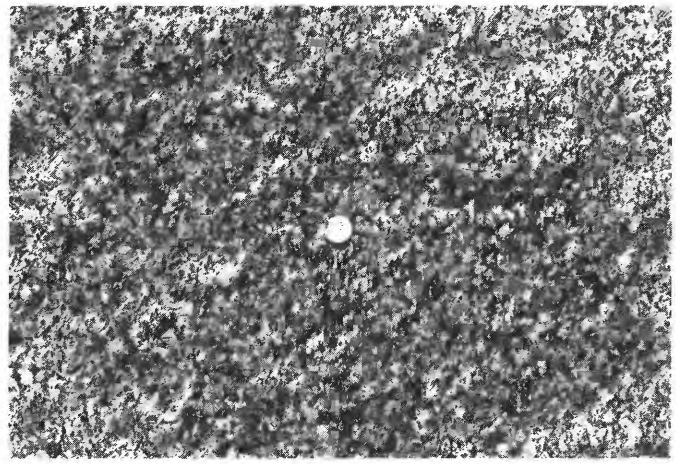
Medlin and Crawford (1973; Crawford and Medlin, 1974) mapped a narrow outcrop belt of schist (which they called the Union Grove schist) that forms a fold-like curved pattern within the Austell Gneiss. Abrams and McConnell (1981) recognized that this unit, which also contains metagraywacke, belongs to the Bill Arp Formation, but they mapped it as truncated by the Chattahoochee fault along the southeast side of the Austell-Frolona fold. Our mapping shows that this thin band of Bill Arp rocks is not truncated by the Chattahoochee fault but continues southwestward, dividing the Austell Gneiss, and connects with the main body of the Bill Arp in the anticlinorium, making it even more perplexing. This narrow belt of Bill Arp rocks is a puzzle in any structural interpretation of the Austell Gneiss; it must either be an infolded roof-pendant or a thin septum separating two intrusive masses of the Austell.

Structural features within the Austell Gneiss also indicate that it has been folded. As previous workers have noted, the gneiss has a weak to moderately well developed foliation formed by alignment of microcline phenocrysts and biotite that appears to conform with its crescent shape. Is this foliation the result of folding

[12]McConnell and Abrams (1984) and Abrams and McConnell (1984) gave the name "Blairs Bridge fault" to that part of Hurst's (1973) Chattahoochee fault lying southeast of the Austell Gneiss and the Austell-Frolona anticlinorium. Our mapping indicates that there is no fault at Blairs Bridge—Chattahoochee Palisades Quartzite on the northwest limb of a major isoclinal fold crosses Sweetwater Creek uninterrupted within a few tens of meters of Blairs Bridge. The Chattahoochee fault is a valid fault. We recommend abandonment of the name "Blairs Bridge fault."



A



B

C

FIGURE 53.—*A*, Xenoliths of Bill Arp Formation metagraywackes in Austell Gneiss. Arrow points to xenolith that has partially become a "ghost." Knife on largest xenolith is 8 cm long. Outcrop on north side of eastbound lanes of Interstate 20, 2 km west of Georgia Highway 5, in the Winston, Ga. 7.5-min quadrangle. *B*, Texture of Austell Gneiss a few meters away from xenoliths. Same outcrop as *A*. Coin is 1.9 cm in diameter. *C*, Protoclastic texture of Austell Gneiss developed at contact with large xenolith in same outcrop as *A*. Texture is interpreted to result from "freezing" of the moving Austell magma as it came into contact with the cooler xenolith. Coin is 1.9 cm in diameter.

under metamorphic conditions, or is it an igneous flow-foliation formed during intrusion of the gneiss? Our study indicates that it is a combination of the two; the Austell Gneiss was probably intruded after the Austell-Frolona fold had begun to grow, but before its formation was complete, thereby explaining the discordance between the gneiss and the Bill Arp Formation. The Sandy Springs and higher thrust sheets in the Georgiabama stack were then thrust upon the Austell Gneiss and the Bill Arp and Zebulon thrust sheets and subsequently folded with the gneiss and these thrust sheets as the anticlinorium continued to grow. We suggest that the Austell obtained its foliation partly as a result of igneous flowage as it was emplaced semiconcordantly into the Austell-Frolona anticlinorium, molding itself around the growing fold, and partly as a result of being folded under metamorphic conditions as the anticlinorium continued forming. Its lunate shape is the result not of refolding but of being overthrust and folded with the sheets below and above it and further modified by faulting along its southeast side.

CARBONIFEROUS PLUTONS

The youngest group of granitic plutons in the southernmost Appalachians are Carboniferous-Permian (on the basis of radiometric age dates), with age dates ranging from about 350 Ma to about 260 Ma (Fullagar and Butler, 1979; Sinha and Zietz, 1982, and references therein) but clustering around 300 to 320 Ma (more likely the crystallization age of most of the plutons). Those that have intruded the Little River thrust stack generally have initial $^{87}Sr/^{86}Sr$ ratios less than 0.705 and $\delta^{18}O$ ratios less than 7.5, whereas those that have intruded the Georgiabama thrust stack have $^{87}Sr/^{86}Sr$ ratios greater than 0.706 and $\delta^{18}O$ ratios greater than 7.5 (Sinha and Zietz, 1982, and references therein). Some of the Carboniferous plutons that have intruded the Georgiabama thrust stack appear from field evidence to be relatively thin, shallow-bottomed bodies that were emplaced during folding (for example, Grant and others, 1980). In contrast, many of the Carboniferous granite plutons that have intruded the Little River allochthon appear to be stock-like bodies (for example, Vincent, 1984) that may extend to relatively great depths. We interpret the Carboniferous plutons that have intruded the Georgiabama thrust stack to have been derived through anatexis of supracrustal rocks in the stack, and the Carboniferous plutons that have intruded the Little River thrust stack to have been derived through partial melting of depleted, metamorphosed Iapetus Ocean crust and mantle trapped beneath the Little River stack and welded to its base. Some plutons near the thrust boundary between the Georgiabama and Little River thrust stacks, such as the Elberton Granite in eastern Georgia (Whitney and Hess, 1980; Wenner, 1980; Whitney and Stormer, 1980), appear to be gradational between the two groups.

EVOLUTION OF THE SOUTHERNMOST APPALACHIANS

The stacking order of the thrust sheets in the southernmost Appalachians (fig. 1), combined with paleogeographic (paleotectonic) interpretations and facies interpretations (tables 1, 3–5; pl. 2), indicates that the farthest travelled thrust sheets and slices are on top and the least travelled sheets and slices are on the bottom and that the stacking took place from oceanward toward the North American craton. In the interpretive reconstructions it is assumed that (1) thick accumulations of island-arc-related volcanic rocks require the existence of a subduction zone, regardless of the polarity of that zone, and (2) the reverse is also true, the existence of a subduction zone causes plutonism and volcanism in the overriding plate.

PHASE I: OPENING OF THE IAPETUS OCEAN

The earliest record in the southern Appalachians of the opening of the Iapetus Ocean is the thick pile (about 3,000 m) of metamorphosed interbedded and interfingering basaltic and rhyolitic, peralkaline volcanic and immature clastic sedimentary rocks of the Mount Rogers Formation, which nonconformably overlie Grenville basement around the common corner of Virginia, North Carolina, and Tennessee (Rankin, 1975), the correlative but thicker (3,000–9,000 m) Grandfather Mountain Formation, exposed only in the Grandfather Mountain window about 50 km to the south in North Carolina (Bryant and Reed, 1970; Rankin, 1970, 1975, 1976), and the igneous rocks associated with massive sulfide deposits in the lowermost part of the Great Smoky Group in northern Georgia and in the Copperhill and Ducktown areas, Tennessee (Hurst, 1955; Slater, 1982; Slater and others, 1985; Abrams, 1985). There is evidence that the Mount Rogers and Grandfather Mountain sequences were erupted and deposited mostly subaerially (Bryant and Reed, 1970; Rankin, 1970), and probably resulted from rifting associated with the beginning phases of the opening of the Iapetus Ocean (Rankin, 1975, 1976; Rodgers, 1982). We suggest that the metavolcanic, metavolcaniclastic, metavolcanic-epiclastic, and hypabyssal intrusive rocks of the Ducktown assemblage (this paper) also resulted from rifting associated with opening of the Iapetus Ocean (also see Slater and others, 1985). Correlative rocks elsewhere in the southern Appalachians may be covered by the crystalline thrust sheets.

The age of the metavolcanic rocks of the Mount Rogers and Grandfather Mountain Formations has been the subject of some dispute (Rankin and others, 1969; Odom and Fullagar, 1971, 1973). Odom and Fullagar's (1984) recent more detailed study of the Crossnore plutons, which are interpreted to be consanguineous with the Mount Rodgers and Grandfather Mountain metavolcanic rocks, indicates that the plutons crystallized about 690±10 Ma and that zircon samples from the plutons, which had given discordant ages that suggested an age as old as 820 Ma based on a concordia plot (Rankin and others, 1969), contain an inherited xenocrystic component that resulted in the older age. Thus it seems safe to say that the Iapetus Ocean was opening by about 700 Ma and that by that time the oceanward edge of the North American continent was a trailing edge; spreading was probably taking place along a mid-Iapetus ridge, and the absence of preserved island-arc-related volcanic rocks of this age in the southernmost Appalachians suggests a lack of arcs or subduction zones in the Iapetus Ocean near North America (pl. 2*A*).

After eruption and deposition of the Mount Rogers and Grandfather Mountain Formations and the Ducktown assemblage, continued rifting at the continental edge produced a series of stepped fault-bounded depositional basins (called Ocoee basins) along the North American side of the Iapetus Ocean that were filled first by turbiditic flysch deposits in enormous coalescing fans. The sedimentary sequences in these basins record the same general depositional environments throughout, even though the preserved "units" may not be directly "correlative" in age or in continuity. Presumably the basins nearest the opening ocean formed and filled first, but we don't know how many Ocoee basins lie buried beneath the thrust stacks.

Generally considered one of the largest and deepest of the basins was the "Ocoee basin" (King and others, 1958), filled with as much as 12 km of poorly sorted, mostly turbiditic, clastic metasedimentary rocks of the upper Precambrian Ocoee Supergroup (Hurst, 1955; King and others, 1958; Hadley, 1970; Rodgers, 1972; Rankin, 1975). However, even this sequence of rocks appears to have been deposited in more than one basin (also see Bolton, 1985). In North Carolina and Tennessee, King and others (1958, 1968) divided the Ocoee Supergroup rocks into two separate sequences, one north of and below the Greenbriar fault and another south of and above the fault. These two sequences were probably deposited in separate but approximately coeval basins. The lack of volcanogenic material in all but the lowermost parts of this thick pile of metasedimentary rocks (and probably only around the basin-edge rift systems) suggests that at least the North American side of the growing Iapetus Ocean lacked volcanic island arcs and accompanying subduction zones during the time of Ocoee sedimentation (pl. 2*A*).

The oldest sedimentary rocks in the Valley and Ridge basin, belonging to the Chilhowee Group, are beach-barrier-island deposits derived from the craton (Brown, 1970; Whisonant, 1970, 1974; Mack, 1980). In Georgia and Alabama, the Chilhowee Group is without volcanogenic components, but in northeastern Tennessee and southwestern Virginia amygdaloidal basalt flows are present in the lower part (Unicoi Formation) of the group (Rodgers, 1953; Stose and Stose, 1957; Dietrich, 1959; King and Ferguson, 1960; Rankin, 1975, 1976). The fact that these basalts are amygdaloidal flows (Rankin, 1976, p. 5612) and are interbedded with coarse clastic sedimentary rocks (King and Ferguson, 1960) suggests that they are genetically related to extension associated with continued opening of the Iapetus Ocean.

By Early Cambrian time, the waters of the Iapetus Ocean had begun to encroach upon the North American craton, and by Late Cambrian time much of the craton was covered by a warm shallow sea (see Rodgers, 1968, 1982). Clastic sedimentation had largely ceased by the Middle Cambrian because the cratonic source area had been eroded down or (and) covered by the sea, and the Cambrian-Ordovician carbonate shelf sequence, consisting of about 1,500 to 2,900 m of shallow-water carbonate rocks (Rodgers, 1968, and references therein; Cressler, 1970; Thomas and Neathery, 1980; Read, 1985a,b), was deposited upon the slowly subsiding North American continental margin (pl. 2*B*).

With the exception of a few thin "bentonite" beds in the Middle Ordovician part of the sequence (Butts, 1926; Butts and Gildersleeve, 1948; Allen and Lester, 1957; Cressler, 1970; Smith and others, 1971; Chowns and Carter, 1983), which are generally regarded as derived from volcanic ash, the Cambrian-Ordovician carbonate shelf sequence is without volcanogenic components.

Thus it appears that from the time of eruption of the Mount Rogers and Grandfather Mountain Formations, at least 700 Ma (and more likely earlier), through the Early Ordovician, the eastern margin of the North American continent was too far from any volcanic source to receive volcanogenic material.

PHASE II: CLOSING OF THE IAPETUS OCEAN—THE IAPETAN OROGENY

Closing of the Iapetus Ocean must have begun with the establishment of one or more subduction zones (pl. 2*C*). One of these paleosubduction zones must have been located beneath the thick sequences of island-arc metavolcanic rocks preserved in the Little River allochthon; its subduction melange is preserved as the Macon melange. All available evidence suggests that the Little River volcanic arc formed at the edge of a continental mass, and the presence of Atlantic-realm trilobites in some of its rocks (Secor and others, 1983) indicates that the continent was not North America; for the purposes of this paper we refer to it as "Africa," even though it may not have been the continental mass of present Africa. The age of the rocks preserved in the Little River allochthon probably spans from very latest Precambrian (latest Proterozoic, Ediacaran) through Middle Cambrian, indicating that at least by about 600 Ma (depending on whether the lower parts of the arc volcanics are preserved) the arc and subduction zone were active.

Island-arc volcanism and subduction in the Iapetus Ocean are also recorded by the metavolcanic rocks preserved in the Wahoo Creek, Atlanta, and Promised Land thrust sheets, and to a lesser extent by the rocks in the Sandy Springs thrust sheet. We call this island arc the Promised Land arc. The Clairmont melange is interpreted to be the preserved remnants of the subduction melange associated with Promised Land arc volcanism. Zircons with radiometric ages older than a billion years (1 Ga) in Chattahoochee Palisades Quartzite of the Sandy Springs Group (T.W. Stern, oral commun., 1984) indicate that the Promised Land arc was built on old Grenville-age continental crust in a Sandy Springs microcontinent.

A third island arc, the Paulding arc, is represented by the Paulding Volcanic-Plutonic Complex in the Paulding thrust sheet. The abundance of felsic volcanic and volcaniclastic rocks and the presence of K-feldspar-poor plutonic rocks in the Paulding sequences suggest island-arc volcanism, as does the geochemical character of the rocks in the Paulding thrust sheet (Tull and others, 1978; Tull and Stow, 1980a,b; Stow, 1982; Stow and others, 1984; Appendix B). Lack of nonvolcanogenic metasedimentary rocks in this complex suggests that the Paulding was an oceanic arc. The subduction zone probably dipped away from the North American continent (pl. 2). The eclogite-bearing West Point melange is interpreted to be the preserved remnants of the subduction melange associated with Paulding arc volcanism. Sparse chronologic data suggest that most of the metavolcanic rocks in the Paulding thrust sheet are probably older than about Middle Ordovician (Russell and others, 1984) and hence are about the same age as much of the metavolcanic sequence in the Little River allochthon.

Establishment of subduction zones beneath the Little River, Promised Land, and Paulding island arcs marked the beginning of the end of the Iapetus Ocean, even though the effects of plate collision would not be recorded in rocks associated with the continental margin of North America for many millions of years. Opening of the Iapetus Ocean probably began about 700 Ma (the Rb-Sr age of plutons considered consanguineous with the metavolcanic rocks in the Mount Rogers and Grandfather Mountain Formations) and lasted until subduction zones were established beneath the Paulding and Little River arcs during the latest Precambrian, perhaps roughly 600 Ma. The suggestion is that opening of the ocean took at least 100 m.y. Assuming a reasonable average spreading rate along the mid-Iapetus ridge (both sides) of 5 cm/year (Windley, 1976, p. 233; the TiO_2 contents of Ropes Creek Metabasalt suggest at least this rate of spreading) gives a minimum width of 5,000 km for the ocean at the time of its greatest width, just before the subduction zones were established. If the basalts within the Unicoi Formation originated through rifting associated with continued opening of the Iapetus Ocean (as they probably did), or if the average spreading rate along the mid-Iapetus ridge was greater than 5 cm/year, then the width of the Iapetus Ocean may have been far greater than 10,000 km.

Location of the Little River arc seems relatively well fixed. All available data indicate that this arc was located at the oceanward edge of the "African" continent and that the subduction zone beneath its Macon subduction melange dipped toward that continent (pl. 2*B*, *C*). However, there is little firm evidence to indicate either the paleolocation of the Paulding arc or the polarity of its subduction zone. Nevertheless, the stacking order within the Georgiabama thrust stack places some limitations on reconstructions of the paleogeography. If the ultramafic and mafic assemblages of the Soapstone Ridge thrust sheet are altered fragments of Iapetus Ocean crust and mantle (disrupted ophiolite), as all of the evidence indicates, and if their structural position, always at the top of the Georgiabama thrust stack, indicates that they are the most oceanward rocks preserved in the stack, as all of the evidence suggests, then they must have originally resided oceanward from the underlying Ropes Creek, West Point, Paulding, Sandy Springs, Promised Land, Atlanta, Wahoo Creek, and Clairmont thrust sheet rocks. Abundant evidence indicates that the rocks in the Ropes Creek thrust sheet are Iapetus Ocean crust, and its place structurally beneath the Soapstone Ridge sheet indicates that it also resided oceanward from the underlying thrust sheets. The Paulding island arc must therefore have been located toward the North American continent from the Ropes Creek Metabasalt. The position of the ophiolitic, eclogite-bearing West Point subduction melange structurally beneath the Ropes Creek thrust sheet and above the Paulding thrust sheet indicates that the subduction zone associated with the Paulding arc dipped toward the North American continent (pl. 2*B*, *D*). The lack of nonvolcanogenic metasedimentary rocks in the Paulding thrust sheet suggests that the Paulding arc was an oceanic arc rather than being associated with the edge of the North American continent or some microcontinent.

The presence of the Sandy Springs thrust sheet beneath the Paulding thrust sheet indicates that its rocks resided continentward from the Paulding island arc (pl. 2*B*, *D*). Grenville-age detrital zircons in the Chattahoochee Palisades Quartzite of the Sandy Springs Group indicate that Grenville-age basement contributed to the sedimentary protoliths of the Sandy Springs rocks. This suggests that they formed in a different arc from the oceanic Paulding arc. However, thin amphibolites in the Sandy Springs units are probably metabasaltic tuffs, indicating volcanic input into the sedimentary protoliths. Moreover, the Sandy Springs thrust sheet is underlain by the totally igneous (mostly volcanic) Promised Land thrust sheet, which has characteristics of an island-arc assemblage. The Promised Land is structurally underlain by sequences interpreted to be outer-arc basin deposits in the Atlanta thrust sheet, which are in turn underlain by what appear to be altered volcaniclastic deposits and granitic rocks in the Wahoo Creek thrust sheet. The Wahoo Creek is structurally underlain by the Clairmont melange. The most reasonable paleogeographic reconstruction is that the Paulding arc was located separate from the sequences in the underlying thrust sheets and that rocks in these underlying sheets formed in a different arc, the Promised Land island arc, built upon Grenville-age continental crust (Sandy Springs microcontinent) that was rifted away from the North American continent when the Iapetus Ocean opened (pl. 2*A*, *D*). We interpret the Clairmont melange as the remnant of the subduction melange associated with the subduction zone that caused the arc volcanism in the Promised Land arc, and because of its structural position beneath the outer arc basin and island arc rocks of the Wahoo Creek, Atlanta, and Promised Land sheets, we suggest that this subduction zone dipped away from the North American continent.

The lack of volcanogenic rocks younger than Middle Cambrian in the Little River allochthon suggests that subduction under the Little River arc had ceased by Late Cambrian time. We offer the speculation that the Little River arc and Macon melange, at the oceanward edge of the "African" continent, overrode the mid-Iapetus ridge during the Late Cambrian (pl. 2*D*), thereby stopping subduction under the arc, just as the collision of the North American plate with the East Pacific Rise has stopped subduction along part of the west coast of North America. This would have had the net effect of speeding up movement of the Little River arc toward the North American continent and would also have speeded up subduction under the Paulding arc until oceanic crust could no longer be consumed fast enough, so it buckled and broke.

We suggest that collision began with obduction of Soapstone Ridge oceanic crust and mantle onto Ropes Creek oceanic crust (pl. 2*D*), and obduction of the Ropes Creek Metabasalt onto the West Point melange and Paulding island arc rocks (pl. 2*E*). This would have stopped subduction under the Paulding arc and also would have terminated volcanism and plutonism in the arc. Unfortunately, the upper age of the metavolcanic rocks in the Paulding thrust sheet is unknown, but discordant dates of zircons from felsic rocks within the Paulding part of the Hillabee greenstone (discussed above) indicate that these rocks could be as young as Ordovician. Continued assembly of thrust sheets involved rocks of the Promised Land arc, where subduction probably ceased when the Clairmont melange and the arc overrode the spreading center (pl. 2*C*). These Promised Land arc rocks were then thrust upon Zebulon ocean floor deposits (pl. 2*F*). At any rate, we suggest that the ocean-to-continentward (top to bottom) assembly of the Georgiabama thrust stack was nearly complete by the Middle Ordovician. As the Clairmont thrust sheet and the overlying stack moved onto the Zebulon sheet, and it in turn onto the Bill Arp thrust sheet, the earliest response was buckling up of the carbonate shelf at the oceanward edge of the North American craton, causing erosion that resulted in the unconformities at the top of the Upper Cambrian–Lower Ordovician Knox Group, and later above the Middle Ordovician Lenoir Limestone—the shelf was literally bobbing up and down in response to the arriving thrust sheets (pl. 2*F*). With continued movement, the cratonward edge of the Bill Arp sheet was thrust up along with part of the carbonate shelf above it and oceanward equivalents of part of the lower part of the Rockmart Slate below it, to cause a landmass that separated the Rockmart-Athens-Talladega basin from what was left of the Iapetus Ocean (pl. 2*G*). Dark, calcareous, graptolitic pelites were first deposited in this basin. Erosion of carbonate shelf sequence and Bill Arp thrust sheet rocks supplied clastic material to the basin in the form of a clastic wedge (Tellico-Talladega clastic wedge), and continued movement locally at least pushed parts of the dark pelite sequences (Rockmart, Athens, Talladega) up the paleoslope onto the unconformity at the top of the carbonate shelf, folding and mildly metamorphosing the pelites in the process. Continued movement and erosion of the thrust-up Bill Arp sheet rocks caused deposition and cratonward transgression (the source was also moving toward the craton) of a molasse-like clastic wedge composed of the Greensport, Colvin Mountain, and Sequatchee Formations (pl. 2*H*, *I*), and atop these the Silurian Red Mountain Formation (pl. 2*J*). Further cratonward movement of the Clairmont melange and higher thrust sheets in the Georgiabama thrust stack probably loaded the underlying Zebulon and Bill Arp sheets and thereby the oceanward edge of what was left of the carbonate shelf, allowing deposition of the thin Lower and Middle Devonian Armuchee Chert–Frog Mountain Sandstone (including the equivalent Jemison Chert) sequence (pl. 2*K*). By the late Middle Devonian or Late Devonian, the Paulding, West Point, and Ropes Creek thrust sheets had locally transgressed far enough towards the craton to be emplaced upon the Lower and Middle Devonian craton-related Jemison Chert (pl. 2*L*). Cratonward movement of the Georgiabama thrust stack continued, and collision finally shoved the remnants of the Macon subduction melange wedge, the Little River island arc (preserved in the Little River allochthon), and African craton deposits (preserved as the Northern Florida platform sequence now beneath the Coastal Plain in southern Georgia and northern Florida) onto the top of the Georgiabama thrust stack (pl. 2*M*). Oceanic crust and mantle entrapped beneath the Macon melange and Little River allochthon is probably the cause of the major gravity gradient that crosses Georgia and Alabama (American Geophysical Union, 1964; Long and others, 1972). Partial melting of the entrapped oceanic material (by now welded onto the bottom of the thrust stack and metamorphosed and depleted) probably accounts for low initial $^{87}Sr/^{86}Sr$ ratios and low $\delta^{18}O$ ratios (Sinha and Zietz, 1982, and references therein) of Carboniferous granitic rocks that have intruded the Macon melange and Little River allochthon. Such granites appear to be confined to the outcrop area of the Macon melange and Little River allochthon. Final cratonward movement of the whole assembled set of thrust stacks took place along the Emerson, Carters Dam, Rome and Helena, Clinchport, and Kingston faults during the late Carboniferous (pl. 2*N*) and Permian(?).

COMPARISON WITH THE NORTHERN APPALACHIANS

There are obvious similarities between the stacking order and sequence of events depicted above for the southernmost part of the Appalachian orogen and the stacking order and sequence of events in the northern Appalachians, but there are also significant differences, especially in the size and travel distances of the thrust sheets and in the timing of events. In the northern Appalachians (Bird and Dewey, 1970; Williams and others, 1972; St-Julien and Hubert, 1975; Williams, 1975, 1979; Rowley and Kidd, 1981), the major transported terranes are on the order of 50 km wide, some of the ophiolites are complete ophiolite suites (Upadhyay and others, 1971; Williams and Smyth, 1973) with basal metamorphic aureoles interpreted to be the result of obduction and initial transport of hot oceanic crust and mantle (Williams and Smyth, 1973), the ophiolites are at the top of the structural stack and have "transgressed locally farthest west to lie upon autochthonous rocks" (Williams, 1975, p. 1876), and they are the farthest travelled slices with minimum transport distances of 80 to 105 km (Williams and Smyth, 1973). Many of the thrust slices (sheets) in the stack are separated by melanges that have sedimented detritus from higher slices, including detritus from the ophiolite slices (Stevens, 1970; Stevens and Williams, 1973; Williams and Smyth, 1973). In addition, the time of original displacement of the ophiolite slices in the Canadian Appalachians is dated as Early Ordovician by the age of their metamorphic aureoles and by the presence of ophiolite detritus in underlying slices of Lower Ordovician clastic sedimentary rocks, and their time of final emplacement is well dated as Middle Ordovician by overlying neoautochthonous, fossiliferous Middle Ordovician sedimentary rocks (Bergström and others, 1974). Accretion of the thrust stack apparently occurred slightly later in New England than in Canada (Bird and Dewey, 1970). Throughout much of the northern Appalachians there is a relatively wide "foreland" at the western edge of the orogen where autochthonous and parautochthonous Middle Ordovician metasedimentary rocks are overlain by stacked sequences of allochthonous metasedimentary rocks of about the same age (Zen, 1967; Stevens, 1970; St-Julien and Hubert, 1975; Rowley and Kidd, 1981).

In the southernmost Appalachians, most individual thrust sheets appear to have been at least 160 km wide, the ophiolites are altered, dismembered, and generally incomplete, and as far as we know they lack basal metamorphic aureoles. In the southernmost Appalachians, ophiolite occurs in three ways: (1) as sheets (Soapstone Ridge and Ropes Creek thrust sheets) that were obducted and thrust cratonward at the top of an enormous (Georgiabama) thrust stack; (2) as debris shed from the ophiolitic thrust sheets and deposited in protoliths of underlying thrust sheets in the stack during assembly of the stack; and (3) as clasts of all sizes incorporated into subduction melanges (Clairmont, West Point, and Macon melanges). As in the northern Appalachians, the obducted ophiolite sheets are the farthest travelled (excluding rocks in the Little River thrust stack) and have transgressed farthest toward the craton; minimum transport distances must exceed 160 km and are probably more on the order of thousands of kilometers. In contrast to the northern Appalachians, many of the thrust sheets in the Georgiabama thrust stack are separated not by melange but by what appear to have been "hard" thrusts; major melanges appear to separate sequences of thrust sheets whose rocks formed in different tectonic settings such as different island arcs, and most of these melanges have characteristics indicating that they are the preserved remnants of subduction melange complexes. The time of original displacement of the obducted ophiolite sheets in the southernmost Appalachians is not as well known as it is in the northern Appalachians but was probably Late Cambrian–Early Ordovician, whereas the time of final emplacement of these sheets (excluding transport of the whole stack along late Paleozoic thrust faults) and underlying subduction melange (West Point) and island-arc rocks (Paulding) was clearly post-early Middle Devonian because they rest in thrust contact upon fossiliferous Lower and Middle Devonian Valley and Ridge province cherts. Also in contrast to the northern Appalachians, much of the "foreland" in the southernmost Appalachians has been covered by the thrust stack being transported along late Paleozoic thrust faults, so that only the thin cratonward edges of Middle Ordovician dark graptolitic pelites are found resting upon carbonate-shelf rocks.

In the southernmost Appalachians, the Macon melange, a large subduction melange similar in size to the Franciscan melange complex in California, is preserved beneath the bimodal, calc-alkaline "African" continental-margin Little River arc in the Little River allochthon. The metasedimentary and metavolcanic rocks of the "Avalon terrane" in the northern

Appalachians may be older equivalents of the Little River allochthon rocks, but less of them is preserved compared with Little River allochthon rocks in the southernmost Appalachians (Williams, 1975; Zen, 1983). Subduction melange, probably older than the Macon melange, is also present in the northern Appalachians, but again, a much thinner outcrop belt is preserved than in the southernmost Appalachians, possibly because much of it in the northern Appalachians was overridden (Zen, 1983, and references therein).

We suggest that many of the geologic differences between the northern and southernmost Appalachians, and the apparently diachronous sequence of thrusting, deformation, and metamorphism (orogeny), may result from the original configuration of the Iapetus Ocean. Bird and Dewey (1970, p. 1049) suggested that the diachronous sequence of deformation between Newfoundland and New England might be explained if "the rate of development of igneous, metamorphic, and structural events ... was in some way proportionally related to the rate of underthrusting. The rate of underthrusting of a spherical shell will increase away from its rotation pole. If New England were nearer the rotation pole for the contracting Appalachian-Atlantic plate than Newfoundland, the Humberian sequence might be expected to have propagated continentward more rapidly than the Taconian sequence in New England." We suggest a simplistic model in which the Iapetus Ocean, at the time of beginning of closure, was much narrower at the paleolatitude of Newfoundland than at the paleolatitude of the southernmost Appalachians, so that it closed like a door hinged at the north (present direction), with the effects migrating continuously along the continental margin like a triple junction, causing diachronous orogenic deformation that was progressively older and more telescoped to the northeast and progressively younger, longer lasting, and broader in the southwestern parts of the orogen. Thus the oceanic material was farther from its place of origin (mid-Iapetus ridge) and hence was cold when it was obducted in the southernmost Appalachians, thereby accounting for the lack of metamorphic aureoles beneath it. The oceanic material was probably older in the southernmost Appalachians than in the northern Appalachians, but there is, as yet, no evidence of this. The wider part of the ocean would have taken longer to close (slower continentward propagation), and sheets of greater width would have been pushed farther up the paleoslope. Moreover, volcanism associated with subduction would have lasted longer in the southwest than in the northeast, perhaps accounting for southwestward-younging sequences in the "Carolina slate belt" (Samson and others, 1982; Kish and Black, 1982; D.T. Secor, Jr., oral commun., 1982).

In contrast with the drastically telescoped northern Appalachians (Williams, 1979), the southernmost Appalachians (including rocks now beneath the Coastal Plain) contain preserved accreted remnants of sequences of rocks that spanned the Iapetus Ocean from North American craton to African craton, including remnants of clastic sequences formed during the opening rifting phases of the ocean, remnants of island-arc assemblages from both sides of the ocean, remnants of subduction-melange complexes from both sides of the ocean, and ophiolites from both sides of the mid-Iapetus ridge.

COMPARISON WITH THE INDONESIAN REGION

The Indonesian region, which includes most of the southwestern part of the Pacific Ocean and the southernmost part of the Asian continent, is a complicated collage of small plates, each having a different motion and each interacting in a different way with other small plates and (or) with major plates; transcurrent movement between plates is relatively common (Hamilton, 1979, and references therein). One can readily deduce, as Hamilton (1979, p. 307–308) did, that continued movement of the major plates will probably result in the smaller plates (such as island arcs and microcontinents) being "squashed between Australia and Asia." If transcurrent movement is relatively common, why then do we not find evidence of major transcurrent movements in the southernmost Appalachians? The answer is probably a matter of scale. Figure 54 shows the southern Appalachians at the same scale as the Indonesian region; the southern part of the Appalachian orogen (in fact the whole Appalachian orogen) is tiny when viewed with the perspective of the Indonesian region. The whole of the southern Appalachian crystalline terrane could be fitted into the island of Sumatra or Java, and the largest melange known in the Appalachians, the Macon melange, is dwarfed by both active and fossil melanges in the Indonesian region. The along-strike continuity of the Macon melange may seem incredible to many Appalachian geologists, but a melange of this size is small by Indonesian standards. The absence of evidence of major transcurrent movement in the southernmost Appalachians (also see Irving and Strong, 1984) can be explained if this part of the orogen was more like Sumatra and Java than, for example, like New Guinea or Sulawesi (Hamilton, 1979, pl. 1). Nevertheless, the southernmost Appalachians do contain remnants of melange complexes and island arcs (such as the West Point melange and Paulding Volcanic-Plutonic Com-

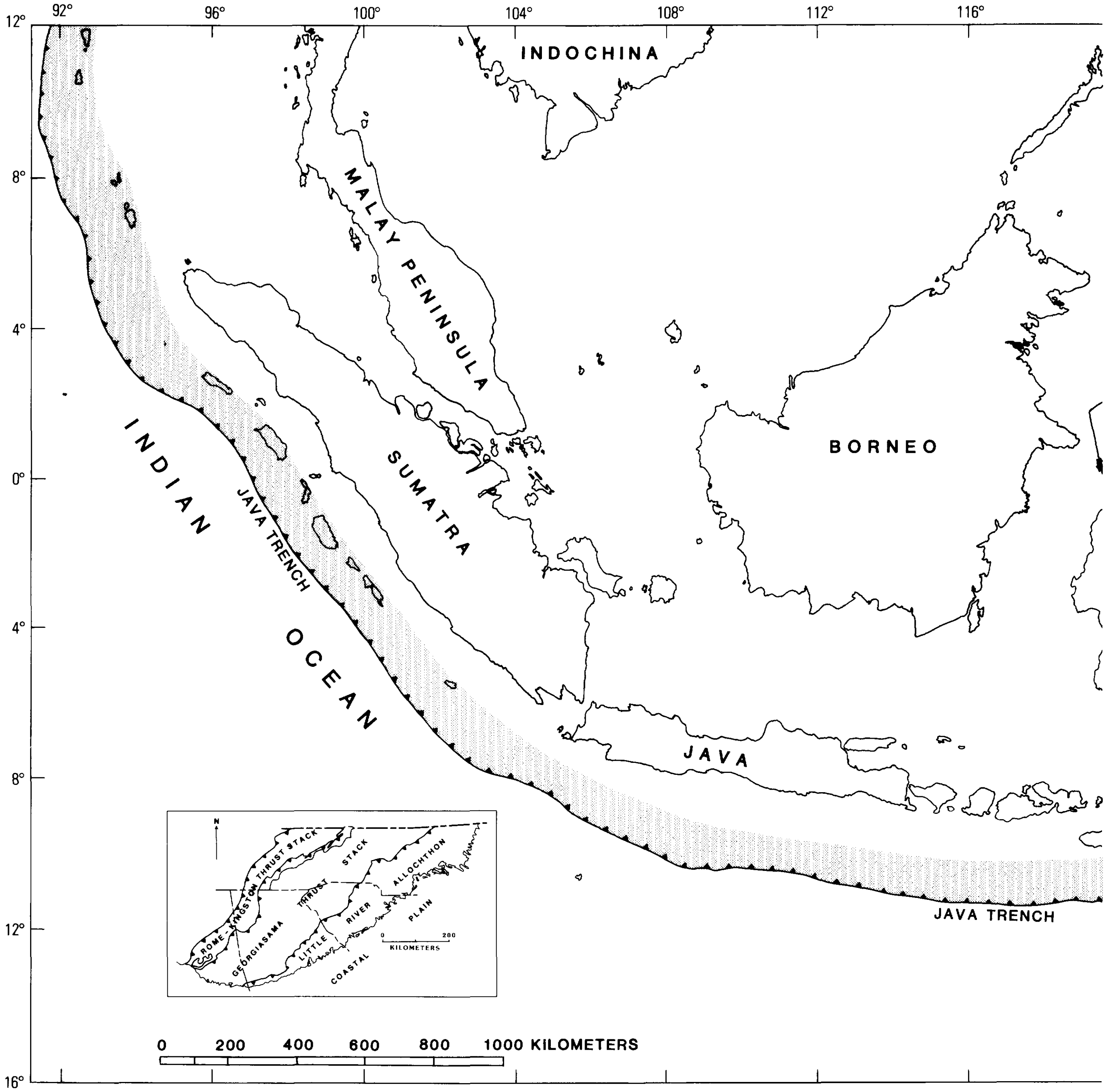
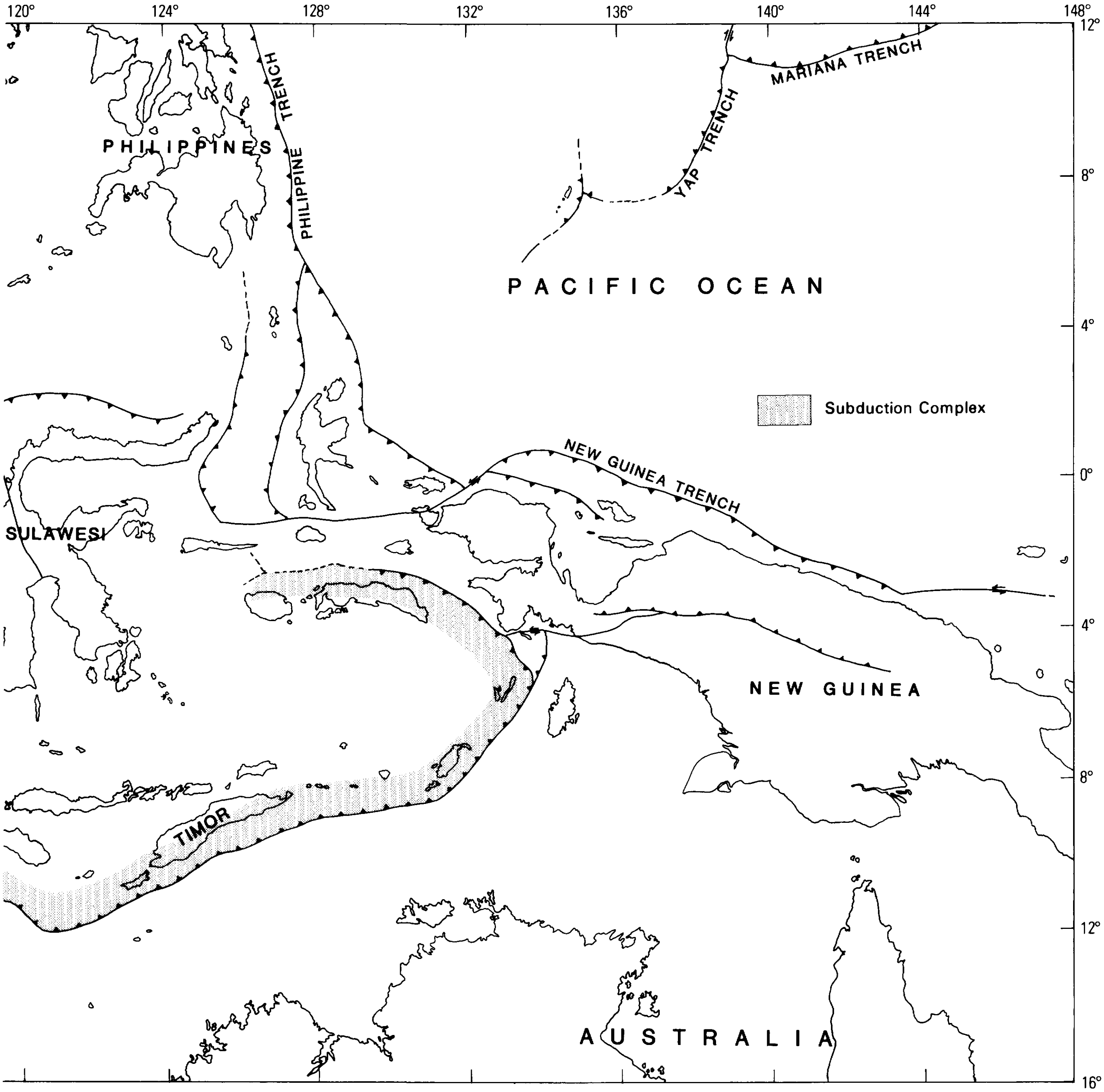


FIGURE 54.—Map showing the Indonesian region and the Appalachian orogen



(Alabama, Georgia, South Carolina, North Carolina, Tennessee) at the same scale.

plex) that are probably not present in the central and northern Appalachians, and the central and northern Appalachians probably contain remnants of melange complexes and island arcs (Sykesville melange and Chopawamsic and James Run Formations of the central Appalachians, for example—see Drake and Morgan, 1981; Pavlides, 1981) that aren't present in the southernmost Appalachians. Our reconnaissance suggests that some of the metavolcanic and metavolcanic-epiclastic rocks in southern Virginia (Virgilina area) that have been assigned to the "Carolina slate belt" (Glover and Sinha, 1973; Williams, 1978) probably originated in a different island arc from the Little River arc. There is also the possibility (A.A. Drake, Jr., and Richard Goldsmith, written communs., 1984) that some of the thrust sheets in the Georgiabama thrust stack accreted to lower sheets in a lateral or oblique fashion; this appears to have been the case with higher sheets arriving upon the Zebulon and Bill Arp sheets.

The characteristics of preserved remnants of subduction melange complexes in the southernmost Appalachians match well with those of both active and fossil melanges in the Indonesian region and with Hamilton's (1979, p. 28–30) model of a subduction melange wedge. The Potato Creek, Juliette, Kings Mountain, and Po Biddy slices of the Macon melange probably represent slightly different tectonostratigraphic (or lithotectonic) facies within the wedge. Sequences with characteristics of outer-arc basin deposits (Atlanta thrust sheet for example) or back-arc basin deposits (Zebulon Formation) fit readily into the Indonesian model, as do island-arc deposits (Promised Land Formation, Paulding Volcanic-Plutonic Complex). Despite transport, deformation, and metamorphism, remnants of subduction melange complexes are preserved beneath remnants of each island-arc sequence in the southernmost Appalachians (West Point melange/Paulding arc, Clairmont melange/Promised Land arc, Macon melange/Little River arc), and both obducted ophiolite (Soapstone Ridge, Ropes Creek) and ophiolite in melanges (clasts in West Point and Macon melanges) are present.

REFERENCES CITED

Abrams, C.E., 1983, Geology of the Austell-Frolona antiform, northwestern Georgia Piedmont: Athens, Ga., University of Georgia, unpublished M.S. thesis, 119 p.

———1985, Base metal mines and prospects of Fannin County, Georgia, an extension of the Ducktown trend [abs.]: Geological Society of America Abstracts with Programs, v. 17, no. 2, p. 77.

Abrams, C.E., and McConnell, K.I., 1981, Stratigraphy of the area around the Austell-Frolona antiform; west-central Georgia, *in* Wigley, P.B., ed., Latest thinking on the stratigraphy of selected areas in Georgia: Georgia Geologic Survey Information Circular 54–A, p. 55–67.

———1982, Banded iron formation: a key marker unit for massive sulfide exploration in the high grade metamorphic terrain of western Georgia [abs.]: Geological Society of America Abstracts with Programs, v. 14, nos. 1 and 2, p. 1.

———1984, Geologic setting of volcanogenic base and precious metal deposits of the west Georgia Piedmont: a multiply deformed metavolcanic terrane: Economic Geology, v. 79, p. 1521–1539.

Absher, B.S., and McSween, H.Y., Jr., 1985, Granulites at Winding Stair Gap, North Carolina: the thermal axis of Paleozoic metamorphism in the southern Appalachians: Geological Society of America Bulletin, v. 96, no. 5, p. 588–599.

Adams, G.I., 1926, The crystalline rocks, *in* Adams, G.I., and others, The geology of Alabama: Alabama Geological Survey Special Report No. 14, p. 25–40.

———1930, The significance of the quartzites of the Pine Mountain in the crystallines of west-central Georgia: Journal of Geology, v. 38, no. 3, p. 271–279.

———1933, General geology of the crystalline rocks of Alabama: Journal of Geology, v. 41, p. 159–173.

Alabama Geological Survey, 1926, Geologic map of Alabama: Tuscaloosa, Ala., Alabama Geological Survey, scale 1:500,000.

———1973, Preliminary geologic map of the crystalline rocks of Alabama: Tuscaloosa, Ala., Alabama Geological Survey open-file map, scale 1:250,000.

Allard, G.O., Carpenter, R.H., and Abrams, C.E., 1985, Canadian greenstone belt models—Do they apply in the southern Appalachians? [abs.]: Geological Society of America Abstracts with Programs, v. 17, no. 2, p. 77.

Allen, A.T., and Lester, J.G., 1957, Zonation of the Middle and Upper Ordovician strata in northwestern Georgia: Georgia Geological Survey Bulletin 66, 110 p.

American Geophysical Union, Special Committee for the Geophysical and Geological Study of the Continents, 1964, Bouguer gravity anomaly map of the United States (exclusive of Alaska and Hawaii): Washington, D.C., U.S. Geological Survey, 2 sheets, scale 1:2,500,000.

Ando, C.J., Cook, F.A., Oliver, J.E., Brown, L.D., and Kaufman, Sidney, 1983, Crustal geometry of the Appalachian orogen from seismic reflection studies, *in* Hatcher, R.D., Jr., Williams, Harold, and Zietz, Isidore, eds., Contributions to the tectonics and geophysics of mountain chains: Geological Society of America Memoir 158, p. 83–101.

Applin, P.H., 1951, Preliminary report on buried pre-Mesozoic rocks in Florida and adjacent states: U.S. Geological Survey Circular 91, 28 p.

Arden, D.D., Jr., 1974a, A geophysical profile in the Suwannee Basin, northwestern Florida, *in* Stafford, L.P., ed., Symposium on the petroleum geology of the Georgia Coastal Plain: Georgia Geological Survey Bulletin 87, p. 111–122.

———1974b, Geology of the Suwannee Basin interpreted from geophysical profiles: Gulf Coast Association of Geological Societies Transactions, v. 24, p. 223–230.

Atkins, R.L., and Higgins, M.W., 1980, Superimposed folding and its bearing on geologic history of the Atlanta, Georgia, area, *in* Frey, R.W., ed., Excursions in southeastern geology, v. 1: Falls Church, Va., American Geological Institute, p. 19–40.

Bayley, W.S., 1928, Geology of the Tate quadrangle, Georgia: Georgia Geological Survey Bulletin 43, 170 p.

Bell, Henry, III, 1982, Strata-bound sulfide deposits, wall-rock alteration, and associated tin-bearing minerals in the Carolina slate belt, South Carolina and Georgia: Economic Geology, v. 77, p. 294–311.

Bell, Henry, III, Carpenter, R.H., and Feiss, P.G., 1980, Volcanogenic ore deposits of the Carolina slate belt, *in* Frey, R.W., ed., Excursions in southeastern geology: Falls Church, Va., American Geological Institute, p. 149–178.

Bentley, R.D., 1969, Strike slip faults in Lee County, Alabama [abs.]: Geological Society of America Abstracts with Programs, part 4, p. 5.

Bentley, R.D., and Neathery, T.L., 1970, Geology of the Brevard fault zone and related rocks of the inner Piedmont of Alabama: Alabama Geological Society 8th Annual Field Trip Guidebook, 119 p.

Bentley, R.D., Neathery, T.L., and Scott, J.C., 1982, Geology and mineral resources of Lee County, Alabama: Tuscaloosa, Ala., Alabama Geological Survey open-file report, 110 p.

Bergström, S.M., 1973, Biostratigraphy and facies relations in the lower Middle Ordovician of easternmost Tennessee: American Journal of Science, v. 273–A, p. 261–293.

Bergström, S.M., and Drahovzal, J.A., 1972, Facies relations in the Middle Ordovician of the southern Appalachians in Alabama [abs.]: Geological Society of America Abstracts with Programs, v. 4, no. 2, p. 60–61.

Bergström, S.M., Riva, John, and Kay, Marshall, 1974, Significance of conodonts, graptolites, and shelly faunas from the Ordovician of western and north-central Newfoundland: Canadian Journal of Earth Sciences, v. 11, p. 1625–1660.

Berkland, J.O., Raymond, L.A., Kramer, J.C., Moores, E.M., and O'Day, M., 1972, What is Franciscan?: American Association of Petroleum Geologists Bulletin, v. 56, p. 2295–2302.

Bird, J.M., and Dewey, J.F., 1970, Lithosphere plate-continental margin tectonics and the evolution of the Appalachian orogen: Geological Society of America Bulletin, v. 81, no. 4, p. 1031–1060.

Bluhm, C.T., and Zimmerman, Jay, Jr., 1977, Structure of the Frank ultramafic tectonite Avery County, North Carolina [abs.]: Geological Society of America Abstracts with Programs, v. 9, no. 2, p. 121.

Bolton, J.C., 1985, Tectonically formed basins within the Ocoee Supergroup [abs.]: Geological Society of America Abstracts with Programs, v. 17, no. 2, p. 82.

Bosworth, William, and Rowley, D.B., 1984, Early obduction-related deformation features of the Taconic allochthon: Analogy with structures observed in modern trench environments: Geological Society of America Bulletin, v. 95, no. 5, p. 559–567.

Bramlett, K.W., 1980, Geology of the Johnston-Edgefield area, South Carolina, and its regional implications: Columbia, S.C., University of South Carolina, unpublished M.S. thesis, 56 p.

Brewer, W.M., 1896, Upper gold belt of Alabama: Alabama Geological Survey Bulletin 5, Part 1, 202 p.

Bridge, Josiah, and Berdan, J.M., 1952, Preliminary correlation of the Paleozoic rocks from test wells in Florida and adjacent parts of Georgia and Alabama: Tallahassee, Fla., Florida Geological Survey Guidebook, Association of American State Geologists, 44th Annual Meeting Field Trip, p. 29–38.

Brown, W.R., 1970, Investigations of the sedimentary record in the Piedmont and Blue Ridge of Virginia, *in* Fisher, G.W., Pettijohn, F.J., Reed, J.C., Jr., and Weaver, K.N., eds., Studies of Appalachian geology—Central and southern: New York, Interscience Publishers, p. 335–349.

Bryant, Bruce, and Reed, J.C., Jr., 1970, Geology of the Grandfather Mountain window and vicinity, North Carolina and Tennessee: U.S. Geological Survey Professional Paper 615, 190 p.

Bucher, W.H., 1933, The deformation of the Earth's crust: Princeton, N.J., Princeton University Press, 518 p.

Buck, W.R., and Toksoz, M.N., 1983, Thermal effects of continental collisions: Thickening a variable viscosity lithosphere: Tectonophysics, v. 100, p. 53–69.

Butler, J.R., 1981, Geology of the Blacksburg South quadrangle, South Carolina, *in* Horton, J.W., Jr., and others, eds., Geological investigations of the Kings Mountain belt and adjacent areas in the Carolinas: Carolina Geological Society Field Trip Guidebook 1981, p. 65–71.

Butler, J.R., and Dunn, D.E., 1968, Geology of the Sauratown Mountains anticlinorium and vicinity, North Carolina: Southeastern Geology Special Publication 1, p. 19–47.

Butler, J.R., and Fullagar, P.D., 1978, Petrochemical and geochronological studies of plutonic rocks in the southern Appalachians: III. Leucocratic adamellites of the Charlotte belt near Salisbury, North Carolina: Geological Society of America Bulletin, v. 89, no. 3, p. 460–466.

Butts, Charles, 1910, Description of the Birmingham quadrangle (Alabama): U.S. Geological Survey Geologic Atlas of the United States, Folio 175, 24 p.

———1926, The Paleozoic rocks, *in* Adams, G.I., and others, Geology of Alabama: Alabama Geological Survey Special Report 14, p. 40–223.

Butts, Charles, and Gildersleeve, Benjamin, 1948, Geology and mineral resources of the Paleozoic area in northwest Georgia: Georgia Geological Survey Bulletin 54, 176 p.

Carpenter, R.H., 1971, Norite intrusives in western Jasper County and eastern Monroe County, Georgia, *in* Georgia Geological Society 6th Annual Field Trip Guidebook: Atlanta, Ga., Georgia Geological Survey, p. 1–7.

Carpenter, R.H., and Allard, G.O., 1982, Aluminosilicate assemblages: An exploration tool for metavolcanic terrains [sic] of the southeast, *in* Exploration for metallic resources in the southeast: [Athens, Ga., University of Georgia, Dept. of Geology,] p. 19–22.

Carpenter, R.H., and Hughes, T.C., 1970, A geochemical and geophysical survey of the Gladesville Norite, Jasper County, Georgia: Georgia Geological Survey Information Circular 37, 7 p.

Carpenter, R.H., and Prather, J.P., 1971, A gravity survey of the south-central Georgia Piedmont: Georgia Geological Survey Information Circular 42, 6 p.

Carrington, T.J., 1973, Metamorphosed Paleozoic sedimentary rocks in Chilton, Shelby, and Talladega Counties, Alabama, *in* Carrington, T.J., ed., Talladega metamorphic front: Alabama Geological Society 11th Annual Field Trip Guidebook, p. 22–38.

Carrington, T.J., and Wigley, P.B., 1967, Redefinition of the Hillabee Schist, Alabama: Southeastern Geology, v. 8, p. 19–31.

Chowns, T.M., 1972, Depositional environments in the Upper Ordovician of northwest Georgia and southeast Tennessee, *in* Chowns, T.M., ed., Sedimentary environments in the Paleozoic rocks of northwest Georgia: Georgia Geological Survey Guidebook 11, p. 3–11.

Chowns, T.M., editor, 1983, [Correlation chart] *in* Geology of Paleozoic rocks in the vicinity of Rome, Georgia; Georgia Geological Society 18th Annual Field Trip Guidebook: [Atlanta, Ga., Georgia State University,] inside front cover.

Chowns, T.M., and Carter, B.D., 1983, Stratigraphy of Middle and Upper Ordovician red beds in Georgia, *in* Chowns, T.M., ed., Geology of Paleozoic rocks in the vicinity of Rome, Georgia; Georgia Geological Society 18th Annual Field Trip Guidebook: [Atlanta, Ga., Georgia State University,] p. 1–15.

Chowns, T.M., and McKinney, F.K., 1980, Depositional facies in Middle-Upper Ordovician and Silurian rocks in Alabama and Georgia, *in* Frey, R.W., ed., Excursions in southeastern geology, v. 2: Falls Church, Va., American Geological Institute, p. 323–348.

Chowns, T.M., and Williams, C.T., 1983, Pre-Cretaceous rocks beneath the Georgia Coastal Plain—Regional implications, *in* Gohn, G.S., ed., Studies related to the Charleston, South Carolina, earthquake of 1886—Tectonics and seismicity: U.S. Geological Survey Professional Paper 1313, p. L1–L42.

Clarke, J.W., 1952, Geology and mineral resources of the Thomaston quadrangle, Georgia: Georgia Geological Survey Bulletin 59, 99 p.

Clarke, O.M., and Carrington, T.J., 1964, Hillabee Chlorite Schist, *in* Deininger, R.W., and others, Alabama Piedmont geology: Alabama Geological Society 2nd Annual Field Trip Guide Book, p. 19–22.

Cloos, Mark, 1982, Flow melanges: numerical modeling and geologic constraints on their origin in the Franciscan subduction complex, California: Geological Society of America Bulletin, v. 93, p. 330–345.

Coleman, S.L., Medlin, J.H., and Crawford, T.J., 1973, Petrology and geochemistry of the Austell gneiss in the western Georgia Piedmont [abs.]: Geological Society of America Abstracts with Programs, v. 5, no. 5, p. 338.

Colton, G.W., 1970, The Appalachian basin—Its depositional sequences and their geologic relationships, *in* Fisher, G.W., Pettijohn, F.J., Reed, J.C., Jr., and Weaver, K.N., eds., Studies of Appalachian geology—Central and southern: New York, Interscience Publishers, p. 5–47.

Conant, L.C., and Swanson, V.E., 1961, Chattanooga Shale and related rocks of central Tennessee and nearby areas: U.S. Geological Survey Professional Paper 357, 91 p.

Cook, F.A., 1983, Some consequences of palinspastic reconstruction in the southern Appalachians: Geology, v. 11, no. 2, p. 86–89.

Cook, F.A., Albaugh, D.S., Brown, L.D., Kaufman, Sidney, Oliver, J.E., and Hatcher, R.D., Jr., 1979, Thin-skinned tectonics in the crystalline southern Appalachians; COCORP seismic-reflection profiling of the Blue Ridge and Piedmont: Geology, v. 7, no. 12, p. 563–567.

Cook, F.A., Brown, L.D., Kaufman, Sidney, Oliver, J.E., and Peterson, T., 1981, COCORP seismic profiling of the Appalachian orogen beneath the Coastal Plain of Georgia: Geological Society of America Bulletin, v. 92, p. 738–748.

Cook, F.A., and Oliver, J.E., 1981, The late Precambrian–early Paleozoic continental edge in the Appalachian orogen: American Journal of Science, v. 281, p. 993–1008.

Cook, T.A., 1982, Stratigraphy and structure of the central Talladega slate belt, Alabama Appalachians, *in* Bearce, D.N., Black, W.W., Kish, S.A., and Tull, J.F., eds., Tectonic studies in the Talladega and Carolina slate belts, southern Appalachian orogen: Geological Society of America Special Paper 191, p. 47–59.

Cooper, B.N., 1964, Relation of stratigraphy to structure in the southern Appalachians: Blacksburg, Va., Virginia Polytechnic Institute and State University, Department of Geological Sciences Memoir 1, p. 81–114.

Costello, J.O., 1978, Shear zones in the Corbin Gneiss of Georgia: Georgia Geologic Survey Bulletin 93, p. 32–37.

Costello, J.O., and McConnell, K.I., 1983, Relationship of the Cartersville fault and the Great Smoky fault in the southern Appalachian orogen: a reinterpretation [abs.]: Geological Society of America Abstracts with Programs, v. 15, no. 2, p. 94.

Costello, J.O., McConnell, K.I., and Power, W.R., 1982, Geology of late Precambrian and early Paleozoic rocks in and near the Cartersville district, Georgia; Georgia Geological Society 17th Annual Field Trip Guidebook: [Atlanta, Ga., Georgia State University,] 40 p.

Cowan, D.S., 1974, Deformation and metamorphism of the Franciscan subduction zone complex northwest of Pacheco Pass, California: Geological Society of America Bulletin, v. 85, no. 10, p. 1623–1634.

———1985, Structural styles in Mesozoic and Cenozoic melanges in the western Cordillera of North America: Geological Society of America Bulletin, v. 96, no. 4, p. 451–462.

Crawford, T.J., 1968a, Geologic map, Columbia County, Georgia: Central Savannah River Area Planning and Development Commission and Geology Department, University of Georgia, scale approximately 1:100,000.

———1968b, Geologic map, Lincoln County, Georgia: Central Savannah River Area Planning and Development Commission and Geology Department, University of Georgia, scale approximately 1:100,000.

———1968c, Geologic map, McDuffie County, Georgia: Central Savannah River Area Planning and Development Commission and Geology Department, University of Georgia, scale approximately 1:100,000.

———1968d, Geologic map, Taliaferro County, Georgia: Central Savannah River Area Planning and Development Commission and Geology Department, University of Georgia, scale approximately 1:100,000.

———1968e, Geologic map, Warren County, Georgia: Central Savannah River Area Planning and Development Commission and Geology Department, University of Georgia, scale approximately 1:100,000.

———1968f, Geologic map, Wilkes County, Georgia: Central Savannah River Area Planning and Development Commission and Geology Department, University of Georgia, scale approximately 1:100,000.

———1983, Pennsylvanian outliers in Georgia, *in* Chowns, T.M., ed., Geology of Paleozoic rocks in the vicinity of Rome, Georgia; Georgia Geological Society 18th Annual Field Trip Guidebook: [Atlanta, Ga., Georgia State University,] p. 30–41.

Crawford, T.J., and Cressler, C.W., 1982, Talladega "Series," Great Smoky fault, and Emerson fault: relationships in the Cartersville area, Georgia, *in* Bearce, D.N., Black, W.W., Kish, S.A., and Tull, J.F., eds., Tectonic studies in the Talladega and Carolina slate belts, southern Appalachian orogen: Geological Society of America Special Paper 191, p. 31–34.

Crawford, T.J., Hurst, V.J., and Ramspott, L.D., 1966, Extrusive volcanics and associated dike swarms in central-east Georgia: Athens, Ga., University of Georgia Geology Department, Guidebook, Field Trip no. 2, Geological Society of America Southeastern Section Meeting 1966, 53 p.

Crawford, T.J., and Medlin, J.H., 1973, The western Georgia Piedmont between the Cartersville and Brevard fault zones: American Journal of Science, v. 273, p. 712–722.

———1974, Brevard fault zone in western Georgia and eastern Alabama: Georgia Geological Survey Guidebook 12, p. 1–67.

Cressler, C.W., 1963, Geology and ground-water resources of Catoosa County, Georgia: Georgia Geological Survey Information Circular 28, 19 p.

———1964a, Geology and ground-water resources of the Paleozoic rock area, Chattooga County, Georgia: Georgia Geological Survey Information Circular 27, 14 p.

———1964b, Geology and ground-water resources of Walker County, Georgia: Georgia Geological Survey Information Circular 29, 15 p.

———1970, Geology and ground-water resources of Floyd and Polk Counties, Georgia: Georgia Geological Survey Information Circular 39, 95 p.

———1974, Geology and ground-water resources of Gordon, Whitfield, and Murray Counties, Georgia: Georgia Geological Survey Information Circular 47, 56 p.

Cressler, C.W., Blanchard, H.E., Jr., and Hester, W.G., 1979, Geohydrology of Bartow, Cherokee, and Forsyth Counties, Georgia: Georgia Geologic Survey Information Circular 50, 45 p.

Crickmay, G.W., 1933, The occurrence of mylonites in the crystalline rocks of Georgia: American Journal of Science, 5th ser., v. 26, no. 152, p. 161–177.

———1936, Status of the Talladega Series in southern Appalachian stratigraphy: Geological Society of America Bulletin, v. 47, p. 1371–1392.

———1939, Geologic map of Georgia: Atlanta, Ga., Georgia Geological Survey, scale 1:500,000.

———1952, Geology of the crystalline rocks of Georgia: Georgia Geological Survey Bulletin 58, 54 p.

Croft, M.G., 1963, Geology and ground-water resources of Bartow County, Georgia: U.S. Geological Survey Water-Supply Paper 1619–FF, 87 p.

Crowley, W.P., 1976, The geology of the crystalline rocks near Baltimore and its bearing on the evolution of the eastern Maryland Piedmont: Maryland Geological Survey Report of Investigations 27, 40 p.

Dallmeyer, R.D., 1974, Eclogite intrusions in an alpine peridotite sill, Georgia-North Carolina: their chemistry and petrogenetic evolution: American Journal of Science, v. 274, p. 356–377.

———1975, $^{40}Ar/^{39}Ar$ age spectra of biotite from Grenville basement gneisses in northwest Georgia: Geological Society of America Bulletin, v. 86, no. 12, p. 1740–1744.

———1978, ^{40}Ar-^{39}Ar incremental-release ages of hornblende and biotite across the Georgia inner Piedmont: Their bearing on late Paleozoic–early Mesozoic tectonothermal history: American Journal of Science, v. 278, p. 124–129.

Dallmeyer, R.D., Courtney, P.S., and Wooten, R.M., 1978, Stratigraphy, structure, and metamorphism east of the Murphy syncline: Georgia-North Carolina; Georgia Geological Society Guidebook 17: [Atlanta, Ga., Georgia State University,] 74 p.

Dallmeyer, R.D., and Hatcher, R.D., Jr., 1985, The Alto allochthon: Part 2, geochronological constraints on tectono-thermal evolution [abs.]: Geological Society of America Abstracts with Programs, v. 17, no. 2, p. 86.

Davis, G.J., 1980, The southwestern extension of the Middleton-Lowndesville cataclastic zone in the Greensboro, Georgia area and its regional implications: Athens, University of Georgia, unpublished M.S. thesis, 151 p.

Dewey, J.F., 1969, The evolution of the Caledonian/Appalachian orogen: Nature, v. 222, p. 124–128.

Dewey, J.F., and Bird, J.M., 1971, Origin and emplacement of the ophiolite suite: Appalachian ophiolites in Newfoundland: Journal of Geophysical Research, v. 76, p. 3179–3206.

Dietrich, R.V., 1959, Geology and mineral resources of Floyd County of the Blue Ridge Upland, southwestern Virginia: Virginia Polytechnic Institute Bulletin of the Engineering Experimental Station., Ser., no. 134, 160 p.

Drahovzal, J.A., and Neathery, T.L., 1971, Middle and Upper Ordovician stratigraphy of the Alabama Appalachians, *in* Drahovzal, J.A., and Neathery, T.L., eds., The Middle and Upper Ordovician of the Alabama Appalachians: Alabama Geological Society 9th Annual Field Trip Guidebook, p. 1–62.

Drahovzal, J.A., and Thomas, W.A., 1977, Pre-Mississippian sandstones in the interior structures of the Appalachian fold and thrust belt of eastern Alabama, *in* Bearce, D.N., ed., Cambrian and Devonian stratigraphic problems of eastern Alabama: Alabama Geological Society 15th Annual Field Trip Guidebook, p. 29–36.

Drake, A.A., Jr., and Lyttle, P.T., 1981, The Accotink Schist, Lake Barcroft Metasandstone, and Popes Head Formation—Keys to an understanding of the tectonic evolution of the northern Virginia Piedmont: U.S. Geological Survey Professional Paper 1205, 16 p.

Drake, A.A., Jr., and Morgan, B.A., 1981, The Piney Branch Complex—A metamorphosed fragment of the central Appalachian ophiolite in northern Virginia: American Journal of Science, v. 281, p. 484–508.

Dribus, J.R., Heimlich, R.A., and Palmer, D.F., 1977, Petrology and petrofabric analysis of the Deposit No. 9 dunite, Macon County, North Carolina [abs.]: Geological Society of America Abstracts with Programs, v. 9, no. 2, p. 135.

Ernst, W.G., 1972, Occurrence and mineralogic evolution of blueschist belts with time: American Journal of Science, v. 272, no. 7, p. 657–668.

Fairley, W.M., 1965, The Murphy syncline in the Tate quadrangle, Georgia: Georgia Geological Survey Bulletin 75, 71 p.

———1966, The Cartersville thrust at Cartersville, Georgia, *in* Bentley, R.D., Fairley, W.M., Fields, H.H., Power, W.R., and Smith, J.M., eds., The Cartersville fault problem: Georgia Geological Survey Geological Guidebook Series Guidebook No. 4, p. 28–33.

———1969, Stratigraphy and structure of the Murphy Marble belt in parts of northern Georgia: Georgia Geological Survey Bulletin 80, p. 89–120.

———1973, Correlations of stratigraphic belts of the northwest Georgia Piedmont and Blue Ridge: American Journal of Science, v. 273, no. 8, p. 686–697.

Finney, S.C., 1978, The affinities of *Isograptus, Glossograptus, Cryptograptus, Corynoides,* and allied graptolites: Acta Palaeontologica Polonica, v. 23, no. 4, p. 481–495.

———1980, Thamnograptid, Dichograptid and Abrograptid graptolites from the Middle Ordovician Athens Shale of Alabama: Journal of Paleontology, v. 54, no. 6, p. 1184–1208.

Fisher, D.W., 1969, Quinquallochthonous succession and a new molasse in the southern Hudson Valley and their bearing on New York tectonic history [abs.]: Geological Society of America Abstracts with Programs, v. 1, p. 66.

———1979, Folding in the foreland, Middle Ordovician Dolgeville facies, Mohawk Valley, New York: Geology, v. 7, p. 455–459.

Fleming, G., Nunan, A., and Neilson, M.J., 1980, The Red Ridge Complex [abs.]: Alabama Academy of Science Journal, v. 51, p. 201.

Fleuty, M.J., 1964, The description of folds: Geologists' Association of London, Proceedings, v. 75, pt. 4, p. 461–492.

Forrest, J.T., 1975, Geologic evaluation of a portion of the Murphy Marble belt in southwestern North Carolina: Houston, Tex., Rice University, unpublished Ph.D. dissertation, 76 p.

Fullagar, P.D., 1971, Age and origin of plutonic intrusions in the Piedmont of the southeastern Appalachians: Geological Society of America Bulletin, v. 82, p. 2845–2862.

———1981, Summary of Rb-Sr whole-rock ages for South Carolina: South Carolina Geology, v. 25, p. 29–31.

———1983, Post-metamorphic Siluro-Devonian granitic plutons in the Charlotte belt of South Carolina [abs.]: Geological Society of America Abstracts with Programs, v. 15, no. 2, p. 64.

Fullagar, P.D., and Butler, J.R., 1979, 325 to 265 m.y.-old granitic plutons in the Piedmont of the southeastern Appalachians: American Journal of Science, v. 279, p. 161–185.

Furcron, A.S., Teague, K.H., and Calver, J.L., 1947, Talc deposits of Murray County, Georgia: Georgia Geological Survey Bulletin 53, 75 p.

Gale, G.H., and Pearce, J.A., 1982, Geochemical patterns in Norwegian greenstones: National Research Council of Canada 1982, p. 385–397.

Galpin, S.L., 1915, The feldspar and mica deposits of Georgia: Georgia Geological Survey Bulletin 53, 190 p.

Georgia Geological Survey, 1976, Geologic map of Georgia: Atlanta, Ga., Georgia Geological Survey, scale 1:500,000.

Gibson, G.G., Teeter, S.A., and Fedonkin, M.A., 1984, Ediacarian fossils from the Carolina slate belt, Stanly County, North Carolina: Geology, v. 12, no. 7, p. 387–390.

Gilbert, O.E., Jr., 1970, The Taconic orogeny in Alabama, *in* Drahovzal, J.A., and Neathery, T.L., eds., The Middle and Upper Ordovician of the Alabama Appalachians: Alabama Geological Society 9th Annual Field Trip Guidebook, p. 153–171.

———1973, The Sylacauga unconformity/Talladega fault: the Piedmont metamorphic front of Alabama as a stratigraphically controlled fault, *in* Carrington, R.J., ed., Talladega metamorphic front: Alabama Geological Society 11th Annual Field Trip Guidebook, p. 39–50.

Gillon, K.A., 1982, Stratigraphic, structural, and metamorphic geology of portions of the Cowrock and Helen, Georgia 7 1/2' quadrangles: Athens, Ga., University of Georgia, unpublished M.S. thesis, 236 p.

Glover, Lynn, III, and Sinha, A.K., 1973, The Virgilina deformation, a late Precambrian to Early Cambrian orogenic event in the central Piedmont of Virginia and North Carolina: American Journal of Science, v. 273–A, p. 234–251.

Glover, Lynn, III, Speer, J.A., Russell, G.S., and Farrar, S.S., 1983, Ages of regional metamorphism and ductile deformation in the central and southern Appalachians: Lithos, v. 16, p. 223–245.

Gottfried, David, Annell, C.S., and Byerly, G.R., 1983, Geochemistry and tectonic significance of subsurface basalts from Charleston, South Carolina: Clubhouse Crossroads test holes 2 and 3, *in* Gohn, G.S., ed., Studies related to the Charleston, South Carolina, earthquake of 1886—Tectonics and seismicity: U.S. Geological Survey Professional Paper 1313, p. A1–A19.

Gottfried, David, Annell, C.S., and Schwarz, L.J., 1977, Geochemistry of subsurface basalt from the deep corehole (Clubhouse Crossroads corehole 1) near Charleston, South Carolina—Magma type and tectonic implications, *in* Rankin, D.W., ed., Studies related to the Charleston, South Carolina, earthquake of 1886—A preliminary report: U.S. Geological Survey Professional Paper 1028, p. 91–113.

Grant, W.H., 1949, Lithology and structure of the Brevard Schist and hornblende gneiss in the Lawrenceville, Georgia area: Atlanta, Ga., Emory University, unpublished M.S. thesis, 45 p.

———1958, The geology of Hart County, Georgia: Georgia Geological Survey Bulletin 67, 75 p.

———1967, Geology of the Barnesville area and Towaliga fault, Lamar County, Georgia; Georgia Geological Society Guidebook 2nd Annual Field Trip, 1967: [Atlanta, Ga., Georgia State University,] 16 p.

———1968, Movements in the Towaliga fault zone, Pike and Lamar Counties, Georgia [abs.]: Geological Society of America Abstracts with Programs, Southeastern Section 17th Annual Meeting, p. 40–41.

Grant, W.H., Size, W.B., and O'Connor, B.J., 1980, Petrology and structure of the Stone Mountain Granite and Mount Arabia migmatite, Lithonia, Georgia, *in* Frey, R.W., ed., Excursions in southeastern geology, v. 1: Falls Church, Va., American Geological Institute, p. 41–57.

Grapes, R.H., 1978, Manganiferous schists and their origin, Hidaka Mountains, Hokkaido, Japan: Contributions to Mineralogy and Petrology, v. 68, no. 1, p. 23–35.

Green, G.B., Cavaroc, V.V., Stoddard, E.F., and Abdelzahir, M.A., 1982, Volcanic and volcaniclastic facies in a part of the slate belt of North Carolina, *in* Bearce, D.N., Black, W.W., Kish, S.A., and Tull, J.F., eds., Tectonic studies in the Talladega and Carolina slate belts, southern Appalachian orogen: Geological Society of America Special Paper 191, p. 109–124.

Greenland, L.P., and Campbell, E.Y., 1974, Spectrophotometric determination of niobium in rocks: U.S. Geological Survey Journal of Research, v. 2, no. 3, p. 353–355.

Greenly, E., 1919, The geology of Anglesey: London, Great Britain Geological Survey Memoir, 2 v.: 980 p.

Gregory, J.P., 1981, Variations in metamorphic grade in the Kings Mountain belt of north-central South Carolina, *in* Horton, J.W., Jr., Butler, J.R., and Milton, D.J., eds., Geological investigations of the Kings Mountain belt and adjacent areas in the Carolinas: Carolina Geological Society Field Trip Guidebook 1981, p. 142–146.

Griffin, R.H., 1951, Structure and petrography of the Hillabee Sill and associated metamorphics of Alabama: Alabama Geological Survey Bulletin 63, 74 p.

Griffin, V.S., Jr., 1970, Position of the Kings Mountain belt in Abbeville County, South Carolina: Southeastern Geology, v. 12, p. 105–113.

———1971, Inner Piedmont belt of the southern crystalline Appalachians: Geological Society of America Bulletin, v. 82, p. 1885–1898.

———1981, The Lowndesville belt north of the South Carolina-Georgia border, *in* Horton, J.W., Jr., Butler, J.R., and Milton, D.J., eds., Geological investigations of the Kings Mountain belt and adjacent areas in the Carolinas: Carolina Geological Society Field Trip Guidebook 1981, p. 166–173.

Guthrie, G.M., 1984, The Kahatchee Mountain Group: A key to understanding relationships between the Lower Cambrian Chilhowee Group and the lower Murphy Group of the western Blue Ridge [abs.]: Geological Society of America Abstracts with Programs, v. 16, no. 3, p. 143.

———1985, The Kahatchee Mountain Group and late Precambrian–Lower Cambrian western margin evolution, *in* Tull, J.F., Bearce, D.N., and Guthrie, G.M., eds., Early evolution of the Appalachian miogeocline: Upper Precambrian–lower Paleozoic stratigraphy of the Talladega slate belt: Alabama Geological Society 22d Annual Field Trip Guidebook, p. 11–19.

Gwinn, V.E., 1970, Kinematic patterns and estimates of lateral shortening, Valley and Ridge and Great Valley provinces, central Appalachians, south-central Pennsylvania, *in* Fisher, G.W., Pettijohn, F.J., Reed, J.C., Jr., and Weaver, K.N., eds., Studies of Appalachian geology—Central and southern: New York, Interscience Publishers, p. 127–146.

Hack, J.T., 1982, Physiographic divisions and differential uplift in the Piedmont and Blue Ridge: U.S. Geological Survey Professional Paper 1265, 49 p.

Hadley, J.B., 1970, The Ocoee Series and its possible correlatives, *in* Fisher, G.W., Pettijohn, F.J., Reed, J.C., Jr., and Weaver, K.N., eds., Studies of Appalachian geology—Central and southern: New York, Interscience Publishers, p. 247–259.

Hadley, J.B., and Nelson, A.E., 1971, Geologic map of the Knoxville quadrangle, North Carolina, Tennessee, and South Carolina: U.S. Geological Survey Miscellaneous Investigations Map I–654, scale 1:250,000.

Hamilton, Warren, 1979, Tectonics of the Indonesian region: U.S. Geological Survey Professional Paper 1078, 345 p.

Hanson, G.N., 1980, Rare earth elements in petrogenetic studies of igneous systems: Earth and Planetary Sciences Annual Report, v. 8, p. 371–406.

Harland, W.B., Cox, A.V., Llewellyn, P.G., Pickton, C.A.G., Smith, A.G., and Walters, R., 1982, A geologic time scale: Cambridge, England, Cambridge University Press, 131 p.

Harris, A.G., Repetski, J.E., Tull, J.F., and Bearce, D.N., 1984, Early Paleozoic conodonts from the Talladega slate belt of the Alabama Appalachians—Tectonic implications [abs.]: Geological Society of America Abstracts with Programs, v. 16, no. 3, p. 143.

Harris, L.D., and Bayer, K.C., 1979, Sequential development of the Appalachian orogen above a master decollement—A hypothesis: Geology, v. 7, no. 12, p. 568–572.

Hartley, M.E., III, 1973, Ultramafic and related rocks in the vicinity of Lake Chatuge: Georgia Geological Survey Bulletin 85, 61 p.

Hartley, M.E., III, and Penley, H.M., 1974, The Lake Chatuge sill outlining the Brasstown antiform; Georgia Geological Society Guidebook 13: [Atlanta, Ga., Georgia State University,] 27 p.

Hatcher, R.D., Jr., 1969, Stratigraphy, petrology and structure of the Brevard zone and Poor Mountain area, northwesternmost South Carolina: Carolina Geological Society Guide Book, South Carolina Development Board, Division of Geology, Geological Notes, v. 13, no. 4, p. 105–141.

———1970, Stratigraphy of the Brevard zone and Poor Mountain area, northwestern South Carolina: Geological Society of America Bulletin, v. 81, p. 933–940.

———1971a, Stratigraphic, petrologic and structural evidence favoring a thrust solution to the Brevard problem: American Journal of Science, v. 270, p. 177–202.

———1971b, The geology of Rabun and Habersham Counties, Georgia: Georgia Geological Survey Bulletin 83, 48 p.

———1972, Developmental model for the southern Appalachians: Geological Society of America Bulletin, v. 83, no. 9, p. 2735–2760.

———1973, Basement versus cover rocks in the Blue Ridge of northeast Georgia, northwestern South Carolina, and adjacent North Carolina: American Journal of Science, v. 273, no. 8, p. 671–685.

———1974, An introduction to the Blue Ridge tectonic history of northeast Georgia: Georgia Geological Survey Guidebook 13–A, 60 p.

———1976, Introduction to the geology of the eastern Blue Ridge of the Carolinas and nearby Georgia: Carolina Geological Society Guidebook 1976, 53 p.

———1978a, Tectonics of the western Piedmont and Blue Ridge, southern Appalachians: Review and speculation: American Journal of Science, v. 278, p. 276–301.

———1978b, The Alto allochthon: A major tectonic unit of the northeast Georgia Piedmont: Georgia Geological Survey Bulletin 93, p. 83–86.

———1981, Thrusts and nappes in the North American Appalachian orogen, *in* McClay, K.R., and Price, N.J., eds., Thrust and nappe tectonics: Geological Society of London Special Publication no. 9, p. 491–499.

———1983, Basement massifs in the Appalachians: their role in deformation during the Appalachian orogenies: Geological Journal, v. 18, p. 255–265.

Hatcher, R.D., Jr., and Butler, J.R., 1979, Guidebook for southern Appalachian field trip in the Carolinas, Tennessee, and northeastern Georgia; International Geological Correlations Program: Raleigh, N.C., North Carolina Geological Survey, 117 p.

Hatcher, R.D., Jr., Hooper, R.J., and Odom, A.L., 1983, The Pine Mountain window, Georgia, Alabama: A detached basement massif flanked by the Avalonian suture [abs.]: Geological Society of America Abstracts with Programs, v. 15, no. 2, p. 110.

Hatcher, R.D., Jr., Hooper, R.J., Petty, S.S., and Willis, J.D., 1981, Tectonics of emplacement and origin of Appalachian ultramafic bodies [abs.]: Geological Society of America Abstracts with Programs, v. 13, no. 7, p. 469–470.

———1984, Structure and chemical petrology of three southern Appalachian mafic-ultramafic complexes and their bearing upon the tectonics of emplacement and origin of Appalachian ultramafic bodies: American Journal of Science, v. 284, p. 484–506.

Hatcher, R.D., Jr., Howell, D.E., and Talwani, Pradeep, 1977, Eastern Piedmont fault system: Speculations on its extent: Geology, v. 5, no. 10, p. 636–640.

Hatcher, R.D., Jr., and Odom, A.L., 1980, Timing of thrusting in the southern Appalachians, USA: Model for orogeny?: Geological Society of London Journal, v. 137, p. 321–327.

Hatcher, R.D., Jr., and Zietz, Isidore, 1978, Thin crystalline thrust sheets in the southern Appalachians Inner Piedmont and Blue Ridge: Interpretation based upon regional aeromagnetic data [abs.]: Geological Society of America Abstracts with Programs, v. 10, p. 417.

———1980, Tectonic implications of regional aeromagnetic and gravity data from the southern Appalachians, *in* Wones, D.R., ed., The Caledonides in the U.S.A.; International Geological Correlation Program, project 27: Caledonide orogen: Blacksburg, Va., Virginia Polytechnic Institute and State University Memoir 2, p. 235–244.

Hayes, C.W., 1891, The overthrust faults of the southern Appalachians: Geological Society of America Bulletin, v. 2, p. 141–154.

———1894, Geology of a portion of the Coosa Valley in Georgia and Alabama: Geological Society of America Bulletin, v. 5, p. 465–480.

———1901, Geological relations of the iron ores in the Cartersville district, Georgia: American Institute of Mining Engineers Transactions, v. 30, p. 403–419.

Hedberg, H.D., ed., 1976, International stratigraphic guide—A guide to stratigraphic classification, terminology, and procedure: New York, Wiley, 200 p.

Hernon, R.M., 1964, Geologic maps and sections of the Ducktown, Isabella, and Persimmon Creek quadrangles, Tennessee and North Carolina: U.S. Geological Survey Open-File Report, scale 1:24,000.

———1968, Geology of the Ducktown, Isabella, and Persimmon Creek quadrangles, Tennessee and North Carolina: U.S. Geological Survey Open-File Report, 71 p.

Hewett, D.F., and Crickmay, G.W., 1937, The warm springs of Georgia, their geologic relations and origin: A summary report: U.S. Geological Survey Water-Supply Paper 819, 40 p.

Higgins, M.W., 1965, The geology of part of Sandy Springs quadrangle, Georgia: Atlanta, Ga., Emory University, unpublished M.S. thesis, 141 p.

———1966, The geology of the Brevard lineament near Atlanta, Georgia: Georgia Geological Survey Bulletin 77, 49 p.

———1971, Cataclastic rocks: U.S. Geological Survey Professional Paper 687, 97 p.

Higgins, M.W., and Atkins, R.L., 1981, The stratigraphy of the Piedmont southeast of the Brevard Zone in the Atlanta, Georgia, area, *in* Wigley, P.B., ed., Latest thinking on the stratigraphy of selected areas in Georgia: Georgia Geologic Survey Information Circular 54–A, p. 3–40.

Higgins, M.W., Atkins, R.L., Crawford, T.J., Crawford, R.F., III, Brooks, Rebekah, and Cook, R.B., 1986, The structure, stratigraphy, tectonostratigraphy, and evolution of the southernmost part of the Appalachian orogen, Georgia and Alabama: U.S. Geological Survey Open-File Report 86–372, 162 p.

Higgins, M.W., Atkins, R.L., Crawford, T.J., Crawford, R.F., III, and Cook, R.B., 1984, A brief excursion through two thrust stacks that comprise most of the crystalline terrane of Georgia and Alabama; Georgia Geological Society, Guidebook, 9th Annual Field Trip: [Atlanta, Ga., Georgia State University,] 67 p.

Higgins, M.W., Crawford, R.F., III, Cressler, C.W., and Crawford, T.J., 1987, Exotic marble slabs in the West Point melange in the

Murphy syncline and revision of the 'Murphy Sequence' in the Cartersville one-degree quadrangle, Georgia; a progress report [abs.]: Geological Society of America Abstracts with Programs, v. 29, no. 2, p. 89.

Higgins, M.W., and McConnell, K.I., 1978, The Sandy Springs Group and related rocks in the Georgia Piedmont; nomenclature and stratigraphy: Georgia Geological Survey Bulletin 93, p. 50–55.

Higgins, M.W., Pickering, S.M., Jr., and Atkins, R.L., 1980, The Soapstone Ridge Complex, Atlanta, Georgia: a transported mafic-ultramafic complex in the southeastern Appalachian Piedmont [abs.]: Geological Society of America Abstracts with Programs, v. 12, no. 7, p. 446.

Higgins, M.W., and Zietz, Isidore, 1975, Geologic interpretation of aeromagnetic and aeroradioactivity maps of northern Georgia: U.S. Geological Survey Miscellaneous Investigations Map I–783, scale 1:500,000, text 16 p.

Hopkins, O.B., 1914, Asbestos, talc, and soapstone deposits of Georgia: Georgia Geological Survey Bulletin 29, 319 p.

Hopson, J.L., Thompson, R.H., Hatcher, R.D., Jr., and Dallmeyer, R.D., 1985, The Alto allochthon: Part I, results of structural and stratigraphic studies [abs.]: Geological Society of America Abstracts with Programs, v. 17, no. 2, p. 96.

Horton, J.W., Jr., 1981a, Geologic map of the Kings Mountain belt between Gaffney, South Carolina, and Lincolnton, North Carolina, *in* Horton, J.W., Jr., Butler, J.R., and Milton, D.J., eds., Geological investigations of the Kings Mountain belt and adjacent areas in the Carolinas: Carolina Geological Society Field Trip Guidebook 1981, p. 6–18.

———1981b, Shear zone between the Inner Piedmont and Kings Mountain belts in the Carolinas: Geology, v. 9, p. 28–33.

Horton, J.W., Jr., and Butler, J.R., 1981, Geology and mining history of the Kings Mountain belt in the Carolinas—A summary and status report, *in* Horton, J.W., Jr., Butler, J.R., and Milton, D.J., eds., Geological investigations of the Kings Mountain belt and adjacent areas in the Carolinas: Carolina Geological Society Field Trip Guidebook 1981, p. 194–212.

Horton, J.W., Jr., Stoddard, E.F., Wylie, A.S., Jr., Moye, R.J., Jr., and Blake, D.E., 1985, Melange terrane in the eastern Piedmont, North Carolina [abs.]: Geological Society of America Abstracts with Programs, v. 17, no. 2, p. 96.

Howell, D.E., and Pirkle, W.A., 1976, Geologic sections across the Modoc fault zone, Modoc, South Carolina, *in* Chowns, T.M., compiler, Stratigraphy, structure, and seismicity in slate belt rocks along the Savannah River: Georgia Geologic Survey Guidebook 16, p. 16–20.

Hsu, K.J., 1968, Principles of melanges and their bearing on the Franciscan-Knoxville paradox: Geological Society of America Bulletin, v. 79, p. 1063–1074.

Hull, J.P.D., LaForge, Laurence, and Crane, W.R., 1919, Report on the manganese deposits of Georgia: Georgia Geological Survey Bulletin 35, 66 p.

Hurst, V.J., 1955, Stratigraphy, structure, and mineral resources of the Mineral Bluff quadrangle, Georgia: Georgia Geological Survey Bulletin 63, 137 p.

———1970, The Piedmont in Georgia, *in* Fisher, G.W., Pettijohn, F.J., Reed, J.C., Jr., and Weaver, K.N., eds., Studies of Appalachian geology—Central and southern: New York, Interscience Publishers, p. 383–396.

———1973, Geology of the southern Blue Ridge belt: American Journal of Science, v. 273, no. 8, p. 643–670.

Hurst, V.J., and Crawford, T.J., 1964, Exploration of mineral deposits in Habersham County, Georgia: U.S. Department of Commerce, Area Redevelopment Administration, 180 p.

———1970, Sulfide deposits, Coosa Valley area, Georgia: U.S. Department of Commerce, Economic Development Administration, 190 p.

Hurst, V.J., and Jones, L.M., 1973, Origin of amphibolites in the Cartersville–Villa Rica area, Georgia: Geological Society of America Bulletin, v. 84, p. 905–912.

Hurst, V.J., and Schlee, J.S., 1962, Ocoee metasediments of north central Georgia–southeast Tennessee: Georgia Geological Survey Guidebook 3, 28 p.

Irvine, T.N., and Baragar, W.R.A., 1971, A guide to the chemical classification of the common volcanic rocks: Canadian Journal of Earth Science, v. 8, p. 523–548.

Irving, E., and Strong, D.F., 1984, Evidence against large-scale Carboniferous strike-slip faulting in the Appalachian-Caledonian orogen: Nature, v. 310, p. 762–764.

Iverson, W.P., and Smithson, S.B., 1982, Master decollement root zone beneath the southern Appalachians and crustal balance: Geology, v. 10, no. 5, p. 241–245.

———1983, Reprocessed COCORP southern Appalachian reflection data: root zone to Coastal Plain: Geology, v. 11, no. 7, p. 422–425.

Jackson, L.E., Jr., 1951, The study of the Blackford breccia in the Dalton quadrangle: Atlanta, Ga., Emory University, unpublished M.S. thesis, 44 p.

Jakeš, P., and White, A.F.R., 1973, Major and trace element abundance in volcanic rocks of orogenic areas: Geological Society of America Bulletin, v. 84, p. 29–40.

Jonas, A.I., 1932, Structure of the metamorphic belt of the southern Appalachians: American Journal of Science, v. 224, p. 228–243.

Jones, L.M., Carpenter, R.H., Whitney, J.A., and Walker, R.L., 1974, Rubidium-strontium age and origin of pegmatites associated with the Gladesville norite, Jasper County, Georgia [abs.]: Geological Society of America Abstracts with Programs, v. 6. no. 4, p. 369.

Jones, L.M., Hurst, V.J., and Walker, R.L., 1973, Strontium isotope composition of amphibolite of the Cartersville–Villa Rica district, Georgia: Geological Society of America Bulletin, v. 84, no. 3, p. 913–918.

Keith, Arthur, 1904, Description of the Asheville quadrangle (North Carolina-Tennessee): U.S. Geological Survey Geologic Atlas of the United States, Folio 116, 10 p.

———1905, Description of the Mount Mitchell quadrangle (North Carolina-Tennessee): U.S. Geological Survey Geologic Atlas of the United States, Folio 124, 10 p.

———1907a, Description of the Nantahala quadrangle (North Carolina-Tennessee): U.S. Geological Survey Geologic Atlas of the United States, Folio 143, 12 p.

———1907b, Description of the Pisgah quadrangle (North Carolina-South Carolina): U.S. Geological Survey Geologic Atlas of the United States, Folio 147, 9 p.

Kellberg, J.M., 1943, Basic intrusives in the Chatuge Reservoir: Manuscript report, Tennessee Valley Authority Files, Knoxville, Tenn.

Kellberg, J.M., and Grant, L.F., 1956, Coarse conglomerates of the Middle Ordovician in the south Appalachian valley: Geological Society of America Bulletin, v. 67, p. 697–716.

Kesler, T.L., 1950, Geology and mineral deposits of the Cartersville district, Georgia: U.S. Geological Survey Professional Paper 224, 97 p.

Kidd, J.T., and Neathery, T.L., 1976, Correlation between Cambrian rocks of the southern Appalachian geosyncline and the interior low plateaus: Geology, v. 4, p. 767–769.

King, P.B., 1955, A geologic cross-section across the southern Appalachians: an outline of the geology in the segment in Tennessee, North Carolina, and South Carolina, *in* Russell, R.J., ed., Guides to southeastern geology: Geological Society of America 1955 Annual Meeting, p. 332–373.

———1964, Geology of the central Great Smoky Mountains; Tennessee: U.S. Geological Survey Professional Paper 349–C, 148 p.

———1970, The Precambrian of the United States of America: Southeastern United States, *in* Rankama, Kalervo, ed., The geologic systems: The Precambrian, Volume 4: New York, Wiley-Interscience, p. 1–71.

King, P.B., and Ferguson, H.W., 1960, Geology of northeasternmost Tennessee: U.S. Geological Survey Professional Paper 311, 136 p.

King, P.B., Hadley, J.B., Neuman, R.B., and Hamilton, Warren, 1958, Stratigraphy of the Ocoee Series, Great Smoky Mountains, Tennessee and North Carolina: Geological Society of America Bulletin, v. 69, p. 947–966.

King, P.B., Neuman, R.B., and Hadley, J.B., 1968, Geology of the Great Smoky Mountains National Park, Tennessee and North Carolina: U.S. Geological Survey Professional Paper 587, 23 p.

Kish, S.A., and Black, W.W., 1982, Part 2, the Carolina Slate belt: origin and evolution of an ancient volcanic arc, Introduction, *in* Bearce, D.N., Black, W.W., Kish, S.A., and Tull, J.F., eds., Tectonic studies in the Talladega and Carolina slate belts, southern Appalachian orogen: Geological Society of America Special Paper 191, p. 93–97.

Kline, S.W., 1980, Sandy Springs sequence rocks southeast of the Brevard Zone, near Atlanta, Georgia, and their bearing on the nature of the zone [abs.]: Geological Society of America Abstracts with Programs, v. 12, no. 4, p. 181.

———1981, The geology of the northern half of the Suwanee quadrangle, Gwinnett County, Georgia: Atlanta, Ga., Georgia Institute of Technology, unpublished M.S. thesis, 180 p.

Lash, G.G., and Drake, A.A., Jr., 1984, The Richmond and Greenwich slices of the Hamburg klippe in eastern Pennsylvania—Stratigraphy, sedimentology, structure, and plate tectonic implications: U.S. Geological Survey Professional Paper 1312, 40 p.

Laurent, Roger, 1977, Ophiolites from northern Appalachians of Quebec, *in* Coleman, R.G., and Irwin, W.P., eds., North American ophiolites: Oregon Department of Geology and Mineral Industries Bulletin 95, p. 25–40.

Lawrence, D.P., 1985, Tectonic significance of a Bouguer gravity survey of the Charlotte belt in west-central South Carolina [abs.]: Geological Society of America Abstracts with Programs, v. 17, no. 2, p. 99.

Lochman, Christina, 1956, Stratigraphy, paleontology, and paleogeography of the *Elliptocephala asaphoides* strata in Cambridge and Hoosick quadrangles, New York: Geological Society of America Bulletin, v. 67, p. 1331–1396.

Long, L.T., 1979, The Carolina slate belt—Evidence of a continental rift zone: Geology, v. 7, p. 180–184.

Long, L.T., Bridges, S.R., and Dorman, L.M., 1972, Simple Bouguer gravity map of Georgia: Georgia Geological Survey Map GM–4.

Mack, G.H., 1980, Stratigraphy and depositional environments of the Chilhowee Group (Cambrian) in Georgia and Alabama: American Journal of Science, v. 280, p. 497–517.

Mack, G.H., 1985, Provenance of the Middle Ordovician Blont clastic wedge, Georgia and Tennessee: Geology, v. 13, no. 4, p. 299–302.

Maher, H.D., Jr., Palmer, A.R., Secor, D.T., and Snoke, A.W., 1981, New trilobite locality in the Piedmont of South Carolina, and its regional implications: Geology, v. 9, no. 1, p. 34–36.

Martin, B.F., 1974, The petrology of the Corbin Gneiss: Athens, Ga., University of Georgia, unpublished M.S. thesis, 133 p.

Matthews, Vincent, III, 1967, Geology and petrology of the pegmatite district in southwestern Jasper County, Georgia: Athens, Ga., University of Georgia, unpublished M.S. thesis, 68 p.

McCalley, Henry, 1897, Repert on the valley regions of Alabama, Part II, the Coosa Valley region: Alabama Geological Survey Special Report 9, 826 p.

McConnell, K.I., 1980, Origin and correlation of the Pumpkinvine Creek Formation: a new unit in the Piedmont of northern Georgia: Georgia Geologic Survey Information Circular 52, 19 p.

McConnell, K.I., and Abrams, C.E., 1982, Geology of the New Georgia Group and associated massive sulfide and gold deposits: West-central Georgia: Exploration for metallic resources in the southeast: [Athens, Ga., University of Georgia, Dept. of Geology,] p. 143–170.

———1983, Geochemistry of metamorphosed banded iron formation and aluminosilicate assemblages of western Georgia [abs.]: Geological Society of America Abstracts with Programs, v. 15, no. 2, p. 90.

———1984, Geology of the greater Atlanta region: Georgia Geologic Survey Bulletin 96, 127 p.

McConnell, K.I., and Costello, J.O., 1980, Guide to geology along a traverse through the Blue Ridge and Piedmont provinces of north Georgia, *in* Frey, R.W., ed., Excursions in southeastern geology, v. 1: Falls Church, Va., American Geological Institute, p. 241–258.

———1982, Relationship between Talladega belt rocks and Ocoee Supergroup rocks near Cartersville, Georgia, *in* Bearce, D.N., Black, W.W., Kish, S.A., and Tull, J.F., eds., Tectonic studies in the Talladega and Carolina slate belts, southern Appalachian orogen: Geological Society of America Special Paper 191, p. 19–30.

———1984, Basement-cover relationships along the western edge of the Blue Ridge thrust sheet in Georgia, *in* Bartholomew, M.J., ed., The Grenville event in the Appalachians and related topics: Geological Society of America Special Paper 194, p. 263–280.

McElhaney, M.S., and McSween, H.Y., Jr., 1983, Petrology of the Chunky Gal Mountain mafic-ultramafic complex, North Carolina: Geological Society of America Bulletin, v. 94, no. 7, p. 855–874.

McLemore, W.H., 1965, The geology of the Pollard's Corner area, Columbia County, Georgia: Athens, Ga., University of Georgia, unpublished M.S. thesis, 49 p.

McSween, H.Y., Jr., Sando, T.W., Clark, S.R., Harden, J.T., and Strange, E.A., 1984, The gabbro-metagabbro association of the southern Appalachian Piedmont: American Journal of Science, v. 284, p. 437–461.

Medlin, J.H., and Crawford, T.J., 1973, Stratigraphy and structure along the Brevard fault zone in western Georgia and Alabama: American Journal of Science, v. 273–A, p. 89–104.

Mellen, James, 1956, Precambrian sedimentation in the northern part of the Cohutta Mountain quadrangle, Georgia: Georgia Mineral Newsletter, v. 9, p. 46–61.

Milici, R.C., 1969, Middle Ordovician stratigraphy in central Sequatchie Valley, Tennessee: Southeastern Geology, v. 11, no. 2, p. 111–127.

———1973, The stratigraphy of Knox County, Tennessee, *in* Geology of Knox County, Tennessee: Tennessee Division of Geology Bulletin 70, p. 9–24.

Milici, R.C., and Smith, J.W., 1969, Stratigraphy of the Chickamauga Supergroup in its type locality: Georgia Geological Survey Bulletin 80, p. 5-35.

Milici, R.C., and Wedow, Helmuth, Jr., 1977, Upper Ordovician and Silurian stratigraphy in Sequatchie Valley and parts of adjacent Valley and Ridge, Tennessee: U.S. Geological Survey Professional Paper 996, 38 p.

Mohr, D.W., 1973, Stratigraphy and structure of part of the Great Smoky and Murphy belt groups, western North Carolina: American Journal of Science, v. 273–A, p. 41–47.

Moore, J.C., and Biju-Duval, Bernard, 1984, Tectonic synthesis, Deep Sea Drilling Project Leg 78A: Structural evolution of offscraped and underthrust sediment, northern Barbados Ridge Complex, *in* Initial Reports of the Deep Sea Drilling Project, 78A: U.S. Government Printing Office, p. 601–613.

Moore, J.C., Cowan, D.S., and Karig, D.E., 1985, Structural styles and deformation fabrics of accretionary complexes: Geology, v. 13, no. 1, p. 77–79.

Moore, J.C., Watkins, J.S., and Shipley, T.H., 1981, Summary of accretionary processes, Deep Sea Drilling Project Leg 66: Offscraping, underplating, and deformation of the slope apron, *in* Initial Reports of the Deep Sea Drilling Project, 66: U.S. Government Printing Office, p. 825–836.

Morgan, B.A., 1977, The Baltimore Complex, Maryland, Pennsylvania, and Virginia, *in* Coleman, R.G., and Irwin, W.P., eds., North American ophiolites: Oregon Department of Geology and Mineral Industries Bulletin 95, p. 41–49.

Munyan, A.C., 1951, Geology and mineral resources of the Dalton quadrangle, Georgia-Tennessee: Georgia Geological Survey Bulletin 57, 128 p.

Murphy, C.F., and Butler, J.R., 1981, Geology of the northern half of the Kings Creek quadrangle, South Carolina, *in* Horton, J.W., Jr., Butler, J.R., and Milton, D.J., eds., Geological investigations of the Kings Mountain belt and adjacent areas in the Carolinas: Carolina Geological Society Field Trip Guidebook 1981, p. 49–64.

Neathery, T.L., 1972, Notes on the stratigraphy of the Hillabee Chlorite Schist in the new Piedmont geology [abs.]: Alabama Academy of Science Journal, v. 43, no. 3, p. 186.

———1975, Rock units in the high-rank belt of the northern Alabama Piedmont, *in* Neathery, T.L., and Tull, J.F., eds., Geologic profiles of the northern Alabama Piedmont: Alabama Geological Society 13th Annual Field Trip Guidebook, p. 9–47.

———1986, Geology and mineral resources of Etowah County, Alabama: Tuscaloosa, Ala., Alabama Geological Survey Bulletin, in press.

Neathery, T.L., and Drahovzal, J.A., 1971, Stop 3 Hensley Mountain Section, *in* Drahovzal, J.A., and Neathery, T.L., eds., The Middle and Upper Ordovician of the Alabama Appalachians: Alabama Geological Society 9th Annual Field Trip Guidebook, p. 185–188.

Neathery, T.L., and Reynolds, J.W., 1973, Stratigraphy and metamorphism of the Wedowee Group: A reconnaissance: American Journal of Science, v. 273, p. 723–741.

Needham, R.E., 1972, The geology of the Murray County, Georgia, talc district: Athens, Ga., University of Georgia, unpublished M.S. thesis, 107 p.

Neilson, M.J., 1983, Structure and stratigraphy of the Dadeville Group within the Tallassee synform, Tallapoosa County, Alabama [abs.]: Geological Society of America Abstracts with Programs, v. 15, no. 2, p. 110.

Nelson, A.E., 1981, Polydeformed rocks of the Lowndesville shear zone in the Greenville 2° quadrangle, South Carolina and Georgia, *in* Horton, J.W., Jr., Butler, J.R., and Milton, D.J., eds., Geological investigations of the Kings Mountain belt and adjacent areas in the Carolinas: Carolina Geological Society Field Trip Guidebook 1981, p. 181–193.

———1982, Geologic map of the Tray Mountain Roadless Area, northern Georgia: U.S. Geological Survey Miscellaneous Field Studies Map MF–1347–A, scale 1:30,000.

Neuman, R.B., 1955, Middle Ordovician rocks of the Tellico-Sevier belt, eastern Tennessee: U.S. Geological Survey Professional Paper 274–F, p. 141–178.

Nisbet, E.G., and Pearce, J.A., 1973, TiO_2 as a possible guide to past spreading rates: Nature, v. 246, p. 468–470.

North American Commission on Stratigraphic Nomenclature, 1983, North American stratigraphic code: American Association of Petroleum Geologists Bulletin, v. 67, p. 841–875.

Odom, A.L., and Fullagar, P.D., 1971, A major discordancy between U-Pb zircon ages and Rb-Sr whole rock ages of late-Precambrian granites in the Blue Ridge province [abs.]: Geological Society of America Abstracts with Programs, v. 3, no. 7, p. 663.

———1973, Geochronologic and tectonic relationships between the Inner Piedmont, Brevard Zone, and Blue Ridge belts, North Carolina: American Journal of Science, v. 273–A, p. 133–149.

———1984, Rb-Sr whole-rock and inherited zircon ages of the plutonic suite of the Crossnore Complex, southern Appalachians, and their implications regarding the time of opening of the petus Ocean, *in* Bartholomew, M.J., ed., The Grenville event in the Appalachians and related topics: Geological Society of America Special Paper 194, p. 255–261.

Odom, A.L., and Hatcher, R.D., Jr., 1980, A characterization of faults in the Appalachian foldbelt: U.S. Nuclear Regulatory Commission Report NUREG/CR–1621, 314 p.

Odom, A.L., Kish, S.A., and Leggo, P.L., 1973, Extension of "Grenville basement" to the southern extremity of the Appalachians: U-Pb ages on zircons [abs.]: Geological Society of America Abstracts with Programs, v. 5, no. 5, p. 425.

Overstreet, W.C., and Bell, Henry, III, 1965, The crystalline rocks of South Carolina: U.S. Geological Survey Bulletin 1183, 126 p.

Palmer, A.R., 1971, The Cambrian of the Appalachian and eastern New England regions, eastern United States, *in* Holland, C.H., ed., Cambrian of the New World: New York, Interscience Publishers, p. 169–217.

———1983, The Decade of North American Geology 1983 geologic time scale: Geology, v. 11, p. 503–504.

Parker, J.M., III, 1979, Geology and mineral resources of Wake County: North Carolina Department of Natural Resources and Community Development, Division of Land Resources, Geological Survey Section Bulletin 86, 122 p.

Pate, M.L., 1980, Gold, pyrite and asbestos deposits of the Villa Rica mining district, west-central Georgia—A preliminary report: Georgia Geologic Survey Open-File Report 81–3, 24 p.

Pavlides, Louis, 1981, The central Virginia volcanic-plutonic belt: an island arc of Cambrian(?) age: U.S. Geological Survey Professional Paper 1231–A, 34 p.

Peacock, M.A., 1931, Classification of igneous rocks: Journal of Geology, v. 39, p. 54–67.

Pearce, J.A., 1975, Basalt geochemistry used to investigate past-tectonic environments on Cyprus: Tectonophysics, v. 25, p. 41–67.

———1979, Geochemical evidence for the genesis and eruptive setting of lavas from Tethyan ophiolites, *in* Panayiotow, A., ed., Ophiolites, Proceedings of the International Ophiolite Symposium, Cyprus: Cyprus Geological Survey Department, p. 261–272.

Pearce, J.A., and Cann, J.R., 1973, Tectonic setting of basic volcanic rocks determined using trace element analyses: Earth and Planetary Science Letters, v. 19, no. 2, p. 290–300.

Pearce, J.A., and Norry, M.J., 1979, Petrogenetic indications of Ti, Zr, Y, and Nb variations in volcanic rocks: Contributions to Mineralogy and Petrology, v. 69, p. 33–47.

Pojeta, John, Jr., Kříž, Jiří, and Berdan, J.M., 1976, Silurian-Devonian pelecypods and Paleozoic stratigraphy of subsurface rocks in Florida and Georgia and related Silurian pelecypods from Bolivia and Turkey: U.S. Geological Survey Professional Paper 879, 32 p.

Posey, H.H., 1981, A model for the origin of metallic mineral deposits in the Kings Mountain belt, *in* Horton, J.W., Jr., Butler, J.R., and Milton, D.J., eds., Geological investigations of the Kings

Mountain belt and adjacent areas in the Carolinas: Carolina Geological Society Field Trip Guidebook 1981, p. 130–141.

Power, W.R., and Forrest, J.T., 1971, Stratigraphy and structure of the Murphy belt, North Carolina; Carolina Geological Society Field Trip Guidebook: Raleigh, N.C., North Carolina Department of Natural Resources, 29 p.

———1973, Stratigraphy and paleogeography in the Murphy Marble belt: American Journal of Science, v. 273, p. 698–711.

Prather, J.P., 1971, The geology of eastern Monroe County, Georgia: Athens, Ga., University of Georgia, unpublished M.S. thesis, 82 p.

Prather, J.P., and Radcliffe, Dennis, 1970, Petrology of the norites of Monroe County, Georgia [abs.]: Geological Society of America Abstracts with Programs, v. 2, no. 3, p. 238.

Price, R.S., and Hatcher, R.D., Jr., 1983, Tectonic significance of similarities in the evolution of the Alabama-Pennsylvania Appalachians and the Alberta-British Columbia Canadian Cordillera, *in* Hatcher, R.D., Jr., Williams, Harold, and Zietz, Isidore, eds., Contributions to the tectonics and geophysics of mountain chains: Geological Society of America Memoir 158, p. 149–160.

Prouty, W.F., 1916, The crystalline and other marbles of Alabama: Alabama Geological Survey Bulletin 18, 48 p.

———1923, Geology and mineral resources of Clay County: Alabama Geological Survey County Report No. 1, 190 p.

Prowell, D.C., 1972, Ultramafic plutons in the central Piedmont of Georgia: Atlanta, Ga., Emory University, unpublished M.S. thesis, 83 p.

Rankin, D.W., 1970, Stratigraphy and structure of Precambrian rocks in northwestern North Carolina, *in* Fisher, G.W., Pettijohn, F.J., Reed, J.C., Jr., and Weaver, K.N., eds., Studies of Appalachian geology—Central and southern: New York, Interscience Publishers, p. 227–245.

———1975, The continental margin of eastern North America in the southern Appalachians: the opening and closing of the proto-Atlantic Ocean: American Journal of Science, v. 275–A, p. 298–336.

———1976, Appalachian salients and recesses: late Precambrian continental breakup and the opening of the Iapetus Ocean: Journal of Geophysical Research, v. 81, no. 32, p. 5605–5619.

Rankin, D.W., Stern, T.W., Reed, J.C., Jr., and Newell, M.F., 1969, Zircon ages of felsic volcanic rocks in the upper Precambrian of the Blue Ridge, central and southern Appalachian Mountains: Science, v. 166, no. 3906, p. 741–744.

Ratcliffe, N.M., 1975, Cross section of the Berkshire massif at 42°N: Profile of a basement reactivation zone, *in* New England Intercollegiate Geological Conference, 67th Annual Meeting, Great Barrington, Mass., Oct. 10–12, 1975, Guidebook for field trips in western Massachusetts, northern Connecticut and adjacent areas of New York: New York, City College of City University of New York, Department of Earth and Planetary Sciences, p. 186–222.

———1979, Field guide to the Chatham and Greylock slices of the Taconic allochthon in western Massachusetts and their relationship to the Hoosac-Rowe sequence, *in* New England Intercollegiate Conference, 71st Annual Meeting, and New York State Geological Association, 51st Annual Meeting, Troy, N.Y., Oct. 5–7, 1979, Guidebook: Troy and Albany, N.Y., Rensselaer Polytechnic Institute and New York State Geological Survey, p. 388–425.

Ratcliffe, N.M., and Hatch, N.L., Jr., 1979, A traverse across the Taconide zone in the area of the Berkshire massif, western Massachusetts, *in* Skehan, J.W., and Osberg, P.H., eds., The Caledonides in the U.S.A., Geological excursions in the northeast Appalachians: Weston, Mass., Weston Observatory, p. 175–224.

Read, J.F., 1985a, Carbonate platform facies models: American Association of Petroleum Geologists Bulletin, v. 69, no. 1, p. 1–21.

———1985b, Evolution of Cambrian-Ordovician carbonate shelf, United States Appalachians [abs.]: American Association of Petroleum Geologists Bulletin (Association Round Table), v. 69, no. 2, p. 299.

Reed, J.C., Jr., and Bryant, Bruce, 1964, Evidence for strike-slip faulting along the Brevard zone in North Carolina: Geological Society of America Bulletin, v. 75, p. 1177–1196.

Reynolds, J.W., 1972, New data on the nature of the Ashland-Hillabee contact in Clay and Coosa Counties, Alabama [abs.]: Alabama Academy of Science Journal, v. 43, no. 3, p. 187.

———1973, Mafic and ultramafic rocks near Goodwater, Alabama: Tuscaloosa, Ala., University of Alabama, unpublished M.S. thesis, 135 p.

Rheams, K.F., 1982, The petrography and structure of the Mitchell Dam Amphibolite and the surrounding Higgins Ferry Formation, Chilton and Coosa Counties, Alabama: Tuscaloosa, Ala., University of Alabama, unpublished M.S. thesis, 124 p.

Rich, J.L., 1934, Mechanics of low-angle overthrusting as illustrated by the Cumberland overthrust block, Va., Ky., and Tenn.: American Association of Petroleum Geologists Bulletin, v. 18, p. 1584–1596.

Rich, Mark, 1983, Stratigraphy of the Floyd Formation (Meramecian-Chesterian) in the Rome area, Georgia, *in* Chowns, T.M., ed., Geology of Paleozoic rocks in the vicinity of Rome, Georgia; Georgia Geological Society 18th Annual Field Trip Guidebook: [Atlanta, Ga., Georgia State University,] p. 16–29.

Rindsberg, A.K., 1982, Ichnology and paleoecology of the Sequatchie and Red Mountain Formations (Ordovician-Silurian), Georgia-Tennessee: Athens, Ga., University of Georgia, unpublished M.S. thesis, 365 p.

Rodgers, John, 1953, Geologic map of east Tennessee with explanatory text: Tennessee Division of Geology Bulletin 58, part 2, 168 p.

———1964, Basement and no-basement hypotheses in the Jura and the Appalachian Valley and Ridge: Virginia Polytechnic Institute and State University, Department of Geological Sciences Memoir 1, p. 71–80.

———1968, The eastern edge of the North American continent during the Cambrian and Early Ordovician, *in* Zen, E-an, White, W.S., Hadley, J.B., and Thompson, J.B., Jr., eds., Studies of Appalachian geology—Northern and maritime: New York, Interscience Publishers, p. 141–149.

———1970, The tectonics of the Appalachians: New York, Wiley Interscience, 271 p.

———1972, Latest Precambrian (post-Grenville) rocks of the Appalachian region: American Journal of Science, v. 272, p. 507–520.

———1982, The life history of a mountain range—The Appalachians, *in* Hsu, K.J., ed., Mountain building processes: London, Academic Press, p. 229–241.

Rogers, J.J.W., 1982, Criteria for recognizing environments of formation of volcanic suites; application of these criteria to volcanic suites in the Carolina slate belt, *in* Bearce, D.N., Black, W.W., Kish, S.A., and Tull, J.F., eds., Tectonic studies in the Talladega and Carolina slate belts, southern Appalachian orogen: Geological Society of America Special Paper 191, p. 99–107.

Roper, P.J., and Dunn, D.E., 1971, Polymetamorphism of the Brevard zone and Blue Ridge of northwestern South Carolina [abs.]: Geological Society of America Abstracts with Programs, v. 3, no. 7, p. 688.

———1973, Microtextures as indicators of polydeformation and metamorphism in the Brevard zone, South Carolina [abs.]:

Geological Society of America Abstracts with Programs, v. 5, no. 5, p. 408.

Roper, P.J., and Justus, P.S., 1973, Polytectonic evolution of the Brevard Zone: American Journal of Science, v. 273–A, p. 105–132.

Ross, C.R., II, and Bickford, M.E., 1980, The U-Pb age of zircons from the Elberton Granite, Piedmont of Georgia, *in* Stormer, J.C., Jr., and Whitney, J.A., eds., Geological, geochemical, and geophysical studies of the Elberton batholith, eastern Georgia: Georgia Geologic Survey Guidebook 19, p. 52–62.

Rowley, D.B., and Kidd, W.S.F., 1981, Stratigraphic relationships and detrital composition of the medial Ordovician flysch of ern New England: Implications for the tectonic evolution of the Taconic orogeny: Journal of Geology, v. 89, p. 199–218.

Rozen, R.W., 1978, The geology of the Elberton East quadrangle, Georgia: Athens, Ga., University of Georgia, unpublished M.S. thesis, 110 p.

———1981, The Middleton-Lowndesville cataclastic zone in the Elberton East quadrangle, Georgia, *in* Horton, J.W., Jr., Butler, J.R., and Milton, D.J., eds., Geological investigations of the Kings Mountain belt and adjacent areas in the Carolinas: Carolina Geological Society Field Trip Guidebook 1981, p. 174–180.

Russell, G.S., 1976, Rb-Sr evidence from cataclastic rocks for Devonian faulting in the southern Appalachians [abs.]: Geological Society of America Abstracts with Programs, v. 8, no. 6, p. 1081.

———1978, U-Pb, Rb-Sr, and K-Ar isotopic studies bearing on the tectonic development of the southernmost Appalachian orogen, Alabama: Tallahassee, Fla., Florida State University, unpublished Ph.D. dissertation, 197 p.

Russell, G.S., Russell, C.W., and Golden, B.K., 1984, The Taconic history of the northern Alabama Piedmont [abs.]: Geological Society of America Abstracts with Programs, v. 16, no. 3, p. 191.

Safford, J.M., 1851, The Silurian basin of middle Tennessee with notices of the strata surrounding it: American Journal of Science, 2d ser., v. 12, p. 352–361.

Salisbury, J.W., 1961, Geology and mineral resources of the northwest quarter of the Cohutta Mountain quadrangle: Georgia Geological Survey Bulletin 71, 61 p.

Salvador, Amos, 1985, Chronostratigraphic and geochronometric scales in COSUNA stratigraphic correlation charts of the United States: American Association of Petroleum Geologists Bulletin, v. 69, no. 2, p. 181–189.

Samson, S.L., Secor, D.T., Jr., Snoke, A.W., and Palmer, A.R., 1982, Geological implications of recently discovered Middle Cambrian trilobites in the Carolina slate belt [abs.]: Geological Society of America Abstracts with Programs, v. 14, no. 7, p. 607.

Sanders, R.P., 1983, Major element chemistry of tonalitic and trondhjemitic rocks in the west Georgia Piedmont [abs.]: Geological Society of America Abstracts with Programs, v. 15, no. 2, p. 46.

Sanders, R.P., Jeffers, L., and Reid, B.J., 1979, Petrology of elliptical calcareous pods in metagreywackes [abs.]: Georgia Journal of Science, v. 37, no. 2, p. 88.

Schamel, Steven, and Bauer, David, 1980, Remobilized Grenville basement in the Pine Mountain window, *in* Wones, D.R., ed., The Caledonides in the U.S.A.; International Geological Correlation Program, project 27: Caledonide orogen: Virginia Polytechnic Institute and State University Department of Geological Sciences Memoir 2, p. 313–316.

Schamel, Steven, Hanley, T.B., and Sears, J.W., 1980, Geology of the Pine Mountain window and adjacent terranes in the Piedmont province of Alabama and Georgia—Guidebook, 29th Annual Meeting of Southeastern Section, Geological Society of America, Birmingham, Ala., 1980: University, Ala., Alabama Geological Society, 69 p.

Sears, J.W., 1985, A model for the growth and detachment of a footwall duplex beneath the Piedmont–Blue Ridge allochthon, Alabama and Georgia [abs.]: Geological Society of America Abstracts with Programs, v. 17, no. 2, p. 134.

Sears, J.W., and Cook, R.B., 1984, An overview of the Grenville basement complex of the Pine Mountain window, Alabama and Georgia, *in* Bartholomew, M.J., ed., The Grenville event in the Appalachians and related topics: Geological Society of America Special Paper 194, p. 281–287.

Sears, J.W., Cook, R.B., and Brown, D.E., 1981, Contrasts in tectonic style between the Inner Piedmont terrane and the Pine Mountain window: Alabama Geological Society 18th Annual Field Trip Guidebook, p. 1–14.

Sears, J.W., Cook, R.B., Gilbert, O.E., Jr., Carrington, T.J., and Schamel, Steven, 1981, Stratigraphy and structure of the Pine Mountain window in Georgia and Alabama, *in* Wigley, P.B., ed., Latest thinking on the stratigraphy of selected areas in Georgia: Georgia Geologic Survey Information Circular 54–A, p. 41–53.

Secor, D.T., Jr., Samson, S.L., Snoke, A.W., and Palmer, A.R., 1983, Confirmation of the Carolina slate belt as an exotic terrane: Science, v. 221, p. 649–650.

Secor, D.T., Jr., and Snoke, A.W., 1978, Stratigraphy, structure, and plutonism in the central South Carolina Piedmont, *in* Snoke, A.W., ed., Geological investigations of the eastern Piedmont, southern Appalachians: Columbia, S.C., South Carolina State Development Board, Division of Geology, Guidebook, Carolina Geological Society, p. 65–123.

Shapiro, Leonard, 1975, Rapid analysis of silicate, carbonate, and phosphate rocks—Revised edition: U.S. Geological Survey Bulletin 1401, 76 p.

Sharp, W.E., and Hornig, C.A., 1981, The barite deposit at Kings Creek, South Carolina, *in* Horton, J.W., Jr., Butler, J.R., and Milton, D.J., eds., Geological investigations of the Kings Mountain belt and adjacent areas in the Carolinas: Carolina Geological Society Field Trip Guidebook 1981, p. 120–129.

Shaw, C.E., 1970, Age and stratigraphic relations of the Talladega Slate: evidence of pre-Middle Ordovician tectonism in central Alabama: Southeastern Geology, v. 11, no. 4, p. 253–268.

———1973, Stratigraphy, structure, and tectonics of rocks adjacent to the Piedmont physiographic front in Talladega County, Alabama, *in* Carrington, T.J., ed., Talladega metamorphic front: Alabama Geological Society 11th Annual Field Trip Guidebook, p. 56–65, 101–103.

Shaw, C.E., and Rodgers, John, 1963, Subdivisions of the Talladega Slate of Alabama [abs.]: Geological Society of America Special Paper 87, p. 239–240.

Shaw, H.F., and Wasserburg, G.J., 1984, Isotopic constraints on the origin of Appalachian mafic complexes: American Journal of Science, v. 284, p. 319–349.

Sibley, D.M., 1983, The structural fabric of the Rockmart Slate and its relation to the timing of orogenesis in the Valley and Ridge province of northwest Georgia: Auburn, Ala., Auburn University, unpublished M.S. thesis, 121 p.

Sinha, A.K., Guy, Russell, Hund, Erik, and Tamburro, Edie, 1985, Thermal and tectonic evolution of the central and southern Appalachians: Evidence from distribution, age, and origin of granitic rocks [abs.]: Geological Society of America Abstracts with Programs, v. 17, no. 7, p. 719.

Sinha, A.K., and Zietz, Isidore, 1982, Geophysical and geochemical evidence for a Hercynian magmatic arc, Maryland to Georgia: Geology, v. 10, no. 11, p. 593–596.

Slack, J.F., 1982, Tourmaline in Appalachian-Caledonian massive sulfide deposits and its exploration significance: Institute of Mining and Metallurgy Transactions, Section B, v. 91, p. B81–B89.

Slater, W.R., 1982, Massive sulfide deposits of the Ducktown mining district, Tennessee, *in* Exploration for metallic resources in the southeast: Athens, Ga., University of Georgia, [Dept. of Geology,] p. 91–99.

Slater, W.R., Misra, K.C., and Acker, C.P., II, 1985, Massive sulfide deposits of the Ducktown district, Tennessee, *in* Woodward, N.B., ed., Field trips in the southern Appalachians, field trips 1–5, 7: University of Tennessee, Department of Geological Sciences Studies in Geology 9, p. 171–190.

Smith, J.W., Wampler, J.M., and Green, M.A., 1969, Isotopic dating and metamorphic isograds of the crystalline rocks of Georgia: Georgia Geological Survey Bulletin 80, p. 121–139.

Smith, R.E., and Smith, S.E., 1976, Comments on the use of Ti, Zr, Y, Sr, K, P, and Nb in classification of basaltic magmas: Earth and Planetary Science Letters, v. 32, p. 114–120.

Smith, W.E., 1979, Pennsylvanian stratigraphy of Alabama, *in* Thomas, W.A., and others, The Mississippian and Pennsylvanian (Carboniferous) systems in the United States—Alabama and Mississippi: U.S. Geological Survey Professional Paper 1110–I, p. I23–I36.

Smith, W.E., Neathery, T.L., and Drahovzal, J.A., 1971, Ordovician K-bentonites in Alabama, *in* Drahovzal, J.A., and Neathery, T.L., eds., The Middle and Upper Ordovician of the Alabama Appalachians: Alabama Geological Society 9th Annual Field Trip Guidebook, p. 125–135.

Snoke, A.W., Secor, D.T., Jr., Bramlett, K.W., and Prowell, D.C., 1980, Geology of the eastern Piedmont fault system in South Carolina, *in* Frey, R.W., ed., Excursions in southeastern geology, v. 1: Falls Church, Va., American Geological Institute, p. 59–100.

St-Julien, Pierre, and Hubert, Claude, 1975, Evolution of the Taconian orogen in the Quebec Appalachians: American Journal of Science, v. 275–A, p. 337–362.

Stanley, R.S., and Ratcliffe, N.M., 1980, Accretionary collapse of the western margin of Iapetus in central New England during the Taconic orogeny [abs.]: Geological Society of America Abstracts with Programs, v. 12, p. 85.

Stanton, R.L., 1976a, Petrochemical studies of the ore environment at Broken Hill, New South Wales: 1—Constitution of "banded iron formation": Transactions of the Institution of Mining and Metallurgy, section B, v. 85, p. B33–B46.

———1976b, Petrochemical studies of the ore environment at Broken Hill, New South Wales: 4—Environmental synthesis: Transactions of the Institution of Mining and Metallurgy, section B, v. 85, p. B221–B233.

Stevens, R.K., 1970, Cambro-Ordovician flysch sedimentation and tectonics in western Newfoundland and their possible bearing on a proto-Atlantic, *in* Lajoie, J., ed., Flysch sedimentology in North America: Geological Association of Canada Special Paper 7, p. 165–178.

Stevens, R.K., and Williams, Harold, 1973, The emplacement of the Humber Arm Allochthon, western Newfoundland [abs.]: Geological Society of America Abstracts with Programs, v. 5, no. 2, p. 222.

Stieve, A.L., 1984, Petrologic variation of the granulites and related gneisses of Pine Mountain Terrane, Georgia: Atlanta, Ga., Emory University, unpublished M.S. thesis, 88 p.

Stonebreaker, J.D., and Harper, C.T., 1973, Potassium-argon geochronology of the Brevard zone [abs.]: Geological Society of America Abstracts with Programs, v. 5, no. 5, p. 439.

Stose, A.J., and Stose, G.W., 1957, Geology and mineral resources of the Gossan Lead district and adjacent areas in Virginia: Virginia Division of Mineral Resources Bulletin 72, 233 p.

Stow, S.H., 1982, Igneous petrology of the Hillabee Greenstone, northern Alabama Piedmont, *in* Bearce, D.N., Black, W.W., Kish, S.A., and Tull, J.F., eds., Tectonic studies in the Talladega and Carolina slate belts, southern Appalachian orogen: Geological Society of America Special Paper 191, p. 79–92.

Stow, S.H., Neilson, M.J., and Neathery, T.L., 1984, Petrography, geochemistry, and tectonic significance of the amphibolites of the Alabama Piedmont: American Journal of Science, v. 284, p. 416-436.

Stow, S.H., and Tull, J.F., 1982, Geology and geochemistry of the stratabound sulfide deposits of the Pyriton district, Alabama: Economic Geology, v. 77, p. 322-334.

Sun, Shen-Su, and Nesbitt, R.W., 1978, Geochemical regularities and genetic significance of ophiolitic basalts: Geology, v. 6, no. 11, p. 689–693.

Sun, Shen-Su, Nesbitt, R.W., and Sharaskin, A.Y., 1979, Geochemical characteristics of mid-ocean ridge basalts: Earth and Planetary Science Letters, v. 44, p. 119–138.

Sundelius, H.W., 1970, The Carolina slate belt, *in* Fisher, G.W., Pettijohn, F.J., Reed, J.C., Jr., and Weaver, K.N., eds., Studies of Appalachian geology—Central and southern: New York, Interscience Publishers, p. 351–367.

Sutley, D.E., 1977, A petrographic and paleoenvironmental study of the Jemison Chert, Chilton County, Alabama: Tuscaloosa, Ala., University of Alabama, unpublished M.S. thesis, 74 p.

Telle, W.R., 1981, Depositional setting of the diamictite facies of the Lay Dam Formation, Talladega slate belt, Chilton County, Alabama: Tuscaloosa, Ala., University of Alabama, unpublished M.S. thesis, 74 p.

Telle, W.R., Tull, J.F., and Russell, C.W., 1979, Tectonic significance of the bouldery facies of the Lay Dam Formation, Talladega slate belt, Chilton County, Alabama [abs.]: Geological Society of America Abstracts with Programs, v. 11, no. 4, p. 215.

Thomas, M.D., 1983, Tectonic significance of paired gravity anomalies in the southern and central Appalachians, *in* Hatcher, R.D., Jr., Williams, Harold, and Zietz, Isidore, eds., Contributions to the tectonics and geophysics of mountain chains: Geological Society of America Memoir 158, p. 113–124.

Thomas, W.A., 1979, Mississippian stratigraphy of Alabama, *in* The Mississippian and Pennsylvanian (Carboniferous) systems in the United States—Alabama and Mississippi: U.S. Geological Survey Professional Paper 1110–I, p. I1–I22.

Thomas, W.A., and Cramer, H.R., 1979, The Mississippian and Pennsylvanian (Carboniferous) systems in the United States—Georgia: U.S. Geological Survey Professional Paper 1110–H, 37 p.

Thomas, W.A., and Drahovzal, J.A., 1973, Regional Paleozoic stratigraphy of Alabama, *in* Carrington, T.J., ed., Talladega metamorphic front: Alabama Geological Society 11th Annual Field Trip Guidebook, p. 66–91.

Thomas, W.A., and Neathery, T.L., 1980, Tectonic framework of the Appalachian orogen in Alabama, *in* Frey, R.W., ed., Excursions in southeastern geology, v. 2: Falls Church, Va., American Geological Institute, p. 465–528.

Thompson, A.M., 1971, Clastic-carbonate facies relationships and paleoenvironments in Upper Ordovician rocks of northeast Alabama, *in* Drahovzal, J.A., and Neathery, T.L., eds., The Middle and Upper Ordovician of the Alabama Appalachians: Alabama Geological Society 9th Annual Field Trip Guidebook, p. 63–78.

———1973, An algal bioherm in the Shady Formation near Oldfield, Alabama, *in* Carrington, T.J., ed., Talladega metamorphic front: Alabama Geological Society 11th Annual Field Trip Guidebook, p. 92–100.

Tull, J.F., 1978, Structural development of the Alabama Piedmont northwest of the Brevard Zone: American Journal of Science, v. 278, p. 442–460.

———1979, Stratigraphic and structural relationships of the eastern Talladega slate belt of Alabama, *in* Tull, J.F., and Stow, S.H., eds., The Hillabee metavolcanic complex and associated rock sequences: Alabama Geological Society 17th Annual Field Trip Guidebook, p. 3–13.

———1982, Stratigraphic framework of the Talladega slate belt, Alabama Appalachians, *in* Bearce, D.N., Black, W.W., Kish, S.A., and Tull, J.F., eds., Tectonic studies in the Talladega and Carolina slate belts, southern Appalachian orogen: Geological Society of America Special Paper 191, p. 3–18.

———1984, Polyphase late Paleozoic deformation in the southeastern foreland and northwestern Piedmont of the Alabama Appalachians: Journal of Structural Geology, v. 6, no. 3, p. 223–234.

———1985, Stratigraphy of the Sylacauga Marble Group, *in* Tull, J.F., Bearce, D.N., and Guthrie, G.M., eds., Early evolution of the Appalachian miogeocline: Upper Precambrian-lower Paleozoic stratigraphy of the Talladega slate belt: Alabama Geological Society 22nd Annual Field Trip Guidebook, p. 21–26.

Tull, J.F., and Guthrie, G.M., 1983, Talladega belt/Blue Ridge belt stratigraphies—Can they be correlated? [abs.]: Geological Society of America Abstracts with Programs, v. 15, no. 2, p. 95.

Tull, J.F., and Stow, S.H., 1980a, The Hillabee Greenstone: a mafic volcanic complex in the Appalachian Piedmont of Alabama: Geological Society of America Bulletin, v. 91, pt. 1, p. 27–36.

———1980b, Structural and stratigraphic setting of arc volcanism in the Talladega slate belt in Alabama, *in* Frey, R.W., ed., Excursions in southeastern geology, v. 2: Falls Church, Va., American Geological Institute, p. 545–581.

———1982, Geologic setting of the Hillabee metavolcanic complex and associated stratabound sulfide deposits in the Appalachian Piedmont of Alabama: Economic Geology, v. 77, p. 312–321.

Tull, J.F., Stow, S.H., Long, Lamar, and Hayes-Davis, Bertram, 1978, The Hillabee Greenstone: Stratigraphy, geochemistry, structure, mineralization and theories of origin: University of Alabama Mineral Resources Institute, Research Report 1, 100 p.

Ulrich, E.O., 1911, Revision of the Paleozoic systems: Geological Society of America Bulletin, v. 22, p. 281–680.

Upadhyay, H.D., Dewey, J.F., and Neale, E.R.W., 1971, The Betts Cove ophiolite complex, Newfoundland: Appalachian oceanic crust and mantle: Geological Association of Canada Proceedings, v. 24, no. 1, p. 27–34.

Vincent, H.R., 1984, Geologic map of the Siloam Granite and vicinity, eastern Georgia: Georgia Geologic Survey Geologic Atlas 1, scale 1:48,000.

Waldbaum, D.R., 1971, Temperature changes associated with adiabatic decompression in geological processes: Nature, v. 232, p. 545–547.

Wallace, B.M., 1981, Petrography and chemistry of the Wahoo Creek Formation, Stone Mountain quadrangle, Georgia [abs.]: Georgia Journal of Science, v. 39, no. 2, p. 71.

Webb, J.E., 1958, Reconnaissance geologic survey of parts of Polk and Haralson Counties, Georgia: Georgia Mineral Newsletter, v. 11, no. 1, p. 19–24.

Wenner, D.B., 1980, Oxygen isotope variations within the Elberton Granite pluton, *in* Stormer, J.C., Jr., and Whitney, J.A., eds., Geological, geochemical, and geophysical studies of the Elberton batholith, eastern Georgia: Georgia Geologic Survey Guidebook 19, p. 31–43.

Whisonant, R.C., 1970, Paleocurrents in basal Cambrian rocks in central Tennessee: Geological Society of America Bulletin, v. 81, p. 2781–2786.

———1974, Petrology of the Chilhowee Group (Cambrian and Cambrian?) in central, eastern, and southern Tennessee: Journal of Sedimentary Petrology, v. 44, p. 228–241.

White, J.S., 1981, Mineralogy of the Foote mine, Kings Mountain, North Carolina, *in* Horton, J.W., Jr., Butler, J.R., and Milton, D.J., eds., Geological investigations of the Kings Mountain belt and adjacent areas in the Carolinas: Carolina Geological Society Field Trip Guidebook 1981, p. 39–48.

White, W.A., 1950, Blue Ridge front—a fault scarp: Geological Society of America Bulletin, v. 71, p. 1309–1346.

Whitney, J.A., and Hess, J.R., 1980, Geochronology and cooling history of the Elberton Granite, *in* Stormer, J.C., Jr., and Whitney, J.A., eds., Geological, geochemical, and geophysical studies of the Elberton batholith, eastern Georgia: Georgia Geologic Survey Guidebook 19, p. 63–79.

Whitney, J.A., Paris, T.A., Carpenter, R.H., and Hartley, M.E., III, 1978, Volcanic evolution of the southern slate belt of Georgia and South Carolina: a primitive oceanic island arc: Journal of Geology, v. 86, p. 173–192.

Whitney, J.A., and Stormer, J.C., Jr., 1980, Road log for the 1980 Georgia Geological Society field trip, *in* Stormer, J.C., Jr., and Whitney, J.A., eds., Geological, geochemical, and geophysical studies of the Elberton batholith, eastern Georgia: Georgia Geologic Survey Guidebook 19, p. 108–134.

Williams, Harold, 1975, Structural succession, nomenclature, and interpretation of transported rocks in western Newfoundland: Canadian Journal of Earth Sciences, v. 12, p. 1874–1894.

———(compiler), 1978, Tectonic lithofacies map of the Appalachian orogen: St. Johns, Newfoundland, Memorial University of Newfoundland, Map no. 1, scale 1:1,000,000, Map no. 1a, scale 1:2,000,000.

———1979, Appalachian orogen in Canada: Canadian Journal of Earth Sciences, v. 16, no. 3, p. 792–807.

Williams, Harold, and Hatcher, R.D., Jr., 1982, Suspect terranes and accretionary history of the Appalachian orogen: Geology, v. 10, no. 10, p. 530–536.

———1983, Appalachian suspect terranes, *in* Hatcher, R.D., Jr., Williams, Harold, and Zietz, Isidore, eds., Contributions to the tectonics and geophysics of mountain chains: Geological Society of America Memoir 158, p. 33–53.

Williams, Harold, Kennedy, M.J., and Neale, E.R.W., 1972, The Appalachian structural province, *in* Price, R.A., and Douglass, R.J.W., eds., Variations in tectonic styles in Canada: Geological Association of Canada Special Paper 11, p. 181–261.

Williams, Harold, and Smyth, W.R., 1973, Metamorphic aureoles beneath ophiolite suites and Alpine peridotites: tectonic implications with west Newfoundland examples: American Journal of Science, v. 273, no. 7, p. 594–621.

Williams, Harold, and Stevens, R.K., 1974, The ancient continental margin of eastern North America, *in* Burke, C.A., and Drake, C.L., eds., The geology of continental margins: New York, Springer-Verlag, p. 781–796.

Williams, Harold, and Talkington, R.W., 1977, Distribution and tectonic setting of ophiolites and ophiolitic melanges in the Appalachian orogen, *in* Coleman, R.G., and Irwin, W.P., eds., North American ophiolites: Oregon Department of Geology and Mineral Industries Bulletin 95, p. 1–11.

Willis, Bailey, 1893, Mechanics of Appalachian structure: U.S. Geological Survey 13th Annual Report, p. 211–281.

Wilson, C.W., Jr., 1949, Pre-Chattanooga stratigraphy in central Tennessee: Tennessee Division of Geology Bulletin 56, 407 p.

Wilson, F.A., 1981, Geologic interpretation of geophysical data from the "Mecklenburg-Weddington" gabbro complex, southern Mecklenburg County, North Carolina, *in* Horton, J.W., Jr., Butler, J.R., and Milton, D.J., eds., Geological investigations of the Kings Mountain belt and adjacent areas in the Carolinas: Carolina Geological Society Field Trip Guidebook 1981, p. 28–38.

Windley, B.F., 1976, The evolving continents: New York, Wiley, 385 p.

Wood, D.A., 1980, The application of a Th-Hf-Ta diagram to problems of tectonomagmatic classification and to establishing the nature of crustal contamination of basaltic lavas of the British Tertiary volcanic province: Earth and Planetary Science Letters, v. 50, no. 1, p. 11–30.

Wood, S.A., and Spera, F.J., 1984, Adiabatic decompression of aqueous solutions: Applications to hydrothermal fluid migration in the crust: Geology, v. 12, no. 12, p. 707–710.

Worthington, J.E., 1964, An exploration program for nickel in the southeastern United States: Economic Geology, v. 59, p. 97–109.

Zen, E-an, 1961, Stratigraphy and structure at the north end of the Taconic Range in west-central Vermont: Geological Society of America Bulletin, v. 72, p. 293–338.

———1967, Time and space relationships of the Taconic allochthon and autochthon: Geological Society of America Special Paper 97, 107 p.

———1968, Nature of the Ordovician orogeny in the Taconic area, *in* Zen, E-an, White, W.S., Hadley, J.B., and Thompson, J.B., Jr., eds., Studies of Appalachian geology—Northern and maritime: New York, Interscience Publishers, p. 129–139.

———1981, An alternative model for the development of the allochthonous southern Appalachian Piedmont: American Journal of Science, v. 281, p. 1153–1163.

———1983, Exotic terranes in the New England Appalachians--Limits, candidates, and ages: A speculative essay, *in* Hatcher, R.D., Jr., Williams, Harold, and Zietz, Isidore, eds., Contributions to the tectonics and geophysics of mountain chains: Geological Society of America Memoir 158, p. 55–81.

APPENDIXES A, B

APPENDIX A.—STRATIGRAPHIC NOMENCLATURE

The purpose of this appendix is to revise and adopt some of the stratigraphic nomenclature of the Appalachian orogen in Georgia and Alabama. Our purpose is to simplify stratigraphic nomenclature as much as possible by abandoning names where more than one name has been used for the same unit, or where one name has been used for two or more very different units, by using established names where possible rather than proposing new names (unless the established names are improper), and by naming as few new units as possible. For rules on stratigraphic nomenclature we adhere to the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983). Following Salvador (1985, p. 187), we use the term Precambrian preferentially over the term Proterozoic as "a general term for that part of the time scale that preceded the Cambrian."

CHICKAMAUGA TERRANE AND KINGSTON, CLINCHPORT, AND ROME THRUST SHEETS

The Chickamauga terrane and overlying Kingston, Clinchport, and Rome thrust sheets of the Rome-Kingston thrust stack are composed of sedimentary and metasedimentary rocks of the Valley and Ridge province and the Cumberland Plateau province.

CHILHOWEE GROUP

Mack (1980) proposed that the Chilhowee Group in Georgia and Alabama is made up of (lowest to highest) the Cochran Formation, a fluvial deposit composed of arkosic conglomerate, arkose, and discontinuous mudstone; the Nichols Formation, an offshore marine deposit composed of greenish-gray mudstone with minor siltstone and very fine sandstone; the Wilson Ridge Formation, a tidal-flat deposit composed of interbedded crossbedded orthoquartzite and ripple-laminated silty mudstone; and the Weisner Formation, a beach-barrier deposit composed of crossbedded and horizontally laminated orthoquartzite, conglomerate, and minor mudstone. The formational names are well documented and are here adopted as defined by Mack (1980).

CONASAUGA GROUP

Hayes (1891, p. 143) used the name Conasauga Shale for "alternating beds of limestone and calcareous shale" exposed along the Conasauga River in northwest Georgia. Milici (1973, p. 11) elevated the name Conasauga to group status and included in it (lowest to highest) the Pumpkin Valley Shale, Rutledge Limestone, Rogersville Shale, Maryville Limestone, Nolichucky Shale, and Maynardville Limestone. We here adopt the name Conasauga Group, for use in Georgia and Alabama, as defined by Milici (1973), but restrict the formations in it to those used by Chowns and McKinney (1980) and Chowns (1983). Chowns and McKinney (1980) and Chowns (1983) divided the Conasauga Group into (lowest to highest) the Honaker Dolomite (Rodgers, 1953), Rogersville Shale, Maryville Limestone, Nolichucky Shale, and Maynardville Limestone (see Milici, 1973). We here adopt these names, for use in Georgia and Alabama, as defined by Milici (1973) and Rodgers (1953) and as used by Chowns and McKinney (1980) and Chowns (1983).

CHICKAMAUGA GROUP AND SUPERGROUP

The name Chickamauga Limestone was used by Hayes (1891, p. 143), from the valley of West Chickamauga Creek in northwestern Georgia, for all strata between the top of the Knox Group and the base of the Rockwood Formation of Hayes (1894), which probably included the Sequatchie Formation of present usage. The Sequatchie was named a separate formation by Ulrich (1911).

The Stones River and Nashville Groups were named by Safford (1851) for exposures in central Tennessee. Following Milici (1969), Milici and Smith (1969) applied the nomenclature of Wilson (1949) to the Chickamauga type area in Georgia, retaining the Stones River and Nashville as group names and elevating the name Chickamauga to supergroup status (table 4). As defined by Milici and Smith (1969), the Chickamauga Supergroup in Georgia is composed of the lower Stones River Group, which consists of (lowest to highest) the Pond Spring Formation, Murfreesboro Limestone, Ridley Limestone, Lebanon Limestone, and Carters Limestone; and the upper Nashville Group, which consists of (lowest to highest) the Hermitage Formation, Cannon Limestone, and Catheys Formation. All of the names are well documented, and we here adopt them, for use in Georgia, as defined by Milici and Smith (1969).

In Alabama, where the section is much thinner, Drahovzal and Neathery (1971) proposed using the Stones River and Nashville as formations (1971, p. 7) "pending more detailed work." They used the name Chickamauga Group and assigned to it (lowest to highest) the Stones River Formation, with its basal Attalla Chert Conglomerate Member, the Nashville Formation, the Inman Formation, and the Leipers Limestone. The names are well documented, and we here adopt them for use in Alabama, as defined by Drahovzal and Neathery (1971).

Neathery (1986), Drahovzal and Neathery (1971), Chowns and McKinney (1980), and Chowns and Carter (1983) have shown that equivalent carbonate-clastic and clastic rocks belonging to the Greensport Formation and Colvin Mountain Sandstone named by Neathery (1986), as used by Drahovzal and Neathery (1971), should be assigned to the Chickamauga Group in Alabama and the Chickamauga Supergroup in Georgia (table 4). The names Greensport Formation and Colvin Mountain Sandstone are here adopted and assigned to the Chickamauga Group and Supergroup.

BILL ARP THRUST SHEET

The Bill Arp thrust sheet is composed of thick sections of clastic metasedimentary rocks that lack volcanogenic components in all but the lowest unit, of generally thin and discontinuous carbonate units that cap the pile of clastic metasediments, of generally calcareous and pelitic units deposited unconformably upon the carbonate units, and of relatively rare Grenville basement upon which the clastic sediments were deposited.

GRENVILLE BASEMENT ROCKS

Known Grenville basement in the Bill Arp thrust sheet crops out in three areas in the crystalline terrane of Georgia: (1) in structurally complex anticlinoria along the western edge of the crystalline terrane, west of the Murphy syncline, in northern Georgia; (2) in the Pine Mountain anticlinorium in central and west-central Georgia and east-central Alabama (pl. 1); and (3) around a complex structural feature in northeast Georgia that has been called the "Tallulah Falls dome" (Hatcher, 1974), where the probable Grenville rocks have been called the Wiley Gneiss by Hatcher (1974). Grenville basement has not yet been identified outside the Pine Mountain anticlinorium in Alabama, but it may be present in anticlinoria cored by the Bill Arp thrust sheet. We here assign all of the Grenville basement rocks in north Georgia to the Allatoona Complex and all of the basement rocks in the Pine Mountain anticlinorium to the Wacoochee Complex.

ALLATOONA COMPLEX (NAMED), CORBIN GNEISS (REVISED AND ADOPTED), RED TOP MOUNTAIN SCHIST (NAMED), FORT MOUNTAIN AND SALEM CHURCH GNEISSES (ABANDONED), COHUTTA SCHIST (ABANDONED)

Rocks of the Grenville basement in northern Georgia are here assigned to the Allatoona Complex, named for exposures along the shores of Lake Allatoona, east of Cartersville, Bartow County (pl. 1; Crawford and Cressler, *in* Cressler and others, 1979; McConnell and Costello, 1984). McConnell and Costello (1984) suggested calling these rocks the Corbin Gneiss Complex to accentuate the lithologic variability of what had previously been called the Corbin Granite (Hayes, 1901) or Corbin Gneiss (see Martin, 1974). Their suggestion was a good one, but they apparently included in their complex the basement schists that have been intruded by the plutonic rocks that had previously been called Corbin Gneiss. This inclusion is proper for the basement complex, which must include the Grenville-age or older country rocks that have been intruded by the plutonic gneisses, but it allows confusion between the names Corbin Gneiss and Corbin Gneiss Complex. We therefore propose that the name Corbin Gneiss be retained for the metaplutonic rocks in the basement complex east and northeast of Cartersville, whereas we propose that the entire assemblage of rocks in the basement complex in northern Georgia be called the Allatoona Complex. We propose that the names Fort Mountain Gneiss (Furcron and others, 1947) and Salem Church Gneiss (Bayley, 1928; Dallmeyer, 1975) be abandoned and the name Corbin Gneiss be used for the Grenville gneisses near Fort Mountain and near Salem Church. These rocks are lithically identical to, in the same stratigraphic position as, and the same age as the Corbin Gneiss. The entire basement complex in these areas is assigned to the Allatoona Complex.

The highly deformed and generally granitized red, silver, and gray schists that occur as xenoliths and roof-pendants in the Corbin Gneiss and also form its country rocks are here named the Red Top Mountain Schist for exposures in Red Top Mountain State Park in the Allatoona Dam, Ga. 7.5-min quadrangle. The type section is designated as the exposures along the shore of Allatoona Reservoir within the park boundaries. The Red Top Mountain is assigned to the Allatoona Complex.

The Allatoona Complex crops out over a relatively large area east and northeast of Cartersville, Ga., where it occupies the core of one of the complex anticlinoria that occur west of the Murphy syncline (pl. 1), and in a smaller outcrop area southwest of Jasper, Ga. In these areas the complex consists primarily of the Corbin Gneiss, which is a coarsely megacrystic (megacrysts are K-feldspar and are probably mostly metaphenocrysts) granitic gneiss (~90 percent) with a pyroxene-bearing phase of the gneiss (~10 percent) that Kesler (1950) called andesine-augite gneiss and Crawford and Cressler (*in* Cressler and others, 1979) mapped as "metagabbro"; older (country rock) metasedimentary schists of the Red Top Mountain Schist that occur chiefly as xenoliths and roof pendants (see Costello, 1978; Crawford and Cressler, *in* Cressler and others, 1979) in the Corbin Gneiss form about 5 to 15 percent of the complex.

The Allatoona Complex is directly and unconformably overlain by clastic metasedimentary rocks of the Pinelog Formation (Hayes, 1895; Hull and others, 1919; McConnell and Costello, 1984), which structurally underlies the clastic metasedimentary sequences in the Great Smoky Group. Hayes (1901, p. 406) recognized that the rocks of the Pinelog Formation (his Pinelog conglomerate) were derived from the Corbin Gneiss, stating, "This area of Corbin granite at one time probably formed an island, since it is surrounded, in part at least, by rocks derived from its own waste." Kesler (1950), however, discounted Hayes' observations and interpretations, stating (1950, p. 20), "Contact relations show that the gneisses are younger than the enclosing metasediments, and were therefore developed in post-Cambrian time. All evidence obtained in the present work indicates that the gneisses were formed by the alteration through igneous influence of large parts of the older rocks." Kesler (1950) suggested that the Corbin and Salem Church Gneisses are Carboniferous. Crickmay (1936), Croft (1963), Hadley (1970), King (1970), and Hurst (1973) all considered the Corbin and Salem Church Gneisses to be Paleozoic intrusive plutons, whereas Fairley (1966, 1973) followed Hayes and considered these gneisses part of the basement upon which the overlying metasedimentary rocks were deposited.

The unconformity between the Corbin Gneiss and the Pinelog Formation has been documented by Costello (1978) and McConnell and Costello (1984). Basal conglomerates of the Pinelog Formation of McConnell and Costello (1980) locally contain pebbles and cobbles of Corbin Gneiss. Thus, at least the lower part of the clastic pile was derived from erosion of the Allatoona Complex. The Pinelog Formation is adopted and assigned to the Ocoee Supergroup.

The Allatoona Complex appears to be retrograded to the amphibolite facies from the granulite facies (Martin, 1974; Dallmeyer, 1975; McConnell and Costello, 1984). Field relations and radiometric ages (Odom and others, 1973; Dallmeyer, 1975; T.W. Stern, oral commun., 1985) indicate that the Corbin Gneiss is a Grenville-age plutonic rock, thereby indicating that the country rocks in the Allatoona Complex are even older (perhaps roughly the same age as the Sparks Schist of the Grenville basement Wacoochee Complex in the Pine Mountain anticlinorium, which they strongly resemble).

Another outcrop area of Allatoona Complex Grenville basement rocks is in the Fort Mountain area (Furcron and others, 1947; Needham, 1972; Russell, 1976; McConnell and Costello, 1984) in the Bill Arp thrust sheet just east of Chatsworth, Ga. (pl. 1). There the Fort Mountain Gneiss, Corbin Granite, and Cohutta Schist of Furcron and others (1947) represent the Allatoona Complex as recognized by McConnell and Costello (1984; their Corbin Gneiss Complex); the "Corbin Granite" and parts of the "Fort Mountain Gneiss" (abandoned) being Corbin Gneiss equivalents, and parts of the "Fort Mountain Gneiss" being equivalent to the country rocks in the Allatoona Complex east and northeast of Cartersville. Furcron and others (1947) gave the name Cohutta Schist to the small altered ultramafic bodies associated with the Allatoona Complex around Fort Mountain; this name is here abandoned following McConnell and Costello (1984).

WACOOCHEE COMPLEX (ADOPTED)

Bentley and Neathery (1970, p. 34) gave the name Wacoochee Complex to all of the rocks structurally beneath the Hollis Quartzite of the Pine Mountain Group in the Pine Mountain block. These rocks are now considered part of the Grenville basement. We here adopt the name Wacoochee Complex for the Grenville basement rocks in the Pine Mountain anticlinorium in Georgia and Alabama. It includes the Woodland Gneiss, the Cunningham Granite, the Sparks Schist, and the Apalachee Formation (named below). The reasons for the assignment of the Sparks Schist to the Wacoochee Complex are given below in the section on the Pine Mountain Group. The Halawaka Schist of Bentley and others (1982) is considered equivalent to the Sparks Schist.

APALACHEE FORMATION (NAMED)

The Apalachee Formation is here named for exposures along roads on both sides of the Apalachee River in the northern third of the Apalachee, Ga. 7.5-min quadrangle. The type section is designated as the exposures along Wagnon Mill Road in the Apalachee quadrangle, and particularly the exposures at the falls on Jacks Creek. The Apalachee Formation is a coarse-grained, granitized, greatly deformed, schistose, generally reddish garnet–sillimanite–K-feldspar–plagioclase–biotite (and biotite–plagioclase) gneiss with scarce amphibolite that weathers to a chocolate-colored soil. The Apalachee is assigned to the Wacoochee Complex and is considered to be about the same age as the Sparks Schist.

GREAT SMOKY GROUP

The Great Smoky Group in the Bill Arp thrust sheet consists of the Frolona and Bill Arp Formations in the Austell-Frolona anticlinorium, the Ola and Kalves Creek Formations in the Ola anticlinorium, and the Richard Russell Gneiss and Copperhill, Wehutty, Hughes Gap, Hothouse, and Dean Formations in northern Georgia. The names Copperhill, Hughes Gap, Hothouse, and Dean Formations of Hurst (1955) are here adopted. The Wehutty Formation is assigned to the Great Smoky Group, and the other units are discussed below.

FROLONA AND BILL ARP FORMATIONS (ADOPTED)

By the early 1970's, the work of Crawford and Medlin (1973, 1974; Medlin and Crawford, 1973) had shown that one of the dominant structures of the Piedmont in western Georgia and eastern Alabama is a large, tight to isoclinal, steeply inclined, northwest-verging antiform, which they considered anticlinal and named the Austell-Frolona anticlinorium (pl. 1, fig. 2). They established a stratigraphy for the area, in which they considered the section to be (from oldest to youngest) the Frolona Formation, Bill Arp Formation, Sandy Springs sequence (now Sandy Springs Group), and an unnamed sequence of metavolcanic and metaplutonic rocks (now assigned to Paulding Volcanic-Plutonic Complex and Ropes Creek Metabasalt).

Crawford and Medlin's (1973, 1974; Medlin and Crawford, 1973) stratigraphic sequence and the anticlinal nature of the Austell-Frolona fold were challenged by Abrams and McConnell (1981; McConnell and Abrams, 1984). They proposed that the Austell-Frolona fold is an antiformal syncline and that the previously established stratigraphic sequence is mostly upside down, with the metavolcanic sequence (their New Georgia Group) the oldest unit, followed by the Sandy Springs Group, and with the Bill Arp Formation at the top of the section. Abrams and McConnell (1981, p. 63) stated,

> Based on our interpretation of stratigraphic relationships and multiple folding within the Austell-Frolona, we believe it represents a second generation, overturned syncline. The Andy Mountain Formation (our Frolona formation equivalent) is still interpreted to be older than the Bill Arp Formation. While all facing criteria have been destroyed by metamorphism and multiple deformation, the gradual transition from a predominantly metavolcanic sequence (New Georgia Group) upward into a predominantly metasedimentary sequence (Roosterville group) supports this structural interpretation.

We don't see why a "gradual transition" from a predominantly metavolcanic sequence to a predominantly metasedimentary sequence would support an inversion of the sequences. Nevertheless, our detailed mapping of the Atlanta 1° × 30′ quadrangle (Higgins, Atkins, and T.J. Crawford, unpublished), which includes the area described by Abrams and McConnell (1981; McConnell and Abrams, 1984), has shown that the stratigraphy of the area is partly a tectonostratigraphy, that graded bedding is widespread and well preserved in the Bill Arp Formation, and that these facing criteria clearly show that the Austell-Frolona fold (though complex) is an anticlinorium.

The Austell-Frolona anticlinorium (pl. 1) extends from west of Roanoke, Ala., to near Austell, Ga. (Crawford and Medlin, 1973, 1974; Medlin and Crawford, 1973). From near Roanoke, Ala., to a few kilometers northwest of Whitesburg, Ga. (pl. 1), the anticlinorium is cored by a thick assemblage (>1,500 m) of clastic metasedimentary rocks, without volcanogenic components, that Crawford and Medlin (1974) named the Frolona Formation for characteristic exposures along secondary roads south and southwest of the community of Frolona, Heard County, Ga., and along Hillabahatchee Creek northeast of Frolona, in the Frolona, Ga. 7.5-min quadrangle; all of these sections are here designated a composite type section, and we propose formal acceptance of the Frolona Formation as defined by Crawford and Medlin (1974). Crawford and Medlin (1974, p. 9) defined the Frolona as follows:

> The thickness of the Frolona is estimated to be approximately 5,000 feet (1,525 m). It consists of the following rock types, interlayered: graphitic staurolite-kyanite-garnet-feldspar-quartz-muscovite schist, nongraphitic mica schist, feldspathic micaceous quartzite, clean quartzite, and quartz-pebble metaconglomerate. The quartzites are fine to coarse grained, commonly feldspathic and micaceous. Layers of quartz-pebble metaconglomerate contain elongate pebbles as large as 8 × 20 mm in a quartz-feldspar-mica matrix.

We here assign the Frolona Formation to the Great Smoky Group of the Ocoee Supergroup (table 1).

Overlying the Frolona Formation is a thick sequence (>2,700 m) of rhythmically interbedded schist and metagraywacke that Crawford and Medlin (1974, p. 9) named the Bill Arp Formation for characteristic exposures along secondary roads west and south of the community of Bill Arp and along the Dog River southwest of Bill Arp, in the Winston, Ga. 7.5-min quadrangle; these sections are here designated a composite type section, and we here propose formal acceptance of the Bill Arp Formation as defined by Crawford and Medlin (1974).

Crawford and Medlin (1974, p. 9) defined the Bill Arp Formation as follows:

> The unit is approximately 9,000 feet (2,745 m) thick. It consists of several rock types: quartz-muscovite-biotite schist, with some layers composed almost entirely of mica, alternating with muscovite-biotite-quartz-feldspar gneiss and schist, sericite schist, and micaceous quartzite; quartzose-feldspathic layers are dominant. Mafic layers are rare, thin and discontinuous where present. Porphyroblastic mica cuts across schistosity and layering, and fractures are filled with coarse mica. Garnets are scarce, small where present. Thin layers of sericite schist contain abundant finely disseminated magnetite and ilmenite; coarse ilmenite is associated with vein quartz.

McConnell and Abrams (1984) assigned the Bill Arp Formation to the top of the Sandy Springs Group. Because the graded bedding in the Bill Arp Formation shows that McConnell and Abrams' (1984) stratigraphic section is inverted and that the Bill Arp is at the bottom of the stratigraphic section (tectonostratigraphic section), we here assign the Bill Arp Formation to the Great Smoky Group of the Ocoee Supergroup. It is structurally several thrust sheets below the Sandy Springs Group.

OLA AND KALVES CREEK FORMATIONS (NAMED)

About 50 km southeast of the Austell-Frolona anticlinorium, the Bill Arp thrust sheet is again exposed in the Ola anticlinorium (pl. 1, fig. 2), where it is composed of a thick sequence (>2,000 m) of clastic metasedimentary rocks that lack volcanogenic components. The lower unit in the Ola antiform is a sequence of medium- to coarse-grained schists with lensoidal units of biotite-plagioclase gneiss (metagraywacke or metasiltstone), here named the Ola Formation for characteristic outcrops in the Ola, Ga. 7.5-min quadrangle. The type section of the Ola is here designated as the section exposed along Turner Church Road between Georgia Highway 20 and Ola Road in the Ola, Ga. 7.5-min quadrangle (this section also contains the type section of the Kalves Creek Formation).

Infolded with the Ola Formation in the Ola antiform is a unit composed of Ola lithologies, but with significant amounts of white- to yellow-white-weathering, graphite-sillimanite schist (graphite in tiny blebs and flakes on the surfaces of fibrous sillimanite) that commonly breaks into spindles upon weathering, here named the Kalves Creek Formation for characteristic exposures along Turner Church Road between Kalves Creek and Airline Road in the Ola, Ga. 7.5-min quadrangle; these outcrops are here designated the type section. The Kalves Creek is never seen fresh except in drill core. In drill core the Kalves Creek has blebs of pyrite that make up as much as 10 percent of the rock.

We here assign the Ola and Kalves Creek Formations to the Great Smoky Group of the Ocoee Supergroup. The Kalves Creek Formation is a lithic match of the Wehutty Formation in northern Georgia, of part of the Frolona Formation in the Austell-Frolona anticlinorium, and of the Manchester Schist in the Pine Mountain anticlinorium (table 1); all these units probably represent the same depositional environment, even though they may have been deposited in separate Ocoee basins.

RICHARD RUSSELL GNEISS (REVISED)

The Richard Russell Formation (Gillon, 1982; Nelson and Gillon, 1985) was named for exposures along the Richard Russell Scenic Highway (Georgia Highway 348) in the Cowrock, Ga. 7.5-min quadrangle. However, our mapping indicates that the Richard Russell should be restricted to the massive, but highly fractured, biotite gneiss with minor amounts of biotite schist (as in the type section) and should not include the schist-amphibolite-gneiss unit west of the gneiss unit, which is the Zebulon Formation (pl. 1), or the few small mafic and ultramafic slices (also see Nelson, 1982) of the Ropes Creek and Soapstone Ridge thrust sheets. Because gneiss makes up more than 90 percent of the unit, we here modify the formation's name to the Richard Russell Gneiss. We assign it to the Great Smoky Group. However, because the Richard Russell resides in a separate thrust slice from the other Great Smoky units in north Georgia, exactly where it fits in the stratigraphic sequence is unknown. Our mapping has also shown that the amphibolite units that both Gillon (1982) and Nelson (1982) assigned to the Richard Russell belong to the Ropes Creek and Soapstone Ridge thrust sheets; they rest in thrust contact upon the Richard Russell. As far as we know, the Richard Russell Gneiss is present in Georgia only in the area shown as Richard Russell thrust slice in plate 1.

In most outcrops the Richard Russell Gneiss lacks bedding or compositional layering because of transposition along closely spaced S-surfaces. The Richard Russell underlies much of the highest mountainous terrain in Georgia. We interpret this as due to the highly fractured nature of the gneiss rather than to resistance to weathering and erosion: meteoric water tends to penetrate through the gneiss to emerge as springs at the base of the formation rather than weathering and eroding it.

PINE MOUNTAIN GROUP (REVISED)

The Pine Mountain Group was traditionally considered to be composed of (lower to upper) the Sparks Schist, Hollis Quartzite, Manchester Schist, and Chewacla Marble (Adams, 1926; Hewett and Crickmay, 1937; Crickmay, 1952; Clarke, 1952). Bentley and Neathery (1970, p. 35) proposed changing the name of the Hollis Quartzite to Hollis Metaorthoquartzite to "avoid confusion with nonmetamorphic sandstones." They also did not consider the Sparks Schist to be part of the Pine Mountain Group. More recently, Sears, Cook, and others (1981) considered the Pine Mountain Group to consist of the Sparks Schist, the Hollis Quartzite, and the Manchester Formation, which they divided into a (lower) Chewacla Schist Member and an upper Chewacla Marble Member. Our study indicates that the Sparks Schist does not belong with the Pine Mountain Group but instead belongs to the Grenville basement. What has been mapped as Sparks Schist in the past is two different schists, one derived from shearing of granulitic basement gneisses (fig. 55), and the other a pelitic schist that has been intruded by the gneisses. We here reinstate the name Sparks Schist and remove it from the Pine Mountain Group. We restrict the Sparks Schist to the pelitic schists in the Wacoochee Complex of Grenville basement. We see no useful purpose in calling the Hollis a "metaorthoquartzite" and retain the name Hollis Quartzite. Our mapping shows that the Manchester is composed of two mappable formations, both depositional equivalents of formations in the Great Smoky Group, but the use of the name Chewacla for two different members of the Manchester (Sears, Cook, and others, 1981) is improper (North American Commission on Stratigraphic Nomenclature, 1983). We propose that the name Manchester Schist be used for the lowermost unit of graphitic and sillimanitic schists, with lesser amounts of thin metagraywacke beds near its top, and propose the name Mountain Creek Formation for interbedded pelitic schist and graywacke that is well exposed around the valley of Mountain Creek in the Pine Mountain Southwest, Ga. 7.5-min quadrangle. The type section is designated as the roadcuts along the paved road running southeast from Smiths Crossroads, from Mountain Creek to approximately 1.5 km southeast of Mountain Creek. The Mountain Creek Formation is lithologically identical to the Bill Arp Formation described above. The Chewacla Marble is discontinuous and poorly exposed (except in one quarry near Chewacla State Park near Auburn, Ala.), but it appears to occur at the same stratigraphic horizon, and for short distances at least it is a mappable unit. Moreover, because of the scarcity of carbonate rocks in the crystalline terrane of Georgia and Alabama and because of the Chewacla's importance to paleogeographic and paleotectonic interpretations, we believe it should be a formation, as did Prouty (1916), Adams (1926, 1930, 1933), and Bentley and Neathery (1970), and here restore the name Chewacla Marble to formational rank. We consider the Pine Mountain Group to consist (in ascending order) of the Hollis Quartzite, Manchester Schist, Mountain Creek Formation, and Chewacla Marble and assign it to the Ocoee Supergroup.

FIGURE 55.—Sheared Grenville basement gneiss (Woodland Gneiss) in the Pine Mountain anticlinorium. Arrow points to euhedral K-feldspar that has survived the shearing; most K-feldspar crystals have been sheared and deformed. Roadcut at corner of first road to the left (east) south of Pine Mountain and Georgia Highway 354, in the Pine Mountain, Ga. 7.5-min quadrangle. Hammer is 40 cm long.

ZEBULON THRUST SHEET

The Zebulon thrust sheet is composed of intimate mixtures of metasedimentary rocks, metavolcanic rocks, and metavolcanogenic sediments. The only unit formally named here is the Zebulon Formation, which forms most of the sheet. The Senoia Formation (Higgins and Atkins, 1981) is revised from a formation to a member of the Zebulon Formation.

ZEBULON FORMATION (NAMED)

Through much of Georgia and Alabama, the Zebulon thrust sheet is composed mostly of a thick (probably >3,000 m) assemblage of intercalated generally pink- to purple-weathering schists (commonly with abundant aluminosilicate minerals and garnet) and ocher-weathering hornblende-plagioclase amphibolites, with lesser amounts of a wide variety of biotite-plagioclase gneisses and granitic gneisses, which we here name the Zebulon Formation for characteristic outcrops in the Zebulon, Ga. 7.5-min quadrangle. The type section is designated as the roadcuts along U.S. Highway 19 from Zebulon, Ga., in the Zebulon 7.5-min quadrangle to Wasp Creek in the Griffin South, Ga. 7.5-min quadrangle. The name Zebulon Formation has already been used in Alabama by Sears, Cook, and others (1981; based on our oral communication with them) and Stow and others (1984; following Sears, Cook, and others, 1981). Some of the rocks of the Zebulon Formation were assigned by McConnell and Abrams (1984) to their Univeter Formation, which is abandoned in this paper.

SENOIA MEMBER OF THE ZEBULON FORMATION (REVISED)

In its uppermost parts the Zebulon Formation has thin (everywhere less than a meter thick, and generally less than 30 cm thick) beds of gondite (spessartine quartzite) and magnetite-bearing gondite, interpreted as metamorphosed volcanogenic chemical sediments. Higgins and Atkins (1981) named this gondite-bearing interval the Senoia Formation, but it has not been mapped separately from the Zebulon Formation in many areas. We here revise the Senoia from a formation to a member of the Zebulon Formation.

ATLANTA THRUST SHEET

The Atlanta thrust sheet is a composite sheet made up of two thrust slices, the (lower) Stonewall slice and the (upper) Clarkston slice. The Stonewall slice is composed of the Stonewall Formation, and the Clarkston slice is composed of (in ascending structural order) the Ison Branch and Barrow Hill Formations, the Clarkston Formation with its Fairburn Member, and the Big Cotton Indian Formation.

Higgins and Atkins (1981) named 12 formations in the Atlanta area, which they included in the Atlanta Group, before the tectonostratigraphic nature of many of the units was recognized. Further work has shown that the Senoia Formation should be a member of the Zebulon Formation in the Zebulon thrust sheet. The Inman Yard Formation is now known to be Clairmont melange belonging to the Clairmont Formation in the Clairmont thrust sheet, so the name Inman Yard Formation is here abandoned. The Camp Creek and Promised Land Formations are now known to be the same formation. The type locality at Promised Land (Higgins and Atkins, 1981) is better than the type locality at Camp Creek, so the name Camp Creek Formation is here abandoned. The Hannah Member of the Promised Land Formation is now known to be a mylonite schist along the Promised Land thrust fault at the base of the Promised Land thrust sheet, so the name Hannah Member is here abandoned. The Tar Creek Member of the Clarkston Formation is identical with Clarkston Formation undivided, so the name Tar Creek Member is here abandoned. The Intrenchment Creek Quartzite is part of what we name below the Barrow Hill Formation, so we here abandon the name Intrenchment Creek Quartzite. The name Atlanta Group is here abandoned. Of the 12 formations of the former Atlanta Group, the Wolf Creek, Promised Land, Clairmont, Wahoo Creek, Stonewall, Clarkston and its Fairburn Member, and Big Cotton Indian Formations and Norcross Gneiss remain in good usage. The new units proposed here are the Ison Branch and Barrow Hill Formations.

McConnell and Abrams (1984, p. 42–43) have recently proposed that the "stratigraphic" sequence in the Atlanta Group (abandoned) is inverted from that proposed by Higgins and Atkins (1981). They proposed correlation of the Big Cotton Indian Formation, Intrenchment Creek Quartzite (abandoned), and Camp Creek Formation (abandoned) with their New Georgia Group (abandoned); correlation of the Clarkston Formation, Stonewall Formation, Wahoo Creek Formation, Clairmont Formation (Clairmont melange including former Inman Yard Formation), Senoia Formation (now a member of the Zebulon Formation), Wolf Creek Formation, Norcross Gneiss, Inman Yard Formation (abandoned), and Promised Land Formation with their "Powers Ferry Formation undifferentiated," and correlation of the Lanier Mountain Quartzite Member (abandoned) of the Snellville Formation (abandoned) with the Chattahoochee Palisades Quartzite of the Sandy Springs Group and of the Norris Lake Schist Member (abandoned) of the Snellville Formation (abandoned) with the Factory Shoals Formation of the Sandy Springs Group. Their correlations and inversion of the sequence in the Newnan-Tucker synform are based entirely on similarities between the gondite in the Barrow Hill Formation (formerly Intrenchment Creek Quartzite) and some parts of iron formations in their New Georgia Group (abandoned; consists of three different thrust sheets—see below), similarities between the Big Cotton Indian Formation and the part of the Sandy Springs Group that they placed in their New Georgia Group, and what they considered similarities between the Camp Creek Formation (abandoned) and parts of their New Georgia Group. Rocks of the former Camp Creek Formation (now Promised Land Formation) and Intrenchment Creek Quartzite (now Barrow Hill Formation) do not bear a lithologic resemblance to the Ropes Creek Metabasalt, Sandy Springs Group, and Paulding Volcanic-Plutonic Complex, which Abrams and McConnell (1981; McConnell and Abrams, 1984) lumped into their New Georgia Group (abandoned). We (Higgins and others, 1984; this paper) have given evidence that the rocks that Higgins and Atkins (1981) assigned to the Atlanta Group (abandoned) are not found northwest of the Brevard Zone. In addition, because graded bedding in the Bill Arp Formation shows that Abrams and McConnell's (1981) and McConnell and Abrams' (1984) interpretation of the stratigraphic sequence northwest of the Brevard Zone is inverted, their proposed inversion of the sequence (chiefly a tectonostratigraphic sequence) in the Newnan-Tucker synform is invalid.

ISON BRANCH AND BARROW HILL FORMATIONS (NAMED)

The Ison Branch Formation, at the base of the Clarkston slice in the Atlanta thrust sheet (figs. 1, 19) is here named for the large roadcut in saprolite along Hill Street just north of Hill Street's juncture with U.S. Highway 41/19 Business, on the north side of Ison Branch, in the Griffin South 7.5-min quadrangle; this roadcut is also designated the type section. The Ison Branch is a relatively thin unit (at most a few hundred meters are preserved) of metamorphosed, finely laminated, graphitic, calcareous, and pyritic felsic tuff that is seen fresh only in drill core or where very deep excavations have been blasted. It weathers to a very distinctive, finely laminated, nearly white, spongy saprolite (fig. 20) that is easily mapped. Locally it shows chaotic folding (fig. 20) that is interpreted to be soft-sediment deformation.

Structurally, and probably also stratigraphically, above the Ison Branch Formation is a unit of intercalated blocky, sooty-weathering gondite (spessartine quartzite), pink- to purple-weathering garnet-sillimanite-biotite-muscovite schist, and ocher-weathering hornblende-plagioclase amphibolite that we here name the Barrow Hill Formation for exposures along the three roads that cut across Barrow Hill in the Orchard Hill, Ga. 7.5-min quadrangle; these exposures are also designated a composite type section. The Barrow Hill apparently grades upward into the Clarkston Formation.

SANDY SPRINGS THRUST SHEET

The Sandy Springs thrust sheet is composed of the Sandy Springs Group, which consists of (ascending order) the Powers Ferry Formation, Chattahoochee Palisades Quartzite, and Factory Shoals Formation (Higgins and McConnell, 1978). Rottenwood Creek Quartzite, included by Higgins and McConnell (1978) in the Sandy Springs Group, was abandoned by Higgins and others (1984). In this paper we abandon the names (of Higgins and Atkins, 1981) Snellville Formation and its Lanier Mountain Quartzite Member, now shown to be the Chattahoochee Palisades Quartzite, and its Norris Lake Schist Member, now shown to be the Powers Ferry Formation; the Andy Mountain Formation of Abrams and McConnell (1981; McConnell and Abrams, 1984); and the Dog River Formation of McConnell and Abrams (1984).

DOG RIVER FORMATION (ABANDONED)

McConnell and Abrams (1984, p. 38) proposed the name Dog River Formation for a sequence of metagraywacke, schist, and amphibolite with "thin (1–3 in) layers of banded iron formation." They stated, "The presence of this banded iron formation and the lithologic similarity of this unit to upper parts of the underlying New Georgia Group suggest that the contact with the New Georgia Group is gradational and represents a gradual waning of volcanism in this area." The graded bedding in the Bill Arp Formation indicates that the stratigraphic sequence proposed by McConnell and Abrams (1984) is inverted, and our work shows that the rocks they named the New Georgia Group belong to three different thrust sheets (Sandy Springs, Paulding, Ropes Creek). Thin quartzites containing minor amounts of magnetite are present in many outcrops of the Powers Ferry Formation (Higgins, 1965), and this caused McConnell and Abrams (1984) to set aside part of the Powers Ferry around the Dog River southeast of Villa Rica as the "Dog River Formation." Because these rocks clearly belong to the Powers Ferry Formation, the Dog River Formation is here abandoned.

ANDY MOUNTAIN FORMATION (ABANDONED)

Abrams and McConnell (1981 p. 63–64; McConnell and Abrams, 1984) proposed the name Andy Mountain Formation for a unit of graphitic schists, garnetiferous schists, and quartzite in western Georgia northwest of the Brevard Zone. Part of this unit is lithically identical with the Canton Schist of Bayley (1928—abandoned) and Canton Formation of McConnell and Abrams (1984—abandoned) and is assigned to the Cherokee alteration zone of the Ropes Creek Metabasalt (see section on Ropes Creek thrust sheet). Our work shows that part of the Andy Mountain Formation of Abrams and McConnell (1981; McConnell and Abrams, 1984) is the Chattahoochee Palisades Quartzite of the Sandy Springs Group. Because Abrams and McConnell's Andy Mountain Formation belongs to two separate units, we here abandon the Andy Mountain Formation of Abrams and McConnell (1981; McConnell and Abrams, 1984).

TALLULAH FALLS FORMATION (RESTRICTED)

Hatcher (1971b, p. 9–10) proposed the name Tallulah Falls Formation for rocks of the Sandy Springs Group in northeast Georgia. Galpin (1915) had used the name Tallulah Falls Quartzite for the major quartzite unit in the area; he apparently had in mind a section along the old Tallulah Falls Railway (1915, p. 119) for the type locality and type section. Hatcher defined four members of his Tallulah Falls Formation (1971b, p. 11–12), but he failed to give type localities for the members or to formally designate Tallulah Falls, the old Tallulah Falls Railway, or the city of Tallulah Falls as the type locality for the formation. Hatcher (1969) had earlier included the units in his "Whetstone Group." Hatcher (1974, p. 9) stated of his Tallulah Falls Formation, "This formation name was proposed to raise the name Tallulah Falls to group status." Naming a unit a formation cannot raise its name to group status. In light of the lack of designated type localities or sections, confusion over groups versus formations, the fact that the units were never properly named, and the fact that the rocks belong to the Sandy Springs Group (Higgins, 1966; Higgins and McConnell, 1978), the Tallulah Falls is restricted from this area, and we recommend that the name Tallulah Falls Formation be abandoned. The rocks that

Hatcher (1971b) named Tallulah Falls Formation belong to the Powers Ferry Formation, Chattahoochee Palisades Quartzite, and Factory Shoals Formation of the Sandy Springs Group in the Sandy Springs thrust sheet.

PAULDING THRUST SHEET

The Paulding thrust sheet is composed entirely of the Paulding Volcanic-Plutonic Complex (named below). Rocks of the Paulding Complex have been given various names in Alabama (Bentley and Neathery, 1970; Neathery, 1975; Tull and others, 1978; Stow, 1982; Stow and others, 1984), including the Waresville Amphibolite, a small part of the Ketchepedrakee Amphibolite, and the lower part of the Hillabee greenstone. We include these rocks in the Paulding Volcanic-Plutonic Complex and suggest that the name Ketchepedrakee Amphibolite should be abandoned, but it may be reserved for local usage. In Georgia, part of the Waresville Amphibolite of Bentley and Neathery (1970), part of the Pumpkinvine Creek Formation of McConnell (1980), and part of the New Georgia Group of Abrams and McConnell (1981) and McConnell and Abrams (1984) are included in the Paulding Volcanic-Plutonic Complex in the Paulding thrust sheet. In this paper, we abandon the names Waresville Amphibolite, Pumpkinvine Creek Formation, and New Georgia Group.

PAULDING VOLCANIC-PLUTONIC COMPLEX (NAMED)

The Paulding Volcanic-Plutonic Complex is here named for exposures in Paulding County, Ga., where thick sections of these rocks are exposed. The type section is designated as the section along the unnamed dirt road that runs south and southwest from Georgia Highway 120 in the northeast corner of the New Georgia, Ga. 7.5-min quadrangle to the first dirt road to the west and along that east-west road to its intersection with a road running north and southwest to the thrust fault at the base of the Ropes Creek Metabasalt about 320 m west of the cemetery on the south side of the road (fig. 56). The Paulding Volcanic-Plutonic Complex is made up of light-green-weathering, epidote-rich, generally chloritic, green or blue-green hornblende- or (and) actinolite-plagioclase amphibolites (about 50–60 percent) intimately interlayered with light-gray to nearly white, amphibole-bearing granofels and biotite-bearing gneisses (metamorphosed felsic and intermediate tuffs—about 20–30 percent). Dikes, sills, and small plutons of K-feldspar-poor granitic and K-feldspar-bearing granitic rocks are ubiquitous (forming about 15–20 percent of the unit), and pods of epidosite are common. Thin layers and lenses of vermiculitic mica (not included in the percentages) are locally present, but their protolith is unknown. A distinctive siliceous "hardpan" is generally found above the rocks in the Paulding sheet. The Paulding is essentially an all-igneous unit, devoid of clastic metasedimentary rocks, although metamorphosed epiclastic sedimentary rocks are present. This lack of clastic metasedimentary rocks, coupled with its distinctive appearance in outcrop and the fact that its mafic rocks are generally epidotic and chloritic, distinguishes it from rocks of underlying thrust sheets.

WARESVILLE AMPHIBOLITE OR FORMATION (ABANDONED)

Bentley and Neathery (1970, p. 26) used the name "Waresville Formation" for rocks here assigned to the Paulding Volcanic-Plutonic Complex, stating that the unit had been named by Bentley in a report "in preparation" on Heard County, Ga. The report has never been published, no type locality designation has been given (Waresville is a town in Heard County, Ga.), and no type section designated. The name Waresville Amphibolite has been used as a local name in Alabama by Neathery (1975) and Stow and others (1984). Waresville Amphibolite or Formation is here abandoned as a formal name.

PUMPKINVINE CREEK FORMATION (ABANDONED)

McConnell (1980) proposed the name Pumpkinvine Creek Formation for rocks assigned here to the Paulding Volcanic-Plutonic Complex in the Paulding thrust sheet, the Ropes Creek Metabasalt in the Ropes Creek thrust sheet, and the Powers Ferry Formation of the Sandy Springs Group in the Sandy Springs thrust sheet (his fig. 3, 1980, p. 4). Because the rocks reside in three different thrust sheets (compare McConnell's fig. 3 with pl. 1 and fig. 2 of this paper), we here abandon the name Pumpkinvine Creek Formation. McConnell's type locality for his Pumpkinvine Creek Formation is in Ropes Creek Metabasalt, and most of the rocks he called "Pumpkinvine Creek" are Ropes Creek Metabasalt.

ROPES CREEK THRUST SHEET

The Ropes Creek thrust sheet is composed of the Ropes Creek Metabasalt, which includes various unnamed, but mappable, volcanogenic alteration zones, iron formations, pelagic manganiferous metasedimentary rocks, the Cherokee alteration zone (an informally named alteration zone), and the Cedar Lake Member. Named units assigned to the Ropes Creek Metabasalt in Alabama include the Mitchell Dam, Beaverdam, and Ropes Creek amphibolites, most of the Ketchepedrakee amphibolite, part of the Doss Mountain amphibolite, the Slaughters metagabbro, and the upper part of the Hillabee greenstone (Bentley and Neathery, 1970, Neathery, 1975; Tull and others, 1982; Stow, 1982; Neilson, 1983; Stow and others, 1984); these names are retained for informal local usage but should be abandoned as formal names. In Georgia, we here abandon the New Georgia Group and Mud Creek Formation of Abrams and McConnell (1981) and the Univeter Formation of McConnell and Abrams (1984) including its Rose Creek Schist Member and Lost Mountain Amphibolite Member. We propose acceptance of the Cedar Lake Member and Villa Rica Gneiss of Abrams and McConnell (1981; McConnell and Abrams, 1984), as modified here.

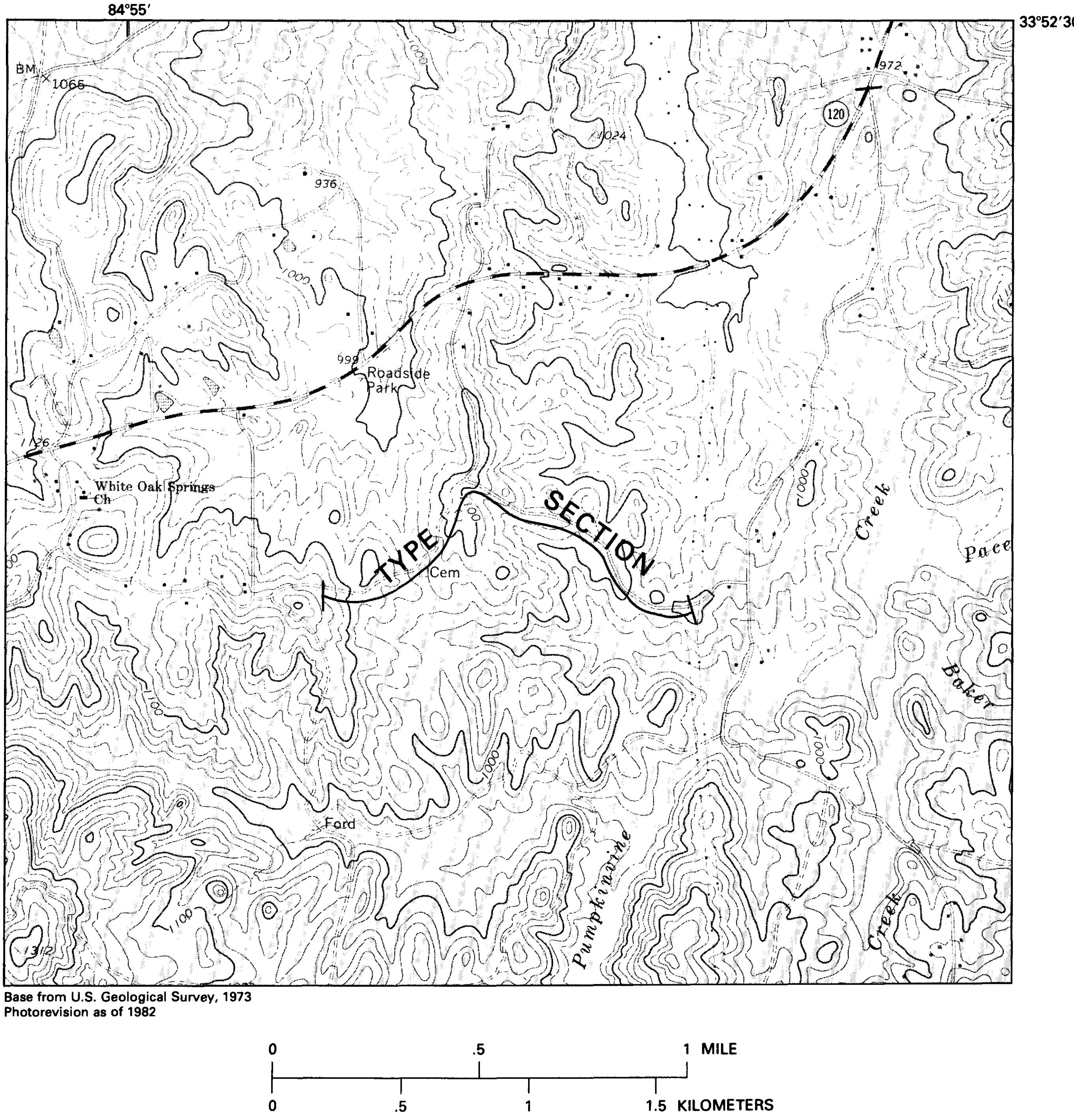


FIGURE 56.—Map showing the location of the type section of the Paulding Volcanic-Plutonic Complex in the New Georgia, Ga. 7.5-min quadrangle.

ROPES CREEK METABASALT (REVISED)

Bentley and Neathery (1970, p. 29–30) used the name Ropes Creek Amphibolite for exposures of amphibolite along Ropes Creek in northeastern Lee County, Ala. This name has since been in common use in Alabama (Neathery, 1975; Sears, Cook, and others, 1981; Stow and others, 1984). We here accept the type locality along Ropes Creek as proposed by Bentley and Neathery (1970), but we propose that the name be changed to Ropes Creek Metabasalt.

The Ropes Creek Metabasalt is composed of ocher-weathering, massive to finely layered, locally laminated, locally pillowed (fig. 33), locally chloritic, commonly garnetiferous, locally magnetite-bearing, generally pyrite-bearing, green to greenish-black hornblende-plagioclase and plagioclase-hornblende amphibolites with persistent but minute amounts (generally less than a very small fraction of a percent) of fine- to medium-grained, generally amphibole-bearing granofels. The final weathering product of the amphibolites is a very characteristic dark-red clayey soil. The mafic rocks of this unit are at least partially chloritized and (or) epidotized; few areas larger than a few square kilometers have escaped some chloritization, epidotization, or uralitization. Many of the rocks in the Ropes Creek Metabasalt contain disseminated pyrite, and, locally, highly pyritiferous zones as much as 20 m wide can be followed for as much as 100 m along strike.

One of the more distinctive features of the Ropes Creek Metabasalt is that it contains a diverse suite of iron-rich, siliceous, and manganiferous metavolcanogenic, largely exhalative, chemical metasediments, divided (terminology modified from Stanton, 1976b) into banded iron formations (Abrams and McConnell, 1982; McConnell and Abrams, 1983, 1984), ironstones, magnetite quartzites (Pate, 1980), manganiferous quartzites, and manganiferous schists. Some of the manganiferous rocks are similar to those found in the Zebulon and Atlanta thrust sheets, but in the Georgiabama thrust stack the iron-rich rocks are unique to the Ropes Creek thrust sheet and can be used almost like index fossils to identify it. Locally associated with the iron-rich rocks are thin layers of fibrous tourmaline (generally dravite). In addition, as far as we know (except for sulfide deposits in the Little River allochthon and Ducktown-type deposits), all of the massive volcanogenic sulfide deposits in Georgia and Alabama are within the Ropes Creek Metabasalt in the Ropes Creek thrust sheet. They are closely associated with the iron formations (Pate, 1980; McConnell and Abrams, 1982) and tourmaline layers (also see Slack, 1982) in mappable linear, siliceous and (or) aluminous, magnetite-, garnet-, and pyrite-rich alteration zones that were probably at or near submarine exhalative vents.

Geochemical studies (Stow and others, 1984; Appendix B) indicate that the amphibolites in the Ropes Creek Metabasalt probably originated as seafloor basalts in an ocean-ridge environment. Isotopic studies (Jones and others, 1973; Shaw and Wasserburg, 1984; see section on West Point melange) also indicate that the Ropes Creek amphibolites are ancient oceanic crust. These interpretations are supported by the fact that the rocks in the Ropes Creek are almost entirely mafic (though ultramafic rocks and insignificant amounts of intermediate to felsic rocks also occur), contain volcanogenic sulfide-rich alteration zones and deposits (probably "black-smoker" deposits), and are associated with metavolcanogenic chemical sediments (iron-rich and, to a slightly lesser extent, manganese-rich cherts) and minor amounts of manganiferous pelagic sediments.

MUD CREEK FORMATION (ABANDONED)

Abrams and McConnell (1981, p. 61) proposed the name Mud Creek Formation for "amphibolite, hornblende gneiss, biotite gneiss, mica schist and quartzite" exposed along Mud Creek north of Villa Rica, Ga. The section along Mud Creek that they designated the type section lies along the contact between the Zebulon Formation in the Zebulon thrust sheet and the Villa Rica Gneiss and Ropes Creek Metabasalt in the Ropes Creek thrust sheet. The Mud Creek Formation as defined by Abrams and McConnell is not a mappable unit. Therefore, we here abandon the name Mud Creek Formation.

CEDAR LAKE MEMBER (REVISED)

Abrams and McConnell (1981, p. 62–63) proposed the name Cedar Lake Quartzite Member of the Mud Creek Formation for a quartzite with layers and disseminated grains of magnetite and specular hematite that is exposed at Cedar Lake, in the Winston, Ga. 7.5-min quadrangle. They also noted that the iron phase of the quartzite grades locally into a manganiferous or garnetiferous quartzite. Abrams and McConnell (1981; McConnell and Abrams, 1984) mapped only the quartzites as the Cedar Lake Quartzite Member, and hence they showed the unit as discontinuous in most places. Our mapping has also shown that the magnetite-hematite, magnetite, and manganiferous (spessartine) magnetite quartzites are discontinuous. However, these quartzose rocks are within a continuous, mappable unit of manganiferous schist (fig. *2A*). We here accept the name Cedar Lake and the type locality designated by Abrams and McConnell (1981), but we modify Abrams and McConnell's (1981; McConnell and Abrams, 1984) Cedar Lake Quartzite Member of the Mud Creek Formation to the Cedar Lake Member of the Ropes Creek Metabasalt, and we include the manganiferous rocks within it.

VILLA RICA GNEISS (REVISED) AND MULBERRY ROCK GNEISS (ABANDONED)

The Ropes Creek thrust sheet also contains various K-feldspar-poor granitic rocks, including trondhjemites (Pate, 1980; Sanders, 1983), that are locally associated with gold-bearing quartz veins and alteration zones. Abrams and McConnell (1981) proposed the name Villa Rica Gneiss Member of the Mud Creek Formation for one such trondhjemite body in western Georgia, and McConnell and Abrams (1984) proposed the name Mulberry Rock Gneiss Member of the Mud Creek Formation for another gneiss body to the northwest (fig. 2). Pate (1980, p. 11–13) had already used the name Villa Rica Gneiss, stating, "While this unit has previously been termed a granite, petrographic examination reveals only minor amounts of potassium feldspar accompanied by relatively low percentages of ferromagnesian minerals." We here accept the name Villa Rica Gneiss as proposed by Pate (1980) and Abrams and McConnell (1981; McConnell and Abrams, 1984). However, Abrams and McConnell (1981) and McConnell and Abrams (1984) assigned the gneiss to their Mud Creek Formation (abandoned) of their New Georgia Group (abandoned) and considered the Villa Rica Gneiss to be a metadacite; McConnell and Abrams (1984, p. 25) changed the name Villa Rica Gneiss Member of the Mud Creek Formation to "Villa Rica Gneiss (Metadacite) Member" of the Mud Creek Formation. The Villa Rica Gneiss is a plutonic rock, however, as recognized by Pate (1980) and Sanders (1983). It contains numerous xenoliths of Ropes Creek Metabasalt, including ultramafic rocks, it is of uniform plutonic texture, and it does not interfinger with its metavolcanic country rocks as indicated by Abrams and McConnell (1981) and McConnell and Abrams (1984). The Ropes Creek Metabasalt locally has very small amounts of intercalated felsic rocks with mineralogic compositions similar to the composition of the Villa Rica Gneiss, and there are dikes and sills of the gneiss in the country rocks near their contact with the gneiss; "metadacite" should be dropped from the name. The Mulberry Rock Gneiss is Corbin Gneiss, so the name Mulberry Rock Gneiss is abandoned.

McConnell and Abrams (1984, p. 26) also applied the name Villa Rica Gneiss to another body of gneiss located roughly along strike from the Villa Rica Gneiss, stating:

> East-northeast of where the Villa Rica antiform plunges out, another gneiss very similar to the Villa Rica Gneiss is exposed in the crest of another elongate antiform. Sanders (personal commun., 1981) found that this gneiss is chemically dissimilar to the Villa Rica Gneiss and contains slightly higher concentrations of K_2O, MgO, total Fe, and CaO and slightly lower values for SiO_2 and Na_2O. Abrams and McConnell (1981a) and Abrams (1983) suggested that the two gneisses were equivalent based on their similar structural and stratigraphic position. In this report, we consider the chemical variations to be minor facies variations within a single lithostratigraphic unit and interpret this body to be equivalent to the Villa Rica Gneiss.

The body of gneiss in question, which we informally refer to as the Gothards Creek gneiss, bears little resemblance in outcrop or thin section to the Villa Rica Gneiss. It has a much better developed foliation that is defined by biotite, whereas biotite is only a minor constituent of the Villa Rica Gneiss. The Gothards Creek gneiss has a different mineralogic composition and a distinctly different chemical composition from the Villa Rica Gneiss. Most important, the Gothards Creek gneiss and the Villa Rica Gneiss are in different thrust sheets; the Villa Rica is in the Ropes Creek thrust sheet, whereas the Gothards Creek is in the Zebulon thrust sheet. There is no scientific reason to correlate these two gneisses.

UNIVETER FORMATION (ABANDONED)

McConnell and Abrams (1984, p. 34–36) proposed the name Univeter Formation, defining it as follows:

> This report serves to formally define the Univeter Formation for exposures at Univeter, southern Cherokee County. The Univeter Formation is composed of hornblende-andesine gneiss (amphibole/hornblende gneiss) with an intervening thin, garnet-biotite-muscovite schist±amphibole. Also present locally is a thin (less than 5 ft) banded iron formation and coarsely garnetiferous chlorite schist.... The hornblende-andesine gneiss in the Univeter Formation is interpreted to form two limbs of a fold. This unit is here termed the Lost Mountain Amphibolite Member of the Univeter Formation for exposures on Lost Mountain in western Cobb County. The intervening schist member is here termed the Rose Creek Schist Member for exposures near Rose Creek Church in southwestern Cherokee County.

The town of Univeter, Ga. (including the "type locality" marked by a small circle on McConnell and Abrams' fig. 21), is underlain by the Zebulon Formation; thin amphibolites present there along with schist are within the Zebulon. In fact, the section exposed in cuts behind buildings in Univeter is so characteristic of the Zebulon that it could be a reference section. The amphibolite at Lost Mountain is Ropes Creek Metabasalt in the Ropes Creek thrust sheet, and the garnetiferous schist unit that McConnell and Abrams (1984) called the "Rose Creek Schist Member" is part of the Cherokee volcanogenic alteration zone within the Ropes Creek Metabasalt; Bayley (1928) named garnetiferous schists in this zone the Canton Schist (see below). Because the "type locality" of McConnell and Abrams' (1984) Univeter Formation is in the Zebulon Formation in the Zebulon thrust sheet, whereas members of the formation are in the Ropes Creek thrust sheet, and for the reasons listed above, we here abandon Univeter Formation, Rose Creek Schist Member of the Univeter Formation, and Lost Mountain Amphibolite Member of the Univeter Formation.

CANTON SCHIST OR FORMATION (ABANDONED), CHEROKEE ALTERATION ZONE OF THE ROPES CREEK METABASALT (INFORMALLY NAMED)

Bailey (1928, p. 43) gave the name Canton schist for "best exposures ... in the neighborhood of Canton" to "a narrow belt of carbonaceous, or graphitic, garnetiferous mica schist." McConnell and Abrams (1984, p. 28-29) proposed changing the Canton Schist to the Canton Formation, stating, "These garnetiferous, graphitic schists occur only locally and ... interfinger with quartzite and metagraywacke." Our mapping in the Cartersville, Ga. 1° × 30' quadrangle (Higgins, R.F. Crawford, III, and Cressler, unpub. data) shows that the rocks that Bailey (1928) mapped as Canton Schist and the rocks that Abrams and McConnell (1984, pl. 1) mapped as Canton Formation are within a sequence of metamorphosed hydrothermal volcanogenic alteration zone rocks and chemical and pelagic sediments in the Ropes Creek Metabasalt in the Ropes Creek thrust sheet. Because these rocks are not a normal metasedimentary sequence and do not occur at a single stratigraphic horizon, but at different horizons within the Ropes Creek Metabasalt, and because the names Canton Schist and Canton Formation have been used for what was thought to be a stratigraphically limited normal metasedimentary unit, we here abandon both names. Nevertheless, the rocks do form a mappable unit and warrant an informal name. To avoid further confusion, we propose the name Cherokee alteration zone of the Ropes Creek Metabasalt for these rocks, for Cherokee County, Ga., where they are well exposed. A typical section through the Cherokee zone can be seen along the road running southeast from Georgia Highway 205 from Hopewell Church to Georgia Highway 5 at Lebanon (Toonigh Sta.), Ga., from the first road entering that road from the northeast to the flood plain of Blankets Creek, in the South Canton, Ga. 7.5-min quadrangle. This section includes the coarsely garnetiferous schists that Bayley (1928) assigned to his Canton Schist, very graphitic schists, metacherts, sericitic schists, and manganiferous schists.

HILLABEE GREENSTONE (INFORMAL)

The name Hillabee, whether modifying schist, chlorite schist, green schist, greenschist, or greenstone, has been in common use in Alabama since the late 19th century (Brewer, 1896; Prouty, 1923; Adams, 1926, 1933; Griffin, 1951; Carrington and Wigley, 1967; Clarke and Carrington, 1964; Neathery, 1972; Reynolds, 1972; Neathery and Reynolds, 1973; Tull and others, 1978; Tull, 1979, 1982; Tull and Stow, 1980a,b, 1982; Stow and Tull, 1982; Stow, 1982) for the northern and northwesternmost infolded slices of the Ropes Creek, West Point melange, and Paulding thrust sheets (see Hillabee greenstone under Ropes Creek thrust sheet in the main part of this paper). Because its rocks reside in three separate thrust sheets, with very different origins, and probably slightly different ages, the name Hillabee should be retained only for local informal usage.

APPENDIX B.—GEOCHEMISTRY

The analyses presented in tables 7–11 were all done in the laboratories of the U.S. Geological Survey, except for the major-oxide analyses of rocks from the Corbin Gneiss, which were done in the laboratory of the Georgia Geologic Survey. Major-oxide analyses were done by the method described by Shapiro (1975), except for samples with "R" and "AR" prefixes in table 11*A*, which were done by X-ray spectroscopy. Rare-earth-element analyses were done by instrumental neutron activation. Trace-element analyses for Ba, Cs, Th, U, Zr, Hf, Ta, Co, Cr, Sc, Zn, and Sb were done by instrumental neutron activation, except where abundances of Ba, Zr, or Zn were low, in which case they were done by quantitative spectrographic analysis. Trace-element analyses for Sr, Li, Ni, Cu, and Y were done by quantitative spectrographic analysis. Nb content was determined spectrophotometrically using the method of Greenland and Campbell (1974). The analytical methods have been further described by Gottfried and others (1977, 1983).

For many years there has been a tendency, especially among Appalachian geologists, to assume that the geochemical characteristics of rocks have been altered to one degree or another by the metamorphism, so that their present compositions may reflect neither their original compositions nor their original tectonomagmatic environments. The comprehensive study of amphibolites from the Alabama crystalline terrane by Stow and others (1984) has shown that at least the Ropes Creek thrust sheet rocks have experienced little alteration or migration of elements. Stow and others (1984, p. 422) stated,

> There is general agreement that many constituents (that is, Y, Zr, Nb, Ti, Cr, REE) are relatively immobile during alteration and metamorphism, while others, especially alkali metals, may be highly mobile (Hanson, 1980; Pearce, 1975; Pearce and Cann, 1973; Smith and Smith, 1976). The degree to which element migration has occurred in amphibolites of the Alabama Piedmont cannot be quantitatively judged presently. Based on adherence to igneous trends, our data suggest that significant movement has not occurred, and, for the DMTA (Doss Mountain Amphibolite), they indicate that migration, even for the alkali metals, is insignificant.

BILL ARP THRUST SHEET

Two sets of samples were analyzed from rocks of the Bill Arp thrust sheet in Georgia: (1) a set of 34 samples of Corbin Gneiss in the Allatoona Complex of Grenville basement rocks and (2) a set of 28 samples of graphitic schists and phyllites from units of the Ocoee Supergroup.

Analyses of major oxides, trace elements, and rare-earth elements (REE) in rocks from the Corbin Gneiss are given in table 7. These analyses show that the Corbin is relatively rich in Ti, Ba, Zr, and light-rare-earth elements (LREE) and relatively poor in Ca. All samples analyzed contain ilmenite and zircon in the norm. Three new analyses of Fort Mountain Gneiss (Corbin Gneiss; Appendix A) given by McConnell and Costello (1984, p. 273) indicate that the gneiss is also rich in Ti and has both ilmenite and rutile in the norm. Analyses given by Stieve (1984) from rocks of the Wacoochee Complex of Grenville basement in the Pine Mountain anticlinorium suggest that mafic and intermediate rocks there are also relatively rich in Ba and Ti, and according to A.K. Sinha (written commun., 1984) rocks of the Grenville basement in North Carolina are also relatively rich in Ti, Ba, Zr, and LREE. These geochemical features may be characteristic of Grenville-basement metaigneous rocks in the southern Appalachians.

Major-oxide analyses of graphitic schists and phyllites from various units in the Ocoee Supergroup are given in table 8. Like the Corbin Gneiss, these metasedimentary rocks are relatively rich in Ba, Ti, Zr, and LREE and anomalously poor in Ca. All samples analyzed contain ilmenite and zircon in the norm, and many contain rutile as well. Comparison of the data from the Corbin Gneiss and various Ocoee Supergroup rocks indicates a striking similarity that we interpret as indicating that these transported sequences were all derived from Grenville basement that was, or was very much like, the Allatoona Complex. The anomalously low CaO content of the pelitic rocks strongly suggests rapid deposition from basement that was relatively poor in CaO.

PAULDING THRUST SHEET

A set of 13 samples of representative rock types from the Paulding Volcanic-Plutonic Complex was analyzed; the data are presented in table 9. In the analyzed samples SiO_2 ranges from 52.8 percent to 63.5 percent (table 9*A*) corresponding to a range of basalt to dacite, with most samples falling into the andesite range. The assemblage of mafic to intermediate igneous rocks in the Paulding Complex appears to be calc-alkalic to calcic (Peacock, 1931), with a $(Na_2O+K_2O)/CaO$ index between 57 and 63; the scatter may be due to alteration, but the limited number of analyses is insufficient to define such alteration. The assemblage plots toward the alkaline side on an F′-M-A (F′=total iron calculated as FeO, M=MgO, A=Na_2O+K_2O) diagram (fig. 57*A*), and within the calc-alkaline field of Irvine and Baragar (1971). Thus, major-element analyses support field and petrographic data indicating that the Paulding Volcanic-Plutonic Complex is a calc-alkaline assemblage.

Trace-element abundances in rocks from the Paulding Complex are given in table 9*B*. The Paulding rocks appear to be enriched in Ba and Sr and somewhat depleted in Cu, Co, Cr, and Ti (low in TiO_2—table 9*A*). Y-Nb ratios average 2.77 and range from 1.22 to 3.39; these low ratios are compatible with an island-arc derivation for the rocks.

Chondrite-normalized REE patterns for rocks from the Paulding Complex (fig. 57*B*) show consistent LREE enrichment and trends compatible with arc environments. Discrimination diagrams (fig. 57*C*–*E*), widely used to determine original tectonomagmatic environment, also support the interpretation of an arc environment for derivation of the Paulding Complex rocks. On the Ti-Zr diagram (fig. 57*C*), most Paulding rocks fall in the field of calc-alkalic basalt of island arc series, with one sample falling in the field of low-potassium tholeiitic basalt of island arc series. On a TiO_2-Zr diagram (fig. 57*D*), the Paulding rocks plot mostly within the arc field, and on an Hf/3-Ta-Th diagram (fig. 57*E*), most of them plot within the calc-alkaline part of the arc field (field of basalts from destructive plate margins), with one sample falling in the field of enriched-type mid-ocean-ridge basalts and tholeiitic within-plate basalts. On an Al_2O_3/TiO_2-TiO_2 diagram (fig. 57*F*), some Paulding samples plot in the arc field whereas others plot between the arc field and the field that includes mid-ocean-ridge basalts; Hillabee dacites are also plotted. On a CaO/TiO_2-TiO_2 diagram (fig. 57*G*), two of the Paulding samples plot in the primitive "source relatively undepleted" arc field and the others plot between that arc field and the field that includes mid-ocean-ridge basalts; Hillabee dacites are also plotted. It must be again emphasized that most of these Paulding rocks are not basalts, so data plotted on these discrimination diagrams are not entirely comparable with data from basalts. The samples analyzed from the Paulding Complex are too low in chromium for use of such diagrams as Cr-Y plots.

All of the available geochemical data from rocks of the Paulding Volcanic-Plutonic Complex are compatible with the field evidence suggesting that the rocks of the complex formed in an island arc environment in the Iapetus Ocean.

ROPES CREEK THRUST SHEET

Geochemical data from 27 samples of Ropes Creek Metabasalt of the Ropes Creek thrust sheet in Georgia are given in table 10. These data are considered an addition to the larger data base from Ropes Creek Metabasalt (including the Ketchepedrakee, Beaverdam, Mitchell Dam, and Ropes Creek amphibolites) in Alabama presented by Stow and others (1984). We agree completely with Stow and others' geochemical assessment of these rocks and with their assignment of the rocks to an original ocean-rift environment.

The Ropes Creek Metabasalt samples (table 10*A*) are low in K_2O, and most are high in TiO_2. Figure 58*A* is an F′-M-A plot of the Ropes Creek Metabasalt samples; the Ropes Creek samples fall mostly within the tholeiitic field and compare well with various Ropes Creek rocks from Alabama (figs. 58*B, C*).

Trace-element abundances in the Ropes Creek Metabasalt (table 10*B*) are similar to those given by Stow and others (1984) for various amphibolites in the unit in Alabama. The Ropes Creek samples are generally low in Ba but appear to be enriched in Sr, Zr, and Ni, somewhat enriched in Co and Cu, and greatly enriched in Cr.

Chondrite-normalized REE patterns are essentially flat (fig. 58*D*), but most samples show slight LREE enrichment; the REE distribution patterns are quite similar to those presented by Stow and others (1984, p. 428, fig. 6) for various amphibolites in the Ropes Creek Metabasalt in Alabama and support the interpretation of Stow and others that the rocks are ocean-ridge basalts.

Tectonomagmatic discrimination diagrams also indicate that the Ropes Creek Metabasalt is ancient oceanic crust. We do not have enough Zr data from samples for which we have Y or Ti data to use discrimination diagrams based on these elements for the Ropes Creek Metabasalt in Georgia. On a TiO_2-Zr diagram (fig. 58*E*), the three Ropes Creek samples for which there are Zr data plot mostly within the ocean-floor basalt field along with the Alabama samples from Stow and others (1984); figure 58*F* shows samples of the Hillabee greenstone from Tull and others (1978) and Stow (1982) plotted on the same diagram, and figure 58*G* shows the various amphibolites in the Ropes Creek Metabasalt in Alabama and the Hillabee greenstone plotted with the three Georgia Ropes Creek samples on a Zr/Y-Zr diagram; most samples plot within the field of ocean-floor basalts. On a Cr-Y plot (fig. 58*H*), the Ropes Creek samples from Georgia plot entirely within the ocean-floor basalt field, though one sample (CA.6) has anomalously low Cr (43 ppm) and five other samples for which Y was not determined also have low Cr abundances. Figure 58*I* shows the Alabama samples of various amphibolites in the Ropes Creek Metabasalt and the Hillabee greenstone (Tull and others, 1978; Stow, 1982) added to the Cr-Y diagram for the Georgia Ropes Creek samples. On an Al_2O_3/TiO_2-TiO_2 diagram (fig. 58*J*), most of the Ropes Creek samples from Georgia plot in the field that includes mid-ocean-ridge basalts with two samples plotting between that field and the arc field; on the same diagram most of the samples from various amphibolites in the Ropes Creek Metabasalt in Alabama plot in the field of mid-ocean-ridge basalts (fig. 58*K*), as do most of the samples from the Hillabee greenstone (fig. 58*L*). On a CaO/TiO_2-TiO_2 diagram (fig. 58*M*), most of the Ropes Creek samples from Georgia plot within the field that includes mid-ocean-ridge basalts, with three samples falling between that field and a primitive or "source relatively undepleted" arc field; on the same diagram almost all the samples of various amphibolites in the Ropes Creek Metabasalt in Alabama plot in the field that includes mid-ocean-ridge basalts (fig. 58*N*), as do most of the samples from the Hillabee greenstone (fig. 58*O*).

Overall, the geochemical data from the Ropes Creek Metabasalt in Georgia and Alabama support the field data indicating that the Ropes Creek is made up of oceanic crust, mostly ocean-floor basalts that originated in a mid-ocean rift (Stow and others, 1984), the mid-Iapetus ridge. Stow and others (1984, p. 432), following a scheme by Nisbet and Pearce (1973), suggested that different spreading rates may be deduced from different TiO_2 contents of different parts of the Ropes Creek Metabasalt in Alabama; on the basis of that scheme, most of the Georgia Ropes Creek samples indicate average spreading rates (TiO_2 percentages average 1.29 but range as high as 2.5).

The Paulding Volcanic-Plutonic Complex was lumped with the Ropes Creek Metabasalt in the Ropes Creek thrust sheet (and probably some of the West Point thrust sheet as well) into various units of their New Georgia Group (abandoned; see Appendix A) by Abrams and McConnell (1981, 1984) and McConnell and Abrams (1984). The two assemblages are quite distinctive in the field, however, and comparison of geochemical data presented here also shows great differences in their chemical compositions as well as their trace-element and REE abundances (fig. 58*P*). Furthermore, their original tectonic settings appear to be different, as deduced both from overall lithologic makeup and from settings suggested by plots of least mobile elements on discrimination diagrams. All of the geochemical data support the field data indicating that the Paulding Volcanic-Plutonic Complex and the Ropes Creek Metabasalt are distinctly different assemblages formed in different tectonomagmatic environments.

SOAPSTONE RIDGE THRUST SHEET

Geochemical data from 41 samples of rocks from the Soapstone Ridge thrust sheet in Georgia are given in table 11; most of the samples are from the Soapstone Ridge Complex. Nearly all of the samples are high in MgO and low in alkalies (table 11*A*), and whereas olivine is present in the norm in over half the samples, normative hypersthene is present in every sample. All of the Soapstone Ridge thrust sheet samples are high in Ni and Co and very high in Cr (table 11*B*).

On an F′-M-A diagram (fig. 59*A*), the altered ultramafic and mafic rocks from the Soapstone Ridge thrust sheet plot along the F′-M side of the triangle and fairly far towards M; the points are tightly clustered. Figure 59*B* shows the Soapstone Ridge samples, the Georgia Ropes Creek samples, and two samples of ultramafic rocks associated with the Ropes Creek Metabasalt in Georgia (table 10) plotted on an F′-M-A diagram; the trend of the points may well define a differentiation trend implying a genetic relationship between the Soapstone Ridge samples and Ropes Creek samples.

Plots of REE normalized to chondrites mostly show patterns of LREE enrichment and extreme HREE (heavy-rare-earth-element) depletion indicative of the chloritization that has affected most of the samples. Hence, REE can be used neither to confirm nor to deny the interpreted ocean crust and mantle origin for the rocks of the Soapstone Ridge thrust sheet.

Table 7A.-- Major-oxide and normative-mineral compositions, in weight percent, of rocks from the Corbin Gneiss in the Allatoona Complex of Grenville basement in northern Georgia. C samples analyst: Z.A. Hamlin, U.S. Geological Survey; others from Martin (1974), as modified by McConnell and Abrams (1984) - analyst: J.R. Landrum, Georgia Geological Survey

Sample No.	68	C.1	64.A	94	49	99	81	C.2	112	62.B	97	95	92	88	28
							Major-oxide composition								
SiO_2	57.84	61.1	62.24	63.20	63.46	63.54	65.20	65.6	66.16	66.20	66.40	67.20	67.20	67.80	67.80
Al_2O_3	17.40	17.0	15.50	14.20	14.50	16.70	14.30	16.4	16.00	14.80	15.00	13.50	14.80	12.80	15.00
Fe_2O_3	1.58	.58	1.65	1.00	1.15	1.98	2.73	1.0	.80	1.18	1.10	1.35	.78	.85	1.88
FeO	7.58	5.0	6.70	7.29	5.98	4.52	5.10	2.9	3.06	4.88	4.23	4.00	3.35	4.37	2.99
MgO	1.45	1.4	1.00	.98	.60	.54	1.95	.93	.80	.75	1.16	1.52	1.45	.98	.83
CaO	4.50	4.1	3.10	3.44	4.06	3.88	2.66	2.5	2.44	2.60	4.66	2.96	2.56	3.36	1.16
Na_2O	3.10	3.5	2.70	2.70	3.64	2.43	2.43	3.1	2.96	2.70	2.83	2.70	2.96	2.70	2.00
K_2O	2.77	3.8	3.97	4.34	3.00	3.73	2.65	5.3	6.26	4.22	3.61	4.22	5.06	4.58	4.82
H_2O+		.30						.30							
H_2O-	.34	.21	.25	.29	.13	.64	.62	.33	.30	.43	.43	.75	.44	.45	2.07
TiO_2	2.50	1.3	2.00	1.66	1.75	1.50	1.75	.82	.78	1.60	1.00	1.32	1.00	1.50	1.10
P_2O_5		.41						.31							
MnO	.09	.06	.08	.09	.05	.09	.08	.03	.02	.05	.04	.04	.02	.04	.04
CO_2		.04						.08							
Total	99.15	98.8	99.19	99.19	98.32	99.55	99.47	99.6	99.58	99.41	99.56	99.56	99.62	99.43	99.69
							C.I.P.W. normative composition								
Q	13.266	13.062	19.464	18.056	19.021	23.773	30.214	19.809	16.792	24.982	23.109	25.274	21.174	25.162	32.822
C	1.008	.372	1.001			1.446	2.523	1.670	.937					4.261	
Z	.193	.133	.187	.191	.141	.175	.092	.113	.077	.134	.098	.078	.086	.099	.089
OR	16.369	22.456	23.461	25.647	17.729	22.043	15.660	31.321	36.994	24.983	21.333	24.938	29.902	27.066	28.484
AB	26.231	29.615	22.846	22.846	30.800	20.561	20.561	26.231	25.046	22.846	23.946	22.846	25.046	22.846	16.923
AN	22.640	18.447	15.699	13.817	14.374	19.707	13.406	10.633	11.892	13.251	17.572	12.261	12.161	9.287	6.095
DI				3.174	5.403				.598		4.917	2.329	.875	6.517	
HY	12.251	10.152	10.268	10.775	5.914	5.695	9.214	5.516	5.387	7.301	5.678	6.746	7.064	4.047	4.257
MT	2.291	.841	2.392	1.450	1.667	2.871	3.958	1.450	1.160	1.711	1.595	1.957	1.131	1.232	2.726
CM	.024	.006	.016	.026	.026	.009	.025	.004	.019	.008	.013	.012	.010	.022	.012
IL	4.748	2.469	3.798	3.153	3.324	2.849	3.324	1.557	1.481	3.039	1.899	2.507	1.899	2.849	2.089
AP		.950						.718							
CC		.091						.182							

Table 7A. -- Continued

Sample No.	76	110	C.3	79	78	51	108	25	53	19	82	30	C.4	40	104
							Major-oxide composition								
SiO_2	68.00	68.02	68.3	68.36	68.40	68.60	68.64	68.90	69.00	69.12	69.60	70.14	70.3	70.60	70.80
Al_2O_3	14.80	15.80	14.5	16.00	15.30	14.80	15.00	15.80	13.80	15.00	14.20	15.30	14.7	14.30	14.7
Fe_2O_3	1.26	.97	.80	1.09	1.67	.47	2.01	1.46	1.76	1.13	1.16	.89	1.1	1.38	.92
FeO	2.92	2.55	2.4	1.90	2.55	2.55	1.97	2.11	2.92	2.04	2.92	2.26	2.3	1.82	1.60
MgO	1.00	.72	.52	.87	.58	.25	1.30	.77	.35	.40	.72	.68	.85	.20	.94
CaO	.76	1.74	1.8	.50	1.76	2.80	1.60	1.00	2.60	1.72	1.86	1.62	1.7	1.84	.10
Na_2O	2.70	2.83	3.0	2.00	2.43	2.96	2.00	2.70	2.63	2.56	2.17	3.37	2.6	2.70	1.62
K_2O	5.42	5.90	5.3	6.62	5.30	6.00	4.58	5.06	5.06	6.00	5.30	4.10	4.8	5.30	6.50
H_2O+			.66										.45		
H_2O-	1.30	.24	.10	1.54	.90	.45	1.59	1.10	.58	.88	.48	.56	.11	.83	1.80
TiO_2	1.50	.90	.51	.80	.80	.80	1.09	.78	1.00	.70	1.32	.80	.71	.78	.80
P_2O_5			.22										.30		
MnO	.04	.02	.03	.02	.02	.02	.02	.04	.04	.04	.02	.02	.04	.02	.00
CO_2			.88										.01		
Total	99.70	99.69	99.02	99.70	99.71	99.70	99.80	99.72	99.74	99.59	99.75	99.74	99.97	99.77	99.78
							C.I.P.W. normative composition								
Q	27.378	22.866	27.407	28.279	21.525	33.842	29.704	27.470	26.001	30.451	29.245	29.748	31.542	29.748	34.340
C	2.979	1.445	2.974	2.264		3.715	3.936		1.023	1.402	2.269	.643	2.717	.643	4.709
Z	.071	.076	.076	.074	.048	.084	.060	.094	.066	.068	.063	.084	.078	.084	.076
OR	32.030	34.866	31.321	31.321	35.457	27.066	29.902	29.902	35.457	31.321	24.299	31.321	28.366	31.321	38.412
AB	22.846	23.949	25.384	20.561	25.046	16.923	22.846	22.254	21.661	18.361	28.515	22.846	22.000	22.846	13.708
AN	4.135	9.048	2.337	9.017	9.385	8.296	5.316	10.913	8.934	9.533	8.329	9.499	6.857	9.499	.799
DI					4.348			2.134							
HY	4.405	4.218	4.254	3.458	1.372	3.426	3.366	2.105	2.724	4.049	3.819	1.447	4.331	1.447	3.193
MT	1.827	1.406	1.160	2.421	.681	2.914	2.117	2.552	1.638	1.682	1.290	2.001	1.595	2.001	1.334
CM	.008	.016	.002	.010	.013	.010	.013	.015	.007	.011	.011	.007	.006	.007	.009
IL	2.849	1.709	.969	1.519	1.519	2.070	1.481	1.899	1.329	2.507	1.519	1.481	1.348	1.481	1.519
AP			.510										.695		
CC			2.001										.023		

Table 7A. -- Continued

Major-oxide composition				
Sample No.	58	67	113	34
SiO_2	71.60	71.80	73.26	73.60
Al_2O_3	12.50	13.80	13.50	13.00
Fe_2O_3	.99	.79	.68	1.09
FeO	2.62	2.62	1.82	1.09
MgO	.40	.30	.33	.24
CaO	3.04	2.10	2.08	2.04
Na_2O	2.70	2.00	2.00	2.63
K_2O	4.02	4.82	5.06	5.42
H_2O+				
H_2O-	.28	.85	.22	.40
TiO_2	.80	.60	.80	.30
P_2O_5				
MnO	.02	.02	.03	.01
CO_2				
Total	98.97	99.70	99.78	99.73

C.I.P.W. normative composition				
Q	33.512	35.077	36.485	32.983
C		1.291	.826	
Z	.076	.055	.042	.049
OR	23.756	28.484	29.902	32.030
AB	22.846	16.923	16.923	22.254
AN	10.122	10.923	10.668	7.666
DI	4.478			2.322
HY	1.410	3.945	2.332	.068
MT	1.435	1.145	.986	1.580
CM	.010	.012	.010	.005
IL	1.519	1.140	1.519	.570
AP				
CC				

Table 7B. -- Trace-element abundances, in parts per million, in rocks from the Corbin Gneiss. Analysts: P.A. Baedecker, N. Rain, and E. Campbell

Sample No.	68	C.1	64A	94	49	99	81	C.2	112	62.B	97	95	92	88	28
Rb	33	96	190	92	35	78	44	160	110	160	58	54	66	140	130
Ba	1330	3800	1410	1905	1895	1920	882	3000	2050	1525	1200	1690	2110	1325	1540
Sr	150	840	110	120	240	220	100	480	250	140	110	130	280	140	90
Cs	3.5	1.55	1.25	.6	.3	.6	.45	.5	.4	.4	1.3	.6	.4	.5	.4
Th	4.75	16.55	2.55	3.8	25.4	3.0	20.9	27.85	14.65	12.15	3.9	21.9	12.65	22.3	36.85
U	1.1	<1.3	2.3	1.85	1.0	1.1	3.1	1.3	1.0	1.5	1.4	1.4	.7	.8	2.6
Zr	961.5	660	929.5	948.5	700.5	869.5	457.5	560	382	668.5	490	390	429.5	490.5	444.5
Hf	20.6	16.25	21.7	23.1	16.95	21.7	11.55	13.2	8.6	15.55	12.5	13.8	10.2	11.65	11.85
Nb	40	27	50	46	26	38	28	22	19	29	30	26	20	21	19
Ta	3.09	1.51	6.7	5.66	3.25	5.38	2.39	.68	6.63	2.37	6.00	6.49	4.84	3.03	2.70
Co	13.25	11.2	19.35	26.85	16.7	15.05	19.1	6.9	21.15	9.15	18.9	24.3	18.4	14.6	10.95
Li	42		52	35	23	27	62		44	38	60	40	28	32	22
Ni	5	8	4	17	16	4	20	5	3	4	<4	<4	4	15	9
Cr	112	28.85	73.75	121	122.5	43.2	118	18.95	87.45	36.7	59.5	57.7	46.75	100.5	56.9
Sc	22.6	15.82	20.05	23	14	18.3	17.25	8.52	6.36	16.55	12.40	11.40	8.79	8.57	12.45
Cu	32	22	30	40	29	13	40	17	14	23	19	25	8	37	24
Zn	176.5	150	200	341	122.5	144.5	115	86	75.5	132.5	125	117	100.5	96	156.5
Sb	.5	1.85	.4	<.9	<.7	.5	<.8	1.75	.35	<.7	<.7	<.9	.4	<.7	<.7
Y	120	44	130	120	50	87	100	35	110	58	55	28	41	110	

Sample No.	76	110	C.3	79	78	51	108	25	53	19	82	30	C.4	40	104
Rb	170	92	220	69	180	78	94	130	86	94	64	260	140	90	58
Ba	1655	1850	1600	1370	1240	2295	1330	1580	2295	1745	1340	1295	1600	1685	1400
Sr	94	130	260	84	110	130	280	110	150	150	110	94	380	94	60
Cs	.4	.4	1.9	.4	.7	.3	.3	.35	.4	.35	.5	.6	.75	.5	.7
Th	20.5	23.45	17.85	18.1	21.85	35.85	27.85	17.7	17.6	18.55	21.75	27.9	28.8	25.25	25.3
U	1.4	1.4	2.55	1.3	2.25	1.4	1.4	1.65	.7	1.15	1.85	3.2	1.7	1.2	1.9
Zr	351	378.5	380	256	366.5	237.5	419.5	300	469	327	340.5	315.5	390	418.5	378
Hf	8.95	9.15	12.15	6.3	9.0	6.95	10.0	7.75	10.9	8.4	8.3	9.65	8.4	10.2	10.1
Nb	22	14	20	18	22	12	17 14	17	16	22	22	17	17	25	
Ta	6.11	1.91	.99	6.79	6.76	1.54	.92	2.7	1.6	1.68	7.69	4.29	.64	2.76	8.36
Co	22.9	8.6	3.45	23.8	25.9	7.95	4.65	9.6	10.65	7.25	27.9	11.25	3.9	12.05	26.0
Li	56	48		27	31	42	46	23	32	22	49	52		28	96
Ni	5	9	3	<4	4	8	4	6	11	5	4	5	5	6	<4
Cr	35.9	74.15	9.1	41.1	48.15	59.75	48.5	58.25	71.75	32.75	51.75	50.85	25.9	31.35	42.0
Sc	8.16	5.67	6.89	6.35	8.31	6.04	8.47	7	9.01	7.13	7.93	5.79	7.33	5.98	6.64
Cu	16	12	24	9	20	12	8	18	22	8	13	15	6	8	14
Zn	92.5	69.5	77	118	58	51	64.5	50	94.5	44	55.5	85	56	59	66
Sb	<.6	.3	3.85	<.6	.3	.3	<.6	.2	.4	<.6	<.6	.3	1.6	<.5	<.6
Y	35	57	47	21	63	33	61	56	41	75	39	280	63	33	35

Table 7B. Continued

Sample No.	58	67	113	34
Rb	180	62	48	66
Ba	1225	2305	1570	1565
Sr	100	130	100	100
Cs	.45	.45	.4	.25
Th	19.55	.75	17.2	14.8
U	2.15	<.8	1.2	.7
Zr	377.5	273.5	210	244.5
Hf	9.15	6.9	6.0	5.7
Nb	17	11	9.6	9.6
Ta	3.67	2.30	1.36	2.27
Co	12.35	9.3	5.5	9.75
Li	30	66	24	14
Ni	4	<4	4	4
Cr	46.6	54.0	47.4	25.5
Sc	6.21	7.15	3.97	3.95
Cu	24	16	8	7
Zn	60	57	40	41
Sb	<.5	<.5	<.4	<.4
Y	33	19	22	18

Table 7C. -- Rare-earth-element abundances, in parts per million, in rocks from the Corbin Gneiss. Analyst: P.A. Baedecker

Sample No.	68	C.1	64.A	94	49	99	81	C.2	112	62.B	97	95	92	88	28
La	105.5	154	99	103.5	170.5	96.5	93	125.5	87.5	94	102	118	92.5	99	136.5
Ce	218	268.5	212.5	198.5	312	188.5	175.5	229	160.5	190	188	223	173	194.5	267
Nd	130	128	143.5	103	132.5	102	79	104	72	102.5	101	103	71.5	88	110
Sm	25.15	20.2	29.3	22.8	20.95	22.0	18.3	16.9	14.4	20.45	18.9	18.1	12.65	16.0	22.3
Eu	4.01	3.89	3.29	3.47	3.23	412.5	2.23	2.83	2.31	2.75	2.64	2.66	2.67	2.11	2.77
Gd	18.05	13.8	19.45	16.5	13.45	15.6	14.2	9.0	9.4	15.35	10.6	11.4	8.4	10.7	16.3
Tb	3.00	1.81	3.52	2.77	1.81	2.37	2.32	1.36	1.33	2.31	1.88	1.79	.93	1.35	2.47
Ho	2.7	1.0	2.8	2.45	1.1	1.7	1.9	.6	1.2	1.75	1.8	.7	.65	.7	1.6
Tm	1.04	.95	.89	.85	.44	.89	.96	<.89	<.2	.70	<.2	.44	<.2	<.2	.84
Yb	7.05	2.8	5.7	6.85	2.3	6.05	7.0	1.6	2.95	5.05	2.9	3.5	1.65	1.8	4.35
Lu	.97	.39	.79	1.05	.31	.87	1.01	.23	.38	.70	.39	.50	.23	.27	.58

Sample No.	76	110	C.3	79	78	51	108	25	53	19	82	30	C.4	40	104
La	101	97	109	63	87	129	103	82.5	90.5	88	94.5	129	101.5	101.5	105
Ce	168.5	184	200.5	124	149.5	253.5	205.5	156.5	172	160.5	153	179.5	186	200	164
Nd	69	80.5	91.5	51	62	108.5	83.5	64.5	74	84.5	69.5	127.5	88.5	77.5	79
Sm	15.5	14.45	18.0	10.6	14.95	18.25	16.85	14.45	13.25	15.55	13.8	27.75	16.8	16.1	19.3
Eu	2.19	2.13	2.33	1.47	1.63	2.47	2.15	2.04	2.56	2.29	1.86	3.41	1.97	2.12	2.36
Gd	10.3	10.7	10.5	6.2	10.05	12.05	11.9	11.05	9.4	11.85	9.35	24.55	11.9	10.35	12.4
Tb	1.51	1.52	1.65	.92	1.59	1.31	1.79	1.72	1.28	1.77	1.45	4.22	1.83	1.6	1.63
Ho	.95	1.15	.9	.4	1.4	.85	1.4	1.05	.75	1.5	.9	3.7	1.3	1.0	1.5
Tm	<.2	.72	<.84	<.2	<.2	.44	.69	.66	.42	.94	<.2	2.26	.57	.58	<.2
Yb	2.4	4.4	1.6	2.1	3.75	2.5	5.75	3.55	2.05	6.4	3.0	13.8	3.9	4.1	3.6
Lu	.33	.59	.22	.30	.60	.38	.78	.43	.27	.87	.44	1.83	.51	.58	.47

Sample No.	58	67	113	34
La	84.5	34	73	73.5
Ce	155	52.5	140	136.5
Nd	68.5	28	46	49
Sm	14.35	4.6	10.3	11.35
Eu	1.62	3.34	1.87	1.84
Gd	9.7	3.15	6.2	7.1
Tb	1.08	.48	.91	.87
Ho	.8	.5	.4	.9
Tm	.38	.24	.38	.37
Yb	2.55	1.7	2.4	2.65
Lu	.35	.24	.33	.39

Table 8A. -- Major-oxide and normative-mineral compositions, in weight percent, of graphitic schists and phyllites from the Ocoee Supergroup in the Bill Arp thrust sheet in Georgia. Analyst: Nancy Skinner

Sample No.	GP.2	GP.3	GP.4	GP.5	GP.8	GP.9	GP.10	GP.11	GP.12	GP.13	GP.14	GP.15	GP.16	GP.17	GP.18
							Major-oxide composition								
SiO_2	42.5	47.9	49.9	50.9	51.7	55.8	56.4	57.0	57.2	57.7	59.2	59.6	59.7	59.8	61.0
Al_2O_3	29.7	29.2	28.6	24.9	24.6	20.5	19.2	20.7	21.9	19.1	21.1	19.9	21.4	19.7	18.4
Fe_2O_3	6.8	4.9	4.7	1.7	4.7	1.6	5.4	5.2	5.2	2.6	5.5	6.3	3.8	6.4	3.7
FeO	1.2	.48	.55	4.9	7.2	6.2	1.2	.50	.80	1.8	.08	.20	.48	.16	1.4
MgO	1.3	.72	.76	1.4	1.0	2.4	2.1	1.3	.62	1.5	.54	1.4	1.1	.85	1.4
CaO	.00	.00	.01	.22	.04	1.5	.46	1.2	.00	.61	.00	.00	.00	.00	.47
Na_2O	.28	1.3	1.0	.70	.46	2.3	1.7	.40	.42	2.0	.76	.21	.43	.43	.29
K_2O	7.6	6.9	6.1	6.2	7.0	3.5	3.3	5.4	4.5	3.9	5.5	6.4	5.1	5.6	5.4
H_2O+	5.6	4.4	3.6	3.4	3.1	2.9	3.2	3.7	4.7	2.8	3.2	2.6	3.9	3.3	1.9
H_2O-	.91	.30	.21	.17	.32	.00	.30	.71	.82	1.1	.22	.21	.44	.61	.31
TiO_2	1.2	.93	1.7	1.2	1.2	.79	.80	1.0	1.2	.70	1.2	.77	1.1	1.1	.91
P_2O_5	.20	.09	.08	.17	.25	.28	.29	.34	.27	.15	.10	.11	.24	.31	.13
MnO	.08	.10	.05	.08	.03	.10	.06	.04	.04	.33	.01	.02	.02	.02	.05
CO_2	.02	.01	.01	.02	.02	.63	.02	.01	.02	.01	.01	.01	.01	.01	.01
IL less CO_2 + H_2O	1.1	1.6	2.0	3.0	4.2	.49	4.2	1.5	1.7	5.1	1.2	1.7	1.5	1.9	3.8
Total	98.49	98.83	99.27	99.01	99.34	98.99	98.63	99.30	99.39	99.40	98.68	99.43	99.22	100.19	99.17
							C.I.P.W. normative composition								
Q	11.57	13.164	19.824	18.320	18.626	20.589	30.551	30.339	38.732	27.638	33.626	32.272	37.804	36.766	35.788
C	21.390	19.687	20.427	16.996	16.637	12.271	12.683	12.755	16.947	10.768	14.101	12.767	15.682	13.549	11.442
Z	.024	.052	.117	.056	.181	.034	.072	.082	.084	.054	.048	.042	.098	.042	.060
OR	44.913	40.776	36.048	36.639	41.367	20.683	19.502	31.912	26.593	23.047	32.503	37.821	30.139	33.094	31.912
AB	.442	10.528	8.084	5.923	1.993	19.461	14.385	3.385	.427	16.923	5.386	1.065	1.025	.466	2.454
AN				.119		1.798	.409	3.939		2.243					1.739
NC	.389	.095	.076		.384			.632		.211	.144	.528	.641		
HY	3.237	1.793	1.893	9.244	9.874	14.917	5.230	3.237	1.544	4.349	1.345	3.486	2.739	2.117	3.486
MT	.637			2.465	6.815	2.320	1.741			3.770					2.033
CM	.020	.016	.024	.019	.018	.019	.011	.012	.017	.016	.024	.013	.016	.014	.016
HM	6.361	4.900	4.700				4.200	5.200	5.200		5.500	6.300	3.800	6.400	2.298
IL	2.279	1.217	1.253	2.279	2.279	1.500	1.519	1.134	1.765	1.329	.174	.456	1.048	.371	1.728
RU		.289	1.041					.403	.271		1.108	.530	.548	.904	
AP*	.463	.209	.185	.394	.579	.649	.672	.788	.626	.348	.232	.255	.556	.718	.301
CC				.045		1.433	.045	.023		.023					.023

* Most analyses contain insufficient Ca to form the proper amount of apatite.

Table 8A. -- Continued

Sample No.	GP.19	GP.20	GP.21	GP.22	GP.23	GP.24	GP.25	GP.26	GP.27	GP.28	GP.29	GP.30	GP.31
						Major-oxide composition							
SiO_2	61.3	61.5	62.1	62.2	62.5	62.7	63.7	64.2	64.3	65.6	66.0	67.7	71.3
Al_2O_3	19.0	20.4	21.4	20.4	20.4	18.5	20.2	19.8	19.4	18.7	17.1	17.5	15.1
Fe_2O_3	2.3	4.5	2.3	4.9	2.4	3.1	3.5	4.3	3.4	2.2	1.9	2.1	2.6
FeO	3.2	.17	.84	.42	.20	1.6	.26	.08	.24	.44	.16	.66	.64
MgO	1.7	.43	.74	.30	1.4	1.3	.54	.80	1.1	.46	.91	1.8	.44
CaO	1.6	.00	.00	.00	.00	.48	.00	.00	.00	.00	.26	.50	.00
Na_2O	2.9	.95	1.2	.44	.23	1.5	1.0	.53	.14	.08	.29	.18	.06
K_2O	3.3	4.2	4.5	3.7	6.7	4.4	3.9	5.5	5.5	8.0	4.0	6.9	5.2
H_2O+	1.3	3.2	2.5	4.2	2.3	2.2	3.2	2.9	3.2	1.6	3.2	2.0	1.9
H_2O-	.27	.35	.23	.92	.04	.66	.41	.23	.28	.22	1.4	.08	.18
TiO_2	.94	1.0	1.1	.87	.72	.98	1.0	.63	1.0	1.0	1.5	.85	.73
P_2O_5	.28	.13	.12	.09	.09	.18	.15	.10	.11	.10	1.3	.14	.09
MnO	.10	.05	.07	.06	.00	.08	.04	.05	.02	.03	.02	.00	.02
CO_2	.01	.03	.02	.01	.02	.00	.01	.02	.00	.01	.01	.01	.01
IL less $CO_2 + H_2O$	1.9	3.8	1.6	2.7	2.2	.57	2.4	1.8	1.5	1.4	1.3		.38
Total	100.05	100.08	99.80	99.61	99.32	99.08	99.40	99.48	99.41	100.54	99.35	100.42	98.65
						C.I.P.W. normative composition							
Q	35.254	28.947	39.118	41.169	32.607	41.910	40.315	36.948	39.104	34.093	56.776	36.842	51.029
C	11.171	11.384	15.221	14.588	12.542	12.825	13.825	12.435	12.754	10.000	14.890	9.139	9.559
Z	.068	.078	.080	.088	.044	.133	.098	.040	.157	.159	.157	.044	.060
OR	19.502	24.820	26.593	21.865	39.594	26.002	23.047	32.503	32.503	47.276	23.638	40.776	30.730
AB	10.154	22.999	6.734	9.301	3.125	1.946	11.086	7.268	3.571	.219		1.523	
AN	6.233					1.460						1.631	
NC		.311	.264	.172	.121		.325	.241	.185	.195	2.699		.193
HY	6.841	1.071	1.843	.747	3.486	3.237	1.345	1.992	2.739	1.146	2.266	4.483	1.096
MT	3.335					2.562							.002
CM	.012	.013	.014	.018	.014	.015	.013	.009	.014	.013	.012	.017	.010
HM		4.500	2.300	4.900	2.400	1.333	3.500	4.300	3.400	2.200	1.900	2.100	2.598
IL	1.785	.459	1.915	1.006	.413	1.861	.626	.398	.540	.986	.373	1.383	1.386
RU		.759	.092	.340	.503		.670	.420	.716	.481	1.304	.122	
AP*	.649	.301	.278	.209	.209	.417	.348	.232	.255	.232	3.012	.324	.209
CC	.023											.023	

* Most analyses contain insufficient Ca to form the proper amount of apatite.

Table 8B. -- Trace-element abundances, in parts per million, in graphitic schists and phyllites from the Ocoee Supergroup in the Bill Arp thrust sheet. Analyst: J.D. Fletcher

Sample No.	GP.2	GP.3	GP.4	GP.5	GP.8	GP.9	GP.10	GP.11	GP.12	GP.13	GP.14	GP.15	GP.16	GP.17	GP.18
Rb	221	246	212	183	200	119	120	171	150	138	201	230	164	175	149
Ba	1833	1411	1093	923	2381	322	501	1106	962	1015	653	1961	1012	1271	1292
Sr	120	360	360	240	220	320	140	140	110	170	92	20	120	110	180
Cs	2.4	3.9	4.2	4.6	2.3	4.4	3.0	2.6	3.6	2.1	4.3	1.1	2.0	1.3	2.5
Th	25.7	28.0	22.7	18.6	20.4	11.0	27.15	20.4	24.7	15.3	15.2	16.6	27.9	26.7	11.1
U	5.7	2.8	3.0	3.8	4.1	3.6	3.5	3.6	5.3	4.3	4.9	2.3	4.3	5.6	2.7
Zr	210	260	580	280	900	170	360	410	420	270	240	210	490	290	300
Hf	7.1	6.9	14.9	8.4	18.3	5.7	10.95	9.9	11.1	6.1	5.8	6.5	11.9	9.7	7.4
Nb	22	19	30	26	31	28	<10	22	38	18	17	18	20	23	<10
Ta	2.06	1.50	2.58	1.70	2.13	1.23	1.24	1.14	2.53	1.00	1.70	1.00	1.28	1.30	1.06
Co	6.4	3.6	1.3	36.9	1.7	16.8	10.2	1.2	8.4	38.2	2.3	.2	2.7	.2	16.5
Ni	17	<2	<2	36	<2	30	19	3	6	34	<2	<2	7	<2	30
Cr	91	75	110	88	85	89	52	56	80	76	110	62	73	64	84
Sc	27.05	26.81	22.53	22.58	23.95	13.12	15.55	19.71	14.50	18.46	21.16	16.98	20.85	15.79	18.45
Cu	40	72	30	58	29	51	46	34	33	100	45	34	45	55	43
Zn	126	104	191	72	87	95	123	64	119	73	40	32	99	37	114
Sb	<1.4	<1.6	<1.3	<1.5	<1.4	.8	.8	1.3	<1.0	<1.2	<1.4	.7	.7	2.3	.6
Y	70	15	<10	68	87	81	76	54	34	49	59	59	75	42	56

Sample No.	GP.19	GP.20	GP.21	GP.22	GP.23	GP.24	GP.25	GP.26	GP.27	GP.28	GP.29	GP.30	GP.31
Rb	162	136	203	114	244	183	154	197	217	173	153	160	110
Ba	542	844	887	846	1895	907	783	611	1066	873	751	588	668
Sr	240	160	120	84	40	220	100	70	54	84	70	28	30
Cs	7.2	2.0	3.5	2.4	1.4	4.6	3.2	1.8	2.1	1.6	2.1	3.0	1.7
Th	23.1	22.0	25.4	22.7	24.2	22.3	22.4	25.3	21.8	16.6	41.3	14.3	12.0
U	5.3	5.3	4.8	5.4	2.3	5.1	4.3	2.9	3.5	4.6	6.2	4.6	3.3
Zr	340	390	400	440	220	660	490	200	780	790	780	220	300
Hf	10.0	11.1	11.3	11.1	5.3	15.9	12.0	7.2	18.2	16.6	15.5	5.9	7.0
Nb	22	31	28	27	15	24	25	<10	30	26	39	22	21
Ta	2.31	2.27	2.40	2.41	1.17	2.27	2.06	0.92	2.47	1.67	1.64	1.30	1.16
Co	9.5	5.9	0.6	12.9	0.4	4.4	4.2	0.5	1.2	9.9	.2	2.0	1.2
Ni	18	5	<2	9	<2	<2	<2	<2	<2	8	<2	<2	<2
Cr	54	60	64	82	66	69	59	40	65	62	54	78	45
Sc	10.37	13.41	13.90	12.39	18.27	13.93	12.88	16.68	13.07	12.85	18.88	15.35	14.95
Cu	20	24	8	34	5	18	27	31	22	9	57	11	28
Zn	111	45	68	67	46	71	52	31	37	25	42	26	<25
Sb	<1.1	<1.3	.6	<.9	<1.2	<1.3	<1.2	1.0	<.8	<1.1	2.2	.6	.6
Y	25	<10	14	18	64	47	<10	36	36	58	76	26	52

Table 8C. -- Rare-earth-element abundances, in parts per million, in graphitic schists and phyllites from the Ocoee Supergroup in north Georgia. Analyst: L.J. Schwarz

Sample No.	GP.2	GP.3	GP.4	GP.5	GP.8	GP.9	GP.10	GP.11	GP.12	GP.13	GP.14	GP.15	GP.16	GP.17	GP.18
La	73	14	9	80	308	40	43.5	98	59	68	85	71	90	96	65
Ce	130	77	20	148	252	84	100.5	182	100	143	120	150	184	192	136
Nd	82	13	<26	71	275	35	54 93	49	68	90	68	87	85	68	
Sm	18.4	2.8	1.5	13.9	53.6	8.2	11.3	18.1	10.9	14.6	19.0	13.2	17.5	18.3	12.8
Eu	2.86	.52	.40	2.28	7.56	1.33	1.31	2.87	1.46	2.11	2.24	1.81	2.31	2.36	2.49
Gd	10.4	1.8	3.8	9.5	26.7	5.3	8.0	11.1	7.0	8.6	11.2	8.0	10.7	12.0	9.3
Tb	2.32	.51	<1.1	1.80	4.37	1.05	1.34	1.83	1.30	1.61	1.87	1.53	2.00	1.89	1.44
Ho	2.5	<.8	<.7	1.4	2.8	1.2	1.4	1.1	1.5	1.4	1.8	1.3	2.0	1.5	1.2
Tm	1.20	.23	.45	.78	1.14	.62	.70	.62	.71	.73	.79	.63	.89	.66	.61
Yb	8.3	2.0	2.1	6.0	6.6	3.5	5.3	5.2	5.1	5.1	5.3	4.7	7.2	4.1	4.1
Lu	1.15	.27	.34	.81	.89	.47	.70	.73	.70	.68	.69	.61	.90	.56	.58

Sample No.	GP.19	GP.20	GP.21	GP.22	GP.23	GP.24	GP.25	GP.26	GP.27	GP.28	GP.29	GP.30	GP.31
La	40	69	55	69	110	59	37	50	34	54	161	57	50
Ce	76	125	95	112	211	113	64	113	64	119	301	122	107
Nd	40	50	46	57	104	47	30	47	32	48	134	49	54
Sm	9.0	10.4	8.9	9.8	21.6	11.4	5.3	9.0	6.8	11.3	24.7	10.3	11.3
Eu	1.41	1.55	1.21	1.44	2.66	1.62	.84	1.23	1.01	1.90	3.14	1.51	1.77
Gd	5.8	5.6	5.2	6.0	12.6	8.3	4.0	6.4	5.9	7.9	15.7	5.1	8.5
Tb	1.21	.90	.76	.99	2.11	1.31	.48	1.13	1.00	1.47	2.73	1.04	1.26
Ho	1.3	.6	.8	1.0	1.9	1.5	.5	1.5	1.2	1.3	2.3	1.4	1.4
Tm	.55	.25	.46	.39	.76	.66	.20	.64	.74	.96	.79	.70	.60
Yb	3.9	1.4	2.9	2.6	4.8	5.0	2.2	4.5	4.8	6.2	5.8	4.1	4.2
Lu	.56	.18	.46	.39	.72	.74	.33	.60	.71	.94	.79	.59	.61

Table 9A. -- Major-oxide and normative-mineral compositions, in weight percent, of rocks from the Paulding Volcanic-Plutonic Complex in the Paulding thrust sheet. Analysts: E. Campbell, M. Doughten, J. Gillison, J. Reid, and H. Smith

Sample No.	B.7J	B.7K	B.7H	B.7I	B.7L	B.7C	B.7G	B.7A	B.7B	B.7E	B.7D	B.7F	WG.33
						Major-oxide composition							
SiO_2	52.8	53.9	56.5	57.3	57.2	57.4	57.6	57.9	61.5	61.6	61.7	62.4	63.5
Al_2O_3	18.5	18.3	17.7	17.3	16.0	16.7	16.9	17.0	17.4	17.0	17.8	16.0	15.4
Fe_2O_3	4.9	4.3	3.9	4.2	3.6	2.9	2.5	3.9	2.7	3.1	2.8	3.4	2.1
FeO	2.5	3.2	3.3	3.8	4.2	4.5	3.8	3.7	2.2	2.1	2.2	2.8	3.1
MgO	2.8	2.9	2.9	2.7	3.4	4.2	3.1	2.5	1.5	1.6	1.5	2.4	2.9
CaO	9.2	8.2	8.0	7.8	5.2	6.8	5.6	7.3	5.3	5.3	5.1	7.0	6.3
Na_2O	4.5	4.9	5.2	4.4	5.3	4.6	5.2	4.1	6.1	5.9	6.0	4.3	3.2
K_2O	1.0	1.1	0.82	1.0	2.0	0.23	2.3	1.2	.92	.79	.49	.78	1.1
H_2O+	1.6	1.6	1.0	1.1	1.2	1.1	1.1	1.2	.60	.72	.58	.85	.35
H_2O-	.89	.80	.53	.37	.41	.39	.35	.39	.24	.23	.28	.19	.19
TiO_2	.57	.59	.57	.63	.54	.53	.55	.66	.52	.56	.52	.37	.35
P_2O_5	.19	.19	.21	.20	.04	.14	.20	.18	.16	.18	.18	.11	.12
MnO	.21	.14	.16	.19	.14	.14	.15	.18	.10	.11	.06	.16	.08
CO_2	.05	.07	.07	.07	.04	.04	.06	.05	.05	.04	.06	.06	.08
Total	99.71	100.19	100.86	100.06	99.27	99.67	99.41	100.26	99.29	99.23	99.27	100.82	98.77
						C.I.P.W. normative composition							
Q	3.173	2.352	4.728	9.270	3.507	8.822	2.849	11.626	10.566	12.415	12.716	17.850	22.956
Z	.024	.018	.026	.026	.013	.018	.020	.020	.034	.019	.032	.011	.017
OR	5.910	6.501	4.846	5.910	11.819	1.359	13.592	7.091	5.437	4.669	2.896	4.609	6.501
AB	38.077	41.461	44.000	37.231	44.846	38.923	44.000	34.692	51.615	49.923	50.769	36.384	27.077
AN	27.336	24.700	22.543	24.510	13.970	24.249	15.989	24.448	17.389	17.579	20.200	22.061	24.416
DI	13.097	11.432	12.291	10.086	8.372	6.784	8.345	8.435	6.125	5.835	2.917	9.370	4.638
HY	.901	3.400	3.538	4.683	8.518	12.422	7.941	4.969	1.943	1.808	3.324	3.501	8.506
MT	7.081	6.235	5.655	6.090	5.220	4.205	3.625	5.655	3.915	4.495	4.060	4.930	3.045
CM	.012	.010	.008	.003	.009	.010	.013	.002	.003	.003	.004	.010	.009
HM	.016												
IL	1.083	1.121	1.083	1.197	1.026	1.007	1.045	1.254	.988	1.064	.988	.703	.665
AP	.440	.440	.487	.463	.463	.324	.463	.417	.371	.417	.417	.255	.278
CC	.114	.159	.159	.159	.091	.091	.136	.114	.114	.091	.136	.136	.182

Table 9B. -- Trace-element abundances, in parts per million, in rocks from the Paulding Volcanic-Plutonic Complex. Analysts: R. Johnson, H.J. Rose, B. McCall, G. Sellers, J. Lindsay

Sample No.	B.7J	B.7K	B.7H	B.7I	B.7L	B.7C	B.7G	B.7A	B.7B	B.7E	B.7D	B.7F	WG.33
Rb	44	47	21	13	54	30	88	41	15	11	15	17	55
Ba	381	426	190	390.5	394	293	375	556	209	160	200	160	389
Sr	455	400	342	182	210	249	294	183	230	224	225	282	330
Cs	.3	.5	.4	.3	.5	.4	.7	.5	.2		.4	.3	.6
Th	4.5	4.2	4.5	5.1	4.1	5.6	4.5	5.1	6.0	6.0	5.9	3.7	7.9
U	6.2	2.3	2.0	2.3	1.7	2.3	3.0	2.9	1.6	1.8	1.8	3.3	<1.4
Zr	120	90	130	130	65	89	99	98	170	97	160	54	86
Hf	2.7	2.5	2.7	2.9	2.5	2.2	2.6	3.3	3.5	3.7	3.6	1.7	2.7
Nb	7.1	8.3	6.9	6.2	6.7	4.5	6.0	6.1	6.6	7.1	7.5	9.8	
Ta	.45	.44	.41	.48	.46	.35	.64	.64	.58	.59	.60	1.60	.22
Co	24.0	23.8	16.3	21.2	19.9	25.9	17.8	21.0	8.5	8.9	7.9	14.3	16.0
Li	7	8	7	4	4	6	4.0	5.0	3.0	2.0	3.0	5.0	
Ni	7.1	<10	<10	<10	<10	4.5	<10	<10	<10	<10	<10	<10	22
Cr	55.1	44.4	35.6	13.2	42.9	46.2	62.6	8.9	14.2	15.0	16.5	48.1	40.1
Sc	28.8	26.1	25.7	27.3	25.9	28.3	24.00	25.30	18.30	17.20	18.30	21.60	16.37
Mo	1.4	.86	.72	1.1	.36	.32	.42	.82	.34	.46	.44	.30	
Cu	16	<10	<10	42	12	20	40	72	32	28	32	64	7
Zn	87	77	79	78	87	65	61	77	41	47	41	70	68
Sb	<.8	.6	.5	.6	.8	1.1	.6	.7	.7	.6	.8	1.2	<1.5
Y	19	24	20	21	14	14	17	22	20	21	19	11	

Table 9C. -- Rare-earth-element abundances, in parts per million, in rocks from the Paulding Volcanic-Plutonic Complex. Analysts: R. Johnson, H.J. Rose, B. McCall, G. Sellers, J. Lindsay

Sample No.	B.7J	B.7K	B.7H	B.7I	B.7L	B.7C	B.7G	B.7A	B.7B	B.7E	B.7D	B.7F	WG.33
La	13	22	13	13	10	7	8	12	13	13	13	7	19
Ce	23	45	22	23	18	17	15	29	24	27	25	12	33
Nd	20	30	19	17	<40	18	13	22	20	21	22	<30	16
Sm	3.2	5.2	3.2	3.4	2.2	2.4	2.6	3.7	3.5	3.6	3.5	1.8	2.9
Eu	.92	1.45	.96	1.08	.63	.83	.85	1.06	1.00	1.08	1.02	.52	.63
Gd	3.3	5.7	3.4	3.9	3.0	3.2	3.3	4.3	4.5	3.8	4.7	<2	
Tb	.59	.84	.65	.66	.46	.43	.54	.76	.72	.75	.72	.38	.72
Ho	.6	.9	.6	.65	.5	.4	.5	.3	.5	.3	.5	.4	<.6
Tm	.40	.45	.31	.38	.30	.27	.46	.33	.34	.36	.34	.22	<.53
Yb	2.4	3.3	2.6	2.5	1.9	1.6	2.1	2.7	2.6	2.8	2.7	1.4	1.3
Lu	.34	.43	.36	.36	.26	.25	.30	.38	.36	.38	.37	.21	.17

Table 10A. -- Major-oxide and normative-mineral compositions, in weight percent, of rocks from the Ropes Creek Metabasalt in the Ropes Creek thrust sheet. Analysts: J. Reid and H. Smith

Sample No.	P.63	CA.12	CA.4	B.2	CA.14	P.326	CC.1	CH.2	CH.6	CH.3	CA.10	WG.11	CA.6	CH.4	CC.2
							Major-oxide composition								
SiO_2	46.5	46.5	46.6	46.8	46.9	47.2	47.6	47.8	48.6	48.6	48.6	48.9	49.0	49.1	49.5
Al_2O_3	14.5	13.0	12.3	14.0	15.3	14.1	15.8	15.2	14.0	15.0	15.2	15.2	15.1	15.2	15.6
Fe_2O_3	6.1	3.5	2.3	4.9	1.8	4.7	3.3	4.3	2.8	4.0	3.1	3.7	2.3	3.7	2.8
FeO	8.0	8.4	8.2	8.7	8.4	5.5	7.8	7.7	5.8	8.2	7.5	8.2	8.9	8.2	7.0
MgO	6.3	5.5	7.5	8.2	8.4	8.0	8.8	7.3	11.2	7.7	8.6	7.4	9.0	7.4	8.8
CaO	11.9	15.0	13.4	9.2	10.1	11.5	11.0	9.3	13.3	8.8	11.1	9.8	9.3	9.8	13.2
Na_2O	2.5	1.7	2.8	2.8	3.3	2.6	3.2	3.4	1.3	3.0	2.6	3.2	3.1	3.2	1.8
K_2O	.13	.12	.08	.06	.15	.16	.40	.13	.07	.15	.10	.14	.11	.14	.22
H_2O+	1.2	1.2	1.5	2.8	2.2	2.5	.76	1.5	.53	1.2	1.4	.24	1.8	.24	.53
H_2O-	.47	.06	.05	1.0	.07	.13	.21	.49	.09	.71	.21	.14	.08	.14	.17
TiO_2	2.1	1.4	1.0	1.7	.87	1.4	.73	1.7	2.5	1.6	.96	1.7	1.1	1.7	.76
P_2O_5	.20	.16	.12	.23	.10	.17	.03	.19	.90	.17	.10	.22	.11	.22	.01
MnO	.15	.27	.23	.22	.21	.25	.23	.22	.16	.15	.19	.17	.20	.17	.20
CO_2	.01	3.2	4.0	.11	2.2	1.5	.01	.02	.02	.04	<.0.5	.03	<.05	.03	.03
Total	100.06	100.01	100.08	100.72	100.00	99.71	99.87	99.25	101.27	99.32	99.66	96.24	100.10	99.24	100.62
							C.I.P.W. normative composition								
Q	.592	5.658	.192			1.808			2.113						
C				26.191											
Z	.022			.042		.015	.006	.014	.056	.012			.010		
OR	.768	.709	.473	.355	.886	.946	2.364	.768	.414	.886	.591	.827	.650	.827	1.300
AB	21.154	14.385	23.692	23.692	27.923	22.000	22.404	28.769	11.000	25.384	22.000	27.077	26.231	27.077	15.231
AN	27.966	27.493	20.764	43.499	26.500	26.337	27.575	25.837	32.165	27.028	29.516	26.705	26.970	26.705	33.844
DI	24.076	21.051	16.019		7.368	16.081	21.650	15.345	22.040	12.397	19.862	16.499	14.747	16.438	25.337
HY	10.539	14.074	22.722	11.583	13.110	16.638		10.457	21.952	21.968	13.406	14.321	12.240	15.170	16.732
OL				13.273	12.427		16.106	6.150		.432	6.041	4.069	11.679	3.452	1.878
MT	8.844	5.075	3.335	7.105	2.610	6.815	4.785	6.235	4.060	5.800	4.495	5.365	3.335	5.365	4.060
CM	.047	.010	.039	.062	.066	.069	.067	.051	.137	.041	.070	.064	.009	.068	.071
IL	3.988	2.659	1.899	3.229	1.652	2.659	1.386	3.229	4.748	3.039	1.823	3.229	2.089	3.229	1.443
AP	.463	.371	.278	.533	.232	.394	.070	.440	2.085	.394	.232	.510	.255	.510	.023
CC	.023	7.278	9.097	.250	5.003	3.411	.023	.045	.045	.091	.114	.068	.114	.068	.068

Table 10A. -- Continued

Sample No.	CH.7	WG.19	CA.1	CH.10	WG.23	WG.25	WG.26	WG.27	WG.28	CM.2	WG.29	P.476
						Major-oxide composition						
SiO_2	50.0	50.3	50.8	51.3	51.5	51.9	52.0	52.2	52.6	52.7	53.0	53.2
Al_2O_3	14.1	15.8	14.3	14.7	14.8	15.6	13.5	15.7	15.9	15.3	15.1	14.7
Fe_2O_3	3.2	3.5	2.9	4.8	6.7	3.5	3.5	4.4	3.6	4.6	4.4	5.2
FeO	9.5	7.6	8.5	8.2	7.0	8.9	8.6	7.1	6.3	7.4	8.8	6.5
MgO	6.7	6.7	6.9	4.7	4.7	5.7	6.4	6.2	6.6	4.1	4.5	3.8
CaO	9.4	9.1	9.5	9.1	8.0	8.1	8.5	3.6	10.3	9.3	8.4	9.8
Na_2O	3.1	3.7	3.7	1.9	4.9	4.0	4.1	4.7	1.5	3.4	3.0	2.6
K_2O	.33	.25	.16	.24	.08	.23	.08	.04	.27	.07	.25	.11
H_2O+	.82	.56	.90	1.3	.36	.50	1.1	3.0	.40	.43	.32	.68
H_2O-	.25	.39	.06	.22	.11	.03	.17	.16	.22	.11	.10	.26
TiO_2	1.2	.65	1.4	1.7	1.3	.58	1.4	.98	.55	1.1	1.0	1.7
P_2O_5	.01	.05	.17	.09	.11	.07	.21	.10	.03	.13	.12	.21
MnO	.30	.25	.21	.21	.11	.24	.19	.22	.24	.17	.24	.13
CO_2	.02	.01	.36	.03	.02	.01	.11	1.4	.02	.06	.06	.03
Total	98.93	98.86	99.86	98.49	99.69	99.36	99.86	99.80	98.53	98.87	99.29	98.92
						C.I.P.W. normative composition						
Q				12.066	.900		.712	8.109	10.576	7.369	8.131	13.397
C								4.852				
Z	.107			.141	.010		.022	.006		.009	.008	.017
OR	1.950	1.477	.946	1.418	.473	1.359	.473	.236	1.596	.414	1.477	.650
AB	26.231	31.308	31.308	16.077	41.461	33.846	34.692	39.769	12.692	28.769	25.384	22.000
AN	23.591	25.774	21.946	30.880	18.161	23.940	18.204	8.391	35.862	26.287	27.005	28.122
DI	18.907	15.476	17.791	11.084	16.790	13.019	17.935		12.115	15.375	11.232	15.510
HY	18.630	11.590	16.300	14.945	8.972	19.246	18.110	23.634	18.705	10.937	16.961	7.012
OL	1.569	5.878	2.523			1.073						
MT	4.640	5.075	4.205	6.960	9.714	5.075	5.075	6.380	5.220	6.670	6.380	7.540
CM	.013	.026	.042			.016	.030	.001	.011	.002	.000	.000
IL	2.279	1.235	2.659	3.229	2.469	1.102	2.659	1.861	1.045	2.089	1.899	3.229
AP	.023	.116	.394	.209	.255	.162	.487	.232	.070	.301	.278	.487
CC	.045	.023	.819	.068	.045	.023	.250	3.184	.045	.136	.136	.068

Table 10B. -- Trace-element abundances, in parts per million, in rocks from the Ropes Creek Metabasalt. Analysts: R. Johnson, H.J. Rose, B. McCall, G. Sellers, J. Lindsay, and L.J. Schwarz

Sample No.	P.63	CA.12	CA.4	B.2	CA.14	P.326	CC.1	CH.2	CH.6	CH.3	CA.10	WG.11	CA.6	CH.4	CC.2
Rb	2						3	5		3		2		13	2
Ba	34			31		9	15						304	12	
Sr	580			156		360	30	230	180	170		230		640	42
Cs		<2.0	<2.0	<1	<2.0		<2.0	<2	<2.0	<1.9	<2.0	<2.1		<2.0	<2.0
Th		.06		.3			<1.0	<1.3	<2.0	<1.3		<1.3		<1.3	.5
U				<.8			<2.0	<1.0	<1.0	<1.0		<1.2		<1.0	<2.0
Zr	110			210		77				58		51		130	
Hf		2.3	1.8	3.1	1.7		.75	2.6	.65	2.4	1.6	1.7	1.6	2.9	<2.0
Nb				4.3			5.7							3.8	
Ta				<.7			<.5	.51		.39		.24		.59	<.70
Co	34	33.7	36.7	47.6	48.0	42	46.35	43.0	48.25	45.0	48.2	42.75	47.6	43.1	48.25
Ni	44			66		73	91	150	160	100		130	318	170	114
Cr	220	45.3	179	289	307	320	312	238.2	635.2	189.0	327	297.75	43.0	315.6	328.5
Sc		40.10	52.00	52.30	40.10		45.60	41.03	40.78	44.95	42.70	44.38	43.00	43.51	52.60
Cu				56			45	170		130		220		160	120
Zn	83	126	141	122	123		71	151	104	153	123	114.5	121	148	107
Sb				1.4			<.9	2.7	.9	<1.4		<1.4	<.9	<1.7	<2.0
Y	54		24			24	24	52	19	34	40		74		38

Sample No.	CH.7	WG.19	CA.1	CH.10	WG.23	WG.26	WG.27	WG.28	CM.2	WG.29	P.476
Rb		2			1	1	1	1	2	2	2
Ba											
Sr	530	9		130	320	190	140	110	170	280	210
Cs	<2.0	<1.6		<1.8	<1.9	<2.0	<2.1	<2.0	<2.6	<2.0	<2.0
Th	<2.1	<1.0	.5	.65	1.1	.8	.7	.85	<1.8	1.15	.95
U	<1.2	<1.2	<1.0	<1.1	<1.2	<1.3	<1.4	<1.2	<1.4	<1.3	<1.1
Zr											47
Hf	1.3	1.4	2.4	1.15	1.5	.9	2.7	1.0	1.0	1.5	1.3
Nb											
Ta		.99	<.7	.28	.16		1.18	1.60		3.40	<.70
Co	42.55	66.6	45.0	27.3	34.7	40.7	48.3	42.65	45.4	29.5	40.9
Ni	51	370		15	12	44	91	6	37	12	6
Cr	59.1	120.5	196.0	27.3	8.5	72.35	141.05	6.8	50.5	10.55	2
Sc	41.17	22.04	46.40	38.25	40.23	45.21	39.92	40.70	94.28	37.79	40.41
Cu		290			3	72	250	41	170	9	2
Zn	130.5	96	139	111.5	80.5	193.5	159.5	131.5	190.5	10.7	129.5
Sb	<1.2	<1.2		<1.1	<1.6		<1.5	<1.5	<1.5		
Y		38	22	62	50			21			

Table 10C. -- Rare-earth-element abundances, in parts per million, in rocks from the Ropes Creek Metabasalt. Analysts: R. Johnson, H.J. Rose, B. McCall, G. Sellers, and J. Lindsay

Sample No.	P.63	CA.12	CA.4	B.2	CA.14	P.326	CC.1	CH.2	CH.6	CH.3	CA.10	WG.11	CA.6	CH.4	CC.2
La	4		3	4	3	3.5	2	9	1	6	3	5	3	8	1.5
Ce	12	10	8	11	7	11	6.5	19	5	15	7	10	8	22	5
Nd	13	10	<20	<50	6	10	<30	17	<35	14	6	11.5	9	17	<30
Sm	5.0	2.9	21	3.4	1.9	3.5	1.4	4.7	1.0	4.2	1.9	3.0	2.2	4.7	.95
Eu	1.47	1.12	.75	1.32	.76	1.06	.50	1.36	.42	1.21	.78	.96	.80	1.36	.57
Gd	4.35	2.1	2.2	4.9	2.6	2.6					1.8		1.9		1.9
Tb	1.14	.85	.77	1.11	.51	1.14	1.6	.95	<1.57	.88	.60	.75	.57	1.21	.55
Ho	1.6	.5	.4	.9	.4	1.3	.38	.8	<.5	.6	.4	.6	.2	.9	.6
Tm	.50	.31	.22	.55	.18	.38	.8	.68	<.62	<.81	.19	.53	.23	.64	.12
Yb	4.2	<.5	2.5	4.4	2.2	2.9	.15	2.9	1.05	3.2	2.2	2.85	2.3	2.7	1.2
Lu	.63	<.06	.41	.60	.32	.45	.45	.44	.14	.50	.34	.42	.35	.36	.23
Sample No.	CH.7	WG.19	CA.1	B.4	CH.10	WG.23	WG.25	WG.26	WG.27	WG.28	CM.2	WG.29	P.476		
La	3.5	3		10	4.5	3.5	3	5.5	4	3	6	4.5	8		
Ce	7.5	7	12.6	12	10.5	7.5	6	16	9.5	8.5	14	11	18		
Nd	<37	<25	13.7	<40	10	<37	<34	12	<38	10	11.5	14	14		
Sm	2.8	.9	16.85	4.6	3.55	2.55	1.25	3.9	1.95	3.15	2.95	2.75	4.6		
Eu	.94	.42	16.5	2.05	1.05	.86	.38	1.19	.68	.73	.96	.87	1.36		
Gd		1.9	10.7	6.4									3.7		
Tb	.62	<1.11	12.98	1.45	.90	.60	<1.47	.92	.46	.73	.63	.64			
Ho	.65	<.5	6.5	1.3	.8	.55	<.6	.75	.4	.7	.6	.5	1.4		
Tm	.50	<.66	11.6	.74	.60	.50	<.67	.79	<.66	.84	<.66	<.64	.41		
Yb	2.75	.7	1.8	5.6	3.25	2.85	1.35	3.7	1.95	2.45	2.75	2.45	3.7		
Lu	.41	.10	.29	.77	.48	.39	.20	.51	.29	.36	.37	.35	.56		

Table 10D. -- Major-oxide and normative-mineral compositions, in weight percent, weight percent of high-magnesium rock associated with the Ropes Creek Metabasalt. Analysts: J. Reid, H. Smith, and J. Lindsay

Sample No.	CH.1	B.1
Major-oxide composition		
SiO_2	44.2	44.5
Al_2O_3	10.9	11.5
Fe_2O_3	6.5	2.3
FeO	6.4	8.5
MgO	15.1	18.6
CaO	9.6	6.7
Na_2O	1.4	1.1
K_2O	.07	.14
H_2O+	1.9	4.4
H_2O-	.17	.31
TiO_2	2.2	.48
P_2O_5	.42	.05
MnO	.21	.20
CO_2	.03	.25
Total	99.10	99.03
C.I.P.W. normative composition		
Z	.038	.005
OR	.414	.827
AB	11.846	9.308
AN	23.256	26.033
DI	16.931	4.237
HY	23.039	27.247
OL	6.946	21.726
MT	9.424	3.335
CM	.154	.280
IL	4.178	.912
AP	.973	.116
CC	.068	.569

Table 10E. -- Trace-element abundances, in parts per million, in CH.1 and B.1. Analysts: L.J. Schwarz, R. Johnson, H.J. Rose, B. McCall, G. G. Sellers, and J. Lindsay

Sample No.	CH.1	B.1
Rb	2	<2
Ba	270	23
Sr	210	23
Cs	<1.7	<.8
Th	3.1	.1
U	1.1	<.6
Zr	190	37
Hf	3.6	.8
Nb	1.8	1.8
Ta	4.32	<.5
Co	75.0	88.2
Ni	660	620
Cr	714.4	1300
Sc	23.90	28.3
Cu	89	50
Zn	139	70
Sb		.9
Y	32	15

Table 10F. -- Rare-earth-element abundances, in parts per million, in CH.1 and B.1. Analyst: L.J. Schwarz

Sample No.	CH.1	B.1
La	32	2
Ce	47	6
Nd	30	<40
Sm	7.7	1.2
Eu	1.30	.44
Gd		1.3
Tb	.93	.41
Ho	.7	.4
Tm	.81	.26
Yb	1.7	1.6
Lu	.23	.22

Table 11A. -- Major-oxide compositions and normative-mineral compositions, in weight percent, of rocks in the Soapstone Ridge thrust sheet. Analyst: Z.A. Hamlin

Sample No.	R.31*	R.16*	R.13*	R.15*	S.2	R.6*	R.1*	R.23*	AR.35*	R.3*	R.29*	R.8*	AR.33	R.17	R.7
Major-oxide composition															
SiO_2	42.0	42.5	42.8	43.1	43.5	44.4	44.5	44.8	44.8	44.8	44.8	45.0	45.4	46.0	46.3
Al_2O_3	11.7	5.80	6.80	6.68	11.6	6.80	6.15	7.36	7.43	7.11	8.36	5.08	5.76	8.68	6.29
Fe_2O_3	4.54	10.57	8.74	6.73	3.84	7.69	6.91	7.06	7.12	6.02	6.33	9.16	8.69	5.81	6.98
FeO	4.13	9.63	7.96	6.13	5.16	7.01	6.29	6.43	6.48	5.49	5.77	8.35	7.91	5.30	6.36
MgO	25.4	25.7	25.3	26.6	23.2	26.7	26.7	27.5	24.9	23.3	22.7	25.7	26.0	24.4	27.1
CaO	5.62	.24	.31	1.34	6.1	.45	1.75	.08	3.97	7.11	6.32	.11	.44	4.08	.43
Na_2O	.48	.59	.19	<.01	.61	.65	.16	.25	.09	.45	.5	.46	.03	1.27	.21
K_2O	.06	.03	.06	.04	.15	.04	.18	.05	<.01	.06	.11	.04	<.01	.08	.04
H_2O+					4.9										
H_2O-					.13										
TiO_2	.14	.65	.94	.61	.27	.55	.55	.36	.31	.54	.27	.43	.99	.72	.35
P_2O_5	.02	.12	.13	.14	.10	.05	.08	.01	.12	.06	.04	.11	<.01	.16	.05
MnO	.14	.27	.20	.19	.14	.26	.22	.18	.21	.20	.27	.25	.22	.23	.20
CO_2					.0										
Total	94.23	96.10	93.43	91.57	99.70	94.6	93.49	94.08	95.44	95.14	95.47	95.69	95.46	96.73	94.31
C.I.P.W. normative composition															
Q			.612							.633	2.754		1.176		
C	.678	4.642	6.168	4.532		4.989	2.702	6.773	.344			4.342	4.911		5.236
Z		.028	.014		.012	.020		.009	.009	.013	.006	.040	.018	.020	.008
OR	.355	.177	.355	.236	.886	.236	1.064	.295	.355	.650	.236		.473	.236	
AB	4.062	4.992	1.608		5.162	5.500	1.354	2.115	.762	3.808	4.231	3.576	.254	10.746	1.777
AN	27.749	.424	.694	5.744	28.476	1.906	8.159	.332	18.933	17.207	20.246		2.183	17.752	1.816
NC												.064			
DI					.941					13.886	8.545			1.142	
HY	24.324	60.819	69.249	66.263	27.465	62.580	62.170	72.255	55.439	35.428	37.771	71.556	70.840	37.428	73.141
OL	30.186	8.225		3.561	25.366	7.084	6.703	1.339	8.619	14.451	14.207			19.027	
MT	6.583	15.326	12.672	9.758	5.568	11.135	10.019	10.236	10.323	8.728	9.178	13.281	12.600	8.424	10.120
CM	.370	.431	.487	.458	.226	.558	.528	.578	.779	.515	.478	.475	.469	.418	.624
IL	.266	1.235	1.785	1.159	.513	1.045	1.045	.684	.589	1.026	.513	.817	1.880	1.367	.665
AP	.046	.278	.301	.324	.232	.116	.185	.023	.278	.139	.093	.255		.371	.116
CC															

* Total iron reported as Fe_2O_3; Fe_2O_3 and FeO calculated using average ratio from other samples where both values were determined.

Table 11A. Continued

Sample No.	R.19*	R.18*	R.12*	R.4*	R.9*	R.14*	S.547	AR.32*	R.11*	S.20	AR.37*	R.21*	R.28*	S.10	SS.RA
						Major-oxide composition									
SiO_2	46.5	46.8	47.0	47.0	47.2	47.3	48.8	48.9	49.3	49.7	49.8	50.0	50.0	50.4	50.6
Al_2O_3	6.69	8.34	6.27	7.07	5.89	6.00	7.3	3.52	4.95	7.7	6.17	6.48	7.94	5.2	9.0
Fe_2O_3	7.90	6.54	6.49	5.14	6.70	7.64	6.2	6.59	7.12	4.7	4.66	5.86	4.58	7.2	3.1
FeO	7.20	5.96	5.91	4.68	6.10	6.96	5.1	6.01	6.48	4.6	4.24	5.34	4.17	4.2	5.2
MgO	25.2	24.5	26.2	22.5	26.7	25.6	21.9	25.5	26.6	15.4	27.5	23.5	23.3	27.4	15.2
CaO	1.86	1.93	2.60	8.24	.75	.84	6.8	3.91	.15	12.3	.20	3.72	5.65	1.2	13.0
Na_2O	.44	.96	.34	.45	.63	.10	.67	<.01	.07	.70	.21	.89	.62	.0	.88
K_2O	.04	.05	.05	.08	.03	.04	.20	<.01	.04	.25	<.01	.08	.07	.0	.23
H_2O+							2.1			.90				2.7	.77
H_2O-							.22			1.5				.97	.13
TiO_2	.65	.73	.29	.28	.33	.61	.37	.38	.63	.86	<.01	.62	.12	.21	.68
P_2O_5	.04	.08	.01	.06	.13	.35	.05	.17	<.01	.12	<.01	.08	.04	.06	.13
MnO	.20	.29	.26	.25	.18	.29	.21	.20	.17	.16	.14	.18	.16	.17	.18
CO_2						.01		.01				.0			.01
Total	96.72	96.18	95.42	95.75	94.64	95.73	99.92	95.20	95.52	98.89	92.95	96.75	96.65	99.71	99.11
						C.I.P.W. normative composition									
Q						4.932		2.405	6.365	3.442	5.365	.769		6.373	1.113
C	2.634	3.390	.949		3.769	5.125			4.517		5.431			3.162	
Z	.010	.020	.007	.008	.010	.016		.013	.007			.028	.005		.096
OR	.236	.295	.295	.473	.177	.236	1.182		.236	1.477		.473	.414		1.359
AB	3.723	8.123	2.877	3.808	5.331	.846	5.669		.592	5.923	1.777	7.531	5.246		7.446
AN	8.976	9.052	12.847	17.038	2.873	1.820	16.324	9.606	.748	17.134	1.075	13.453	18.679	5.561	19.932
NC															
DI				18.396			13.402			33.866		3.518	7.130		34.517
HY	67.441	60.341	63.082	38.744	71.661	69.658	48.641	65.771	71.526	25.924	72.361	61.128	57.166	69.968	27.634
OL	.943	3.936	5.322	9.070	.132		2.577						1.049		
MT	11.454	9.482	9.410	7.453	9.714	11.077	8.989	9.555	10.323	6.815	6.757	8.496	6.641	10.439	4.495
CM	.415	.412	.471	.519	.425	.474		.152	.352		.882	.374	.439	.399	1.291
IL	1.235	1.386	.551	.532	.627	1.159	.703	.722	1.197	1.633		1.178	.228	.139	.301
AP	.093	.185	.023	.139	.301	.811	.116	.394		.278		.185	.093		.023
CC						.023		.023							

* Total iron reported as Fe_2O_3; Fe_2O_3 and FeO calculated using average ratio from other samples where both values were determined.

Table 11A. Continued

Sample No.	S.13	AR.34*	R.20*	R.22*	AR.38*	R.25*	AR.36*	R.24	R.27
					Major-oxide composition				
SiO_2	51.1	51.5	51.7	51.8	52.7	53.0	53.4	54.1	54.5
Al_2O_3	5.3	5.76	5.35	5.11	4.10	5.31	4.81	4.91	3.71
Fe_2O_3	3.4	5.60	7.22	6.97	4.33	5.70	5.07	5.81	5.49
FeO	5.8	5.10	6.58	6.34	3.94	5.19	4.61	5.30	5.00
MgO	17.1	23.5	24.7	24.4	28.5	24.0	25.2	23.5	25.6
CaO	14.1	3.72	1.12	1.10	.44	2.53	1.72	2.07	.20
Na_2O	.61	.15	.55	.41	.30	1.12	.44	.6	.21
K_2O	.05	<.01	.04	.06	<.01	.06	<.01	.06	.04
H_2O+	.52								
H_2O-	.26								
TiO_2	.76	.28	.30	.33	<.01	.37	.38	.26	.03
P_2O_5	.17	<.01	.06	.02	<.01	.05	.01	.02	.02
MnO	.20	.18	.31	.32	.15	.22	.18	.22	.28
CO_2	.02								
Total	99.39	95.81	97.93	96.86	94.49	97.55	95.83	96.79	95.08
					C.I.P.W. normative composition				
Q	1.431	6.278	6.590	7.817	5.819	3.791	7.879	8.817	12.198
C			2.507	2.419	2.807		.975	.143	3.006
Z		.005	.007	.006		.007	.009	.011	.004
OR	.295		.236	.355		.355		.355	.236
AB	5.162	1.269	4.654	3.469	2.538	9.477	3.723	5.077	1.777
AN	11.578	15.046	5.171	5.326	2.183	9.287	8.491	10.138	.862
NC									
DI	45.219	2.675				2.305			
HY	28.032	61.858	67.464	66.696	74.748	63.187	66.565	63.260	69.026
OL									
MT	4.930	8.119	10.468	10.106	6.278	8.264	7.351	8.424	7.960
CM	.290	.318	.579	.327	.559	.459	.587	.587	.344
IL	1.443	.532	.570	.627		.703	.722	.494	.057
AP	.394		.139	.046		.116	.023	.046	.046
CC	.045								

* Total iron reported as Fe_2O_3; Fe_2O_3 and FeO calculated using average ratio from other samples where both values were determined.

Table 11B. -- Trace-element abundances, in parts per million, in rocks from the Soapstone Ridge thrust sheet. Analysts: R. Lerner, N. Rait, and G.A. Wandless

Sample No.	R.31	R.16	R.13	R.15	S.2	R.6	R.1	R.23	AR.35	R.3	R.29	R.8	AR.33	R.17	R.7
Rb											9				
Ba		84	24	52	319				110	76	120	21		38	44
Sr									27			16			
Cs	<.6	<.6	<.6	<.6	<1.0	<.7	<.5	<.6	<.7	.4	<.7	<.7	<.7	<.6	<.7
Th	<.5	.9	.8	.8	1.25	1.7	1.85	1.2	1.0	.9	.3	1.0	.8	1.85	.6
U	<.3	<.4	.3	<.6	<.7	.2	.3	.2	<.4	1.0	.2	<.6	<.4	.45	.3
Zr	<294	140	72		62	98		47	46	63	32	200	91	98	39
Hf	.2	1.25	1.7	1.4	.85	1.05	1.05	.7	.6	1.0	<.8	1.6	.7	1.75	.5
Ta	<.40	.19	.31	<.40	<.6	.31	.23	<.40	<.5	.22	<.40	.22	<.50	.28	.13
Co	90.7	120	112.0	141.0	84.3	144.5	82.5	101.1	97.0	97.75	90.9	92.5	152.0	96.6	128.0
Ni	1100	1300	1400	1300		670	630	1300	840	400	900	1400	1100	1100	1400
Cr	1720	2005	2265	2130	1050	2595	2455	2685	3620	2395	2220	2210	2180	1945	2900
Sc	10.20	14.50	13.70	12.40	12.15	15.75	13.0	12.15	20.80	16.5	27.60	13.60	12.50	17.25	11.20
Cu	38	36	32	38		59	70	38	20	64	81	250	31	16	81
Zn	73	110.5	82	76	73	90.5	90	82	78	75.5	78	109	105	95	81
Sb									1.7						
V	84	150	130	97		82	76	73	120	100	110	94	86	65	
Y	<10	19	21	19		12	15	13	21	25	22	19	22	13	

Sample No.	R.19	R.18	R.12	R.4	R.9	R.14	S.547	AR.32	R.11	AR.37	R.21	R.28	SS.RA	S.8	S.13
Rb										2					
Ba	49		72.5		6				20		31	23		180	255
Sr										260					
Cs	<.5	<.6	<.5	.4	<.5	.5		<.6	.3	<.6	<.6	<.6	<1.9	<1.0	<2.0
Th	.7	2.65	.5	.8	.95	1.3		1.0	.9	.3	4.5	<.6	.4	.4	<.9
U	.3	.65	<.5	<.5	.5	.1		.2	<.4	1.0	.5	<.4	<.5	<.8	.9
Zr	52	100	33	40	48	82		66	34		140	26	480		
Hf	.8	1.65	.4	.73	.75	1.3		1.0	.55	<.5	2.5	.6	1.3	.7	1.6
Ta	.38	.30	<.40	.36	.19	.30		.23	.22	.16	.25	<.4	.15	<.5	<.6
Co	80.0	107	97.6	99.6	72.75	79.35		77.3	89.25	114.0	83.2	72.7	52.0	31.4	47.7
Ni	1200	1200	680	550	670	820		850	880	890	870	1100	270		
Cr	1930	1915	2190	2410	1975	2205		706	1635	4100	1740	2040	1483.1	59.2	1350
Sc	14.10	11.25	9.42	15.27	10.70	12.0		11.10	13.35	7.80	23.20	19.80	47.20	22.95	56.60
Cu	39	7.5	120	35	200	81		40		120	190	6.2	4.3	86	
Zn	95	89.5	83	72	105	111.5		83	100.5	46	111	56	147.5	95.5	139.5
Sb										2.2				<.8	
V	96	71	50	78	59	77	12	65		63	46	82	93		
Y	22	13	14	16	13	25	15	16	29	36	24	25			

Table 11B. Continued

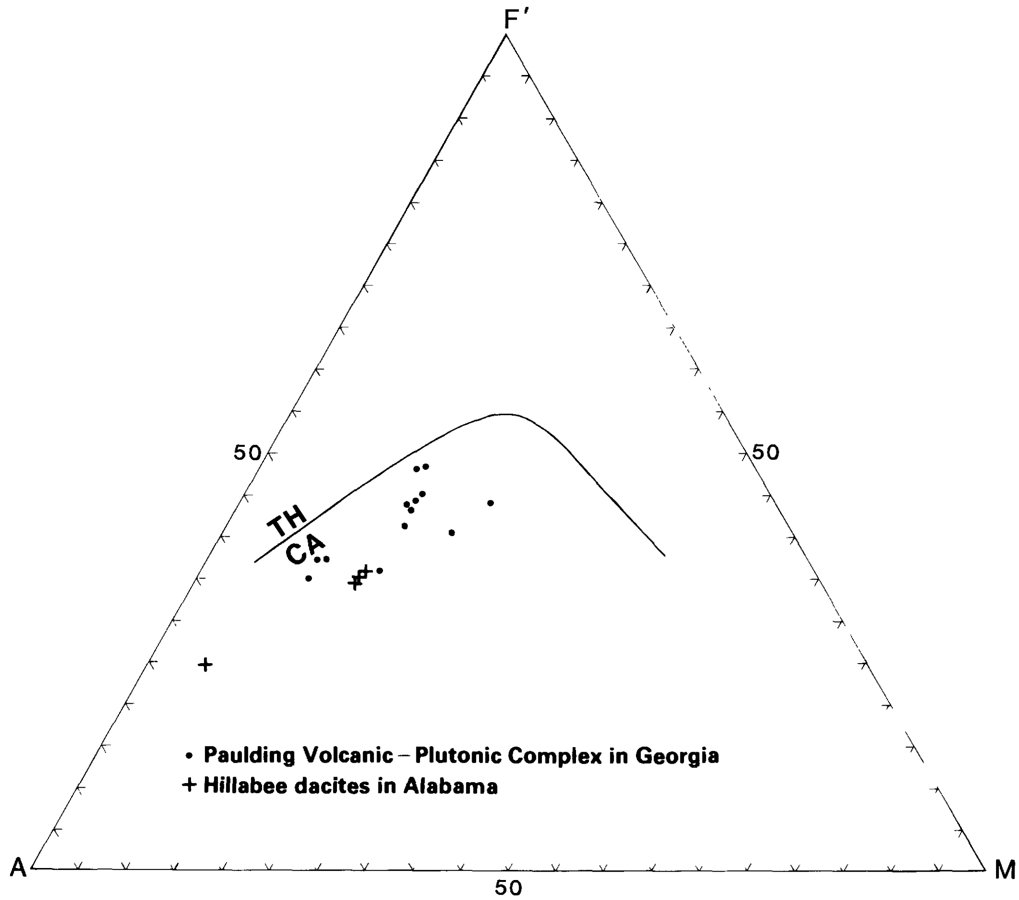
Sample No.	AR.34	R.20	R.22	AR.38	R.25	AR.36	R.24	R.27
Rb								
Ba		33				117		
Sr								
Cs	<.6	<.6	<.6	<.5	<.6	<.6	<.6	<.5
Th	.3	.4	.3	<.4	.2	.3	.7	<.5
U	.1	<.4	<.6	<.3	.2	<.5	.3	<.3
Zr	26	33	28		33	43	55	21
Hf	<.7	.5	.4	<.5	.5	.6	.55	<.5
Ta	<.40	<.4	<.4	<.40	<.4	.22	.55	.24
Co	60.0	81.6	65.4	62.4	63.05	67.1	62.5	92.0
Ni	730	420	850	740	660	760	760	1600
Cr	1480	2690	1520	2600	2135	2730	2730	1600
Sc	23.90	22.50	26.00	4.77	24.35	20.10	24.65	6.73
Cu	28	83	51	68	15	12	19	28
Zn	71	136.5	104	81	93	86	107.5	145
Sb			1.6			1.6		
V	110	68	77	34	87	83	84	37
Y	13	14	14	<10	21	78	53	19

Table 11C. -- Rare-earth-element abundances, in parts per million, in rocks from the Soapstone Ridge thrust sheet. Analysts: G.A. Wandless and L.J. Schwarz

Sample No.	R.31	R.16	R.13	R.15	S.2	R.6	R.1	R.23	AR.35	R.3	R.29	R.8	AR.33	R.17	R.7
La	1	10	12.5	9	8	8	9	5.5	9	25.5	7	12	5	25.5	4
Ce	3 21	25	20	13.5	19	21	12.5	13	40.5	10	27	14	45	10	
Nd	<61	1.5	14.5	5	8.5	77.5	3	5	26.5	9	15	4	24.5	<20	
Sm	.4	1.8	2.75	1.9	1.35	.9	1.6	.8	1.6	5.55	2.3	2.9	1.1	3.95	.7
Eu	.19	.34	.44	.34	.41	.13	.33	.16	.39	1.80	.55	.48	.19	.96	.22
Gd	<2	1.25	1.9	.5	1.2	<2	1.25	<2	1.5	4.1	2.1	2.5	<3.0	3.5	<3
Tb	.12	.17	.35	.28	.15	.09	.22	.10	.24	.81	.48	.30	.08	.42	.08
Ho	<.3	.2	.3	<.8	<.2	<.5	.2	<.4	.2	.5	.4	<.7	<.4	<.9	<.6
Tm	<.10	.09	.09	.06	.07	.03	.07	.04	.14	.26	.30	.04	.05	.17	<.2
Yb	.3	.6	.85	.6	.55	.35	.5	.3	.9	1.7	2.5	.8	.4	1.25	.3
Lu	.06	.10	.14	.11	.08	.05	.09	.05	.15	.22	.37	.11	.06	.19	.06

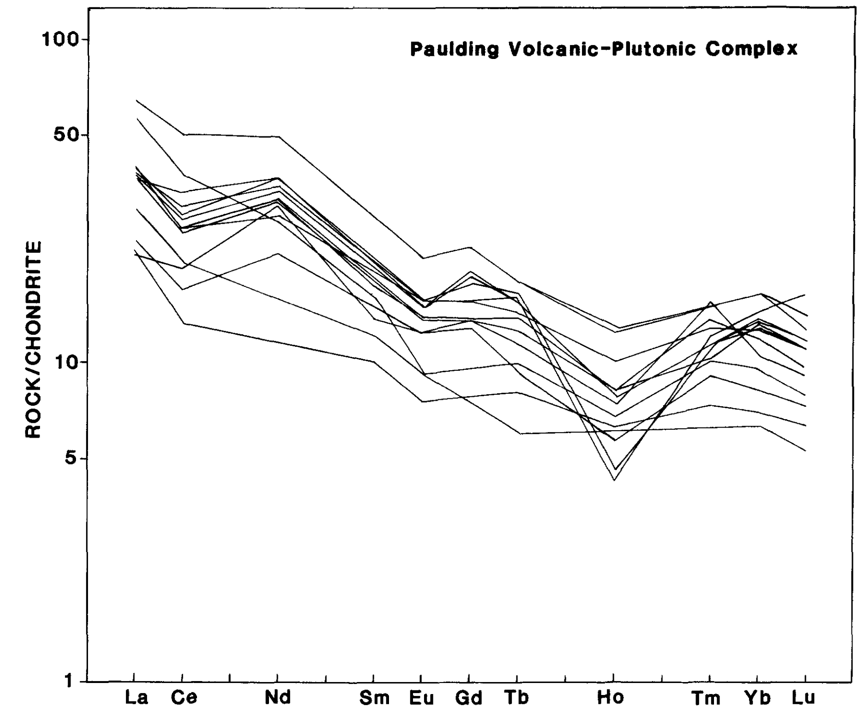
Sample No.	R.19	R.18	R.12	R.4	R.9	R.14	AR.32	R.11	AR.37	R.21	R.28	SS.RA	S.8	S.13	AR.34
La	3	15.5	7	35.6	16	12	20	4	1	61	61	26	10	10	2
Ce	9	33.5	11	60.7	22	26	27	10	4	54	54	28	18.5	18.5	5
Nd	<20	15	8	38	12	11.5	22	3	<6	53	53	28	11.5	17	<7
Sm	1.0	2.55	1.2	7.6	1.9	1.8	4.2	.7	.2	10.1	10.1	5.2	2.25	4.25	.6
Eu	.10	.55	.30	3.32	.39	.26	.70	.08	.03	2.67	2.67	1.00	.84	1.02	.18
Gd	.8	2.05	<2.0	6.2	1.3	1.6	3.2	.9	<2.0	10.2	10.2	4.2	1.75	2.75	<2.0
Tb	.12	.24	.13	1.02	.22	.21	.61	.06	<.3	1.20	1.20	.77	.32	.81	<.3
Ho	.3	<.7	<.7	.63	<.6	<.7	.5	<.5	<.4	.6	.6	.1	.2	.5	<.4
Tm	.04	.12	.08	.23	.09	.08	.23	.04	<.1	.40	.40	.36	.11	.19	.02
Yb	.4	.7	.4	1.86	.7	.7	1.5	.15	.1	2.8	2.8	2.4	1.0	1.75	.4
Lu	.08	.12	.07	.25	.10	.12	.22	.04	.02	.34	.34	.35	.15	.26	.08

Sample No.	R.20	R.22	AR.38	R.25	AR.36	R.24	R.27
La	4	4	1	10	84	32.5	11
Ce	101.5	12	3	22.5	69	19.5	13
Nd	6	7	<6	16	77	36.5	12
Sm	1.9	1.5	.2	2.4	15.1	8.6	2.1
Eu	.44	.38	.03	.50	3.83	1.78	.36
Gd	1.1	1.0	<2.0	2.5	17.7	9.4	2.1
Tb	.33	.24	<.2	.38	2.71	1.60	.33
Ho	<.6	<.9	<.4	<.6	2.0	1.05	.2
Tm	.14	.14	<.08	.11	1.13	.69	.12
Yb	1.15	.8	.2	1.25	8.2	5.2	.8
Lu	.16	.16	.03	.18	1.12	.77	.12



A

FIGURE 57.—Data from rocks of the Paulding Volcanic-Plutonic Complex in Georgia and the Hillabee dacites in Alabama. ARC, volcanic-arc basalt; MORB, mid-ocean-ridge basalt; WPB, within-plate basalt; OFB, ocean-floor basalt. *A*, Paulding Volcanic-Plutonic Complex rocks plotted on an F′-M-A diagram (F′=total iron as FeO; M=MgO; A=Na_2O+K_2O). Data from the Hillabee dacites in Alabama (Tull and others, 1978; Stow, 1982) are also plotted. The line marked by TH/CA represents the boundary between tholeiitic and calc-alkaline rocks (from Irvine and Baragar, 1971; Stow and others, 1984). *B*, Chondrite-normalized rare-earth-element distribution patterns for the Paulding Volcanic-Plutonic Complex. *C*, Paulding Volcanic-Plutonic Complex rocks plotted on a Ti-Zr diagram for tectonomagmatic discrimination (after Pearce and Cann, 1973). *D*, Paulding Volcanic-Plutonic Complex rocks plotted on a TiO_2-Zr diagram for tectonomagmatic discrimination (after Pearce, 1979). *E*, Paulding Volcanic-Plutonic Complex rocks plotted on a Hf/3-Ta-Th diagram for tectonomagmatic discrimination (after Wood, 1980). *F*, Paulding Volcanic-Plutonic Complex rocks and Hillabee dacites plotted on an Al_2O_3/TiO_2-TiO_2 diagram for tectonomagmatic discrimination (as modified by Stow and others, 1984, from Sun and Nesbitt, 1978). *G*, Paulding Plutonic-Volcanic Complex rocks and Hillabee dacites plotted on a CaO/TiO_2-TiO_2 diagram for tectonomagmatic discrimination (as modified by Stow and others, 1984, from Sun and Nesbitt, 1978).



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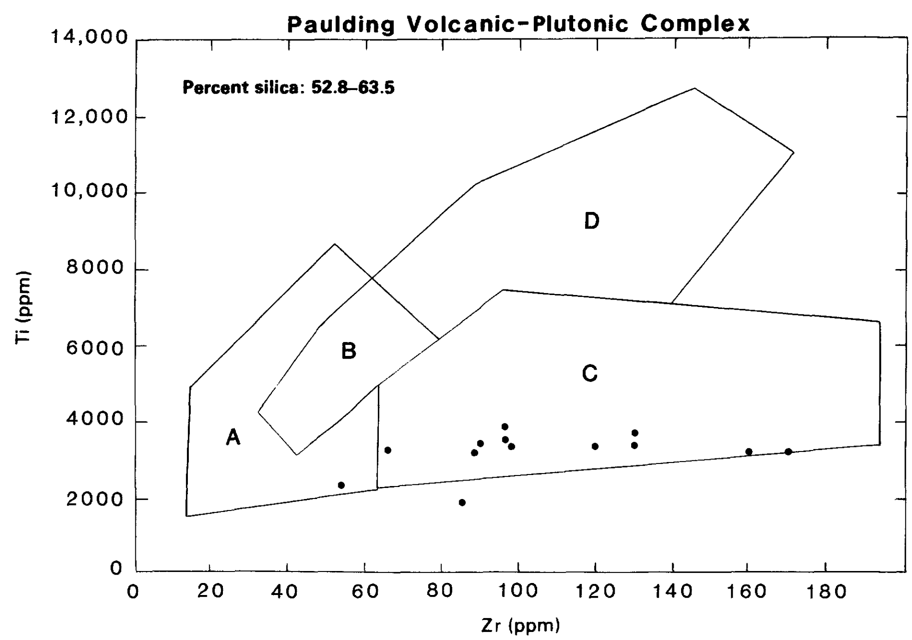
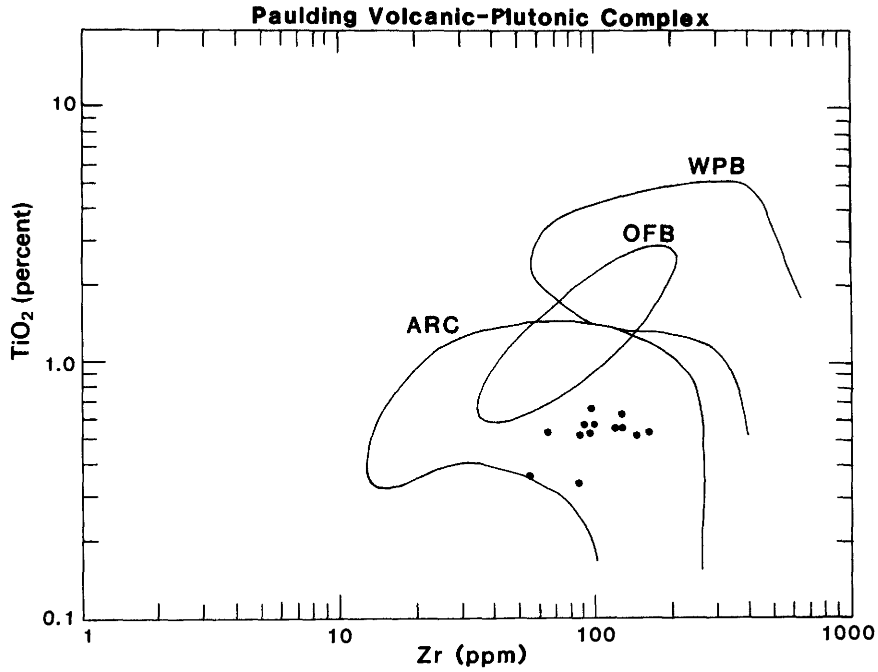


FIELDS
A–B Low-potassium tholeiitic basalt of island-arc series
B–C Calc-alkalic basalt of island-arc series
B–D Ocean-floor basalt

C

FIGURE 57.—Continued.



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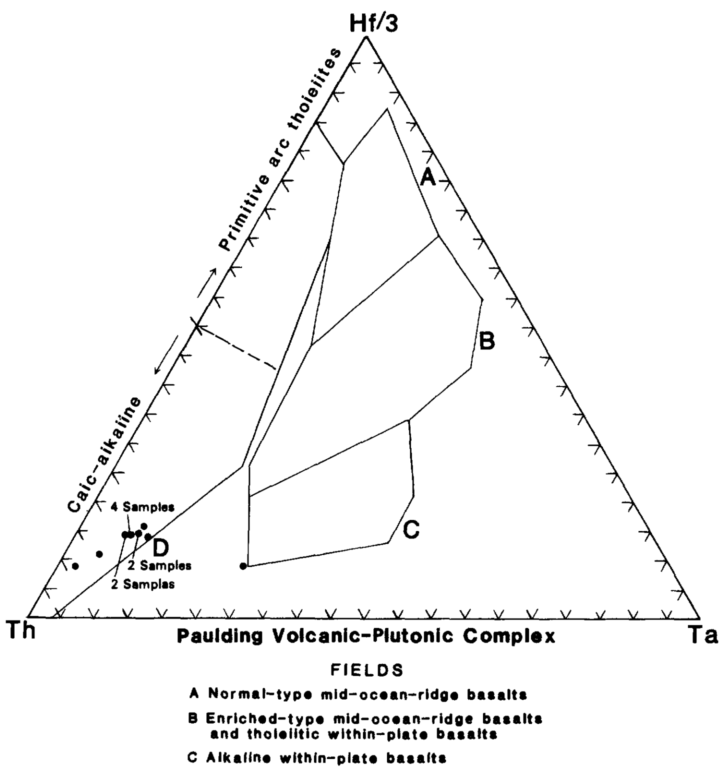
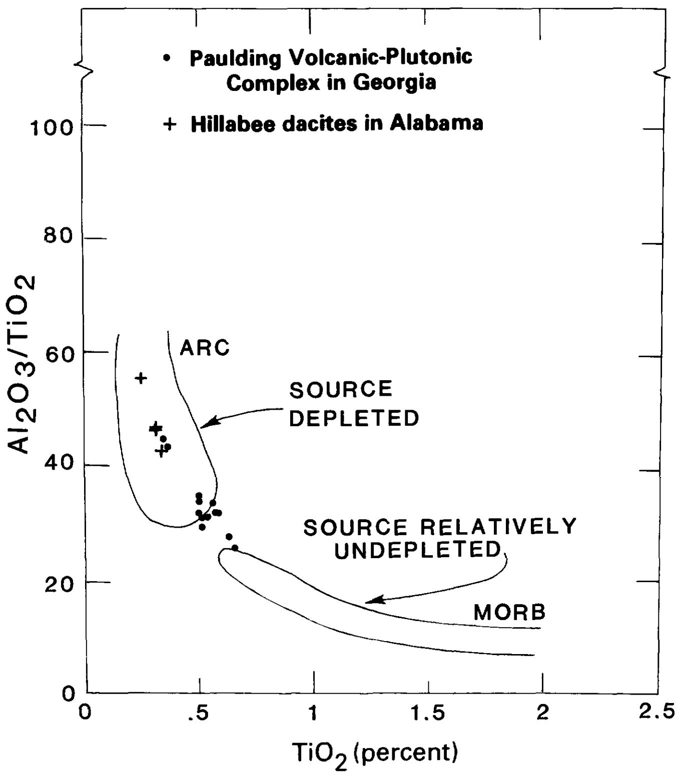
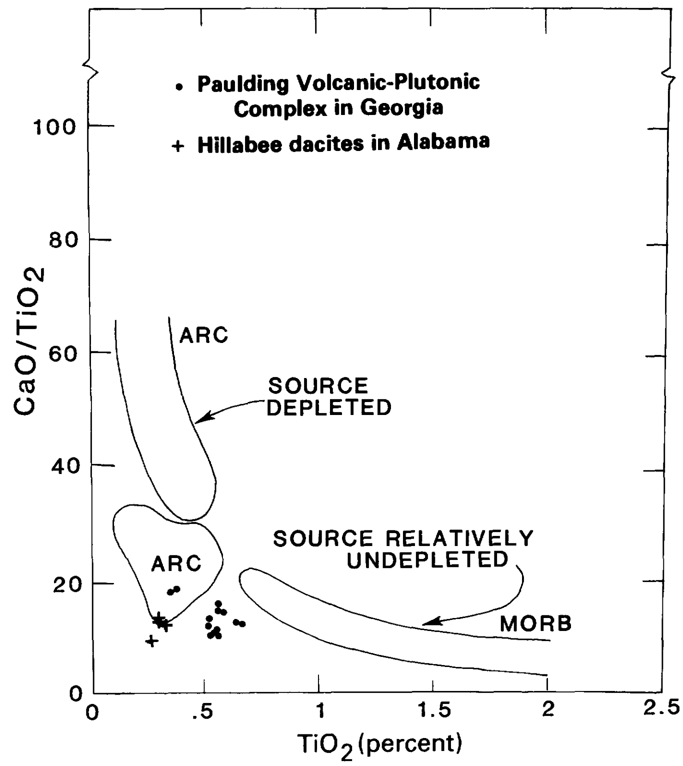


E

FIGURE 57.—Continued.

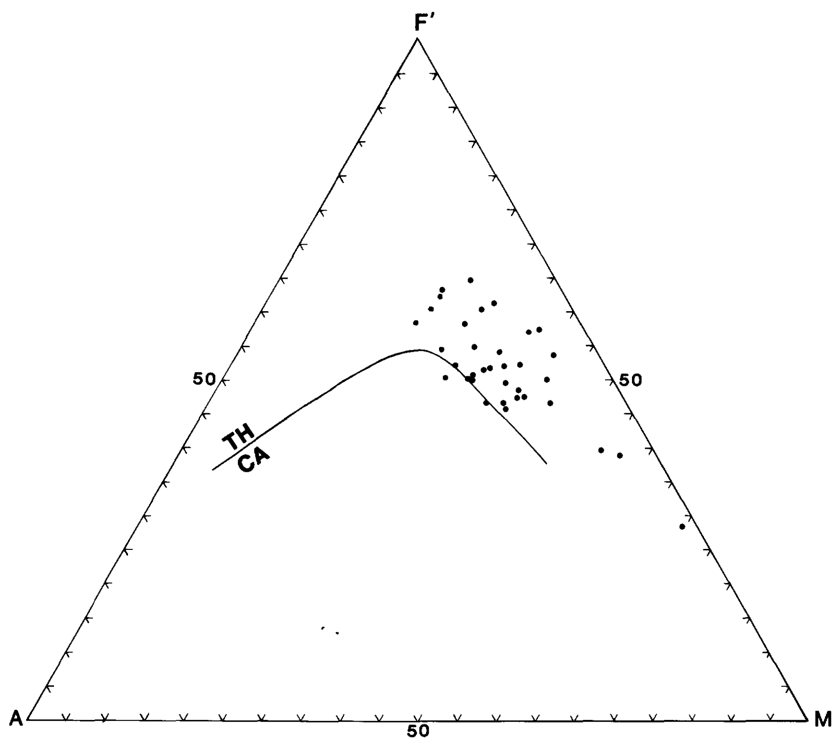


F



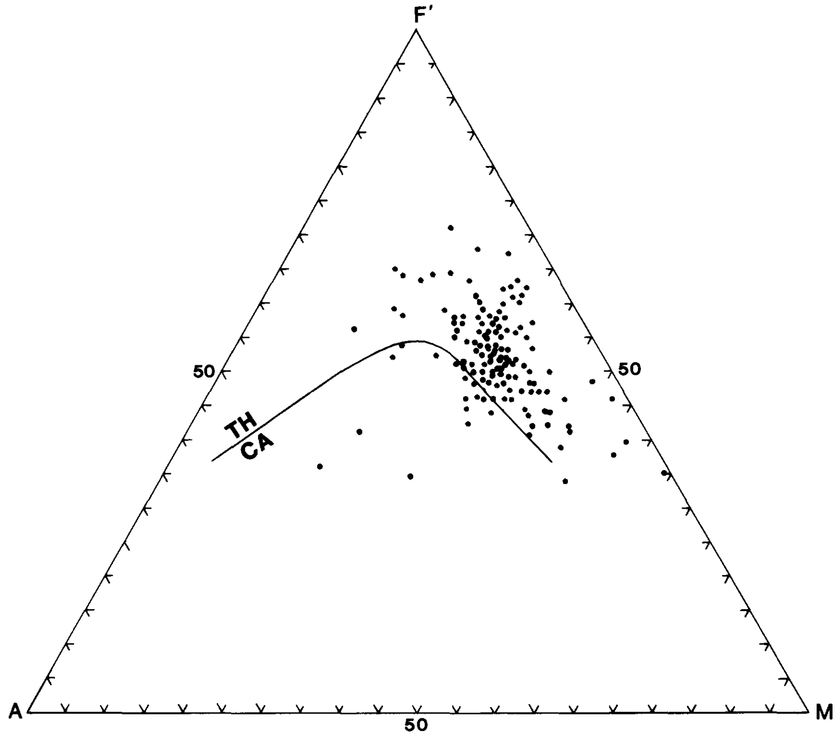
G

FIGURE 57.—Continued.

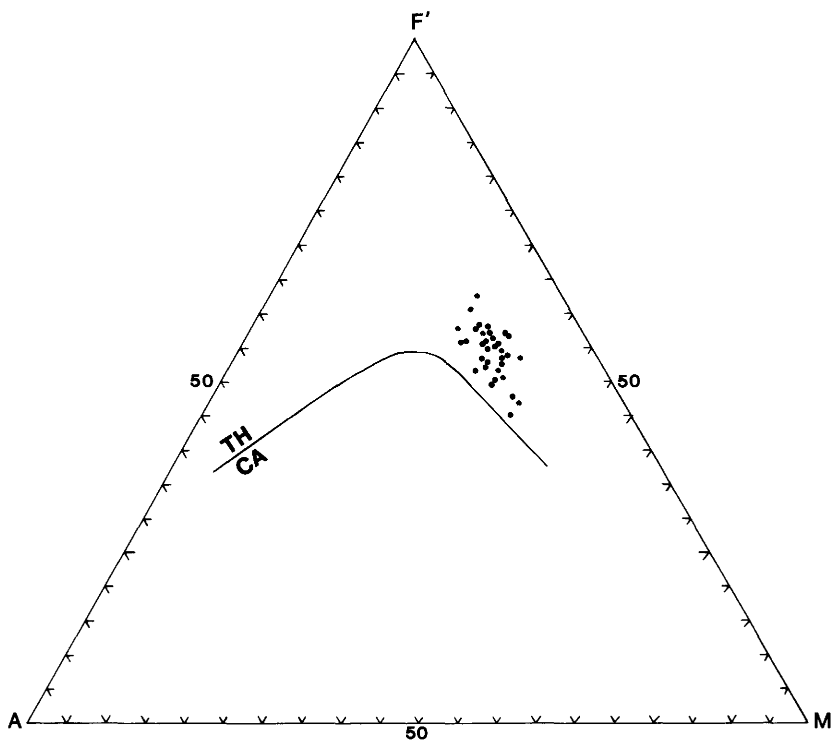


A, From rocks in Georgia, plotted on an F′-M-A diagram (F′=total iron as FeO; M=MgO; A=Na_2O+K_2O). The line marked by TH/CA represents the boundary between tholeiitic and calc-alkaline rocks (Irvine and Baragar, 1971; Stow and others, 1984).

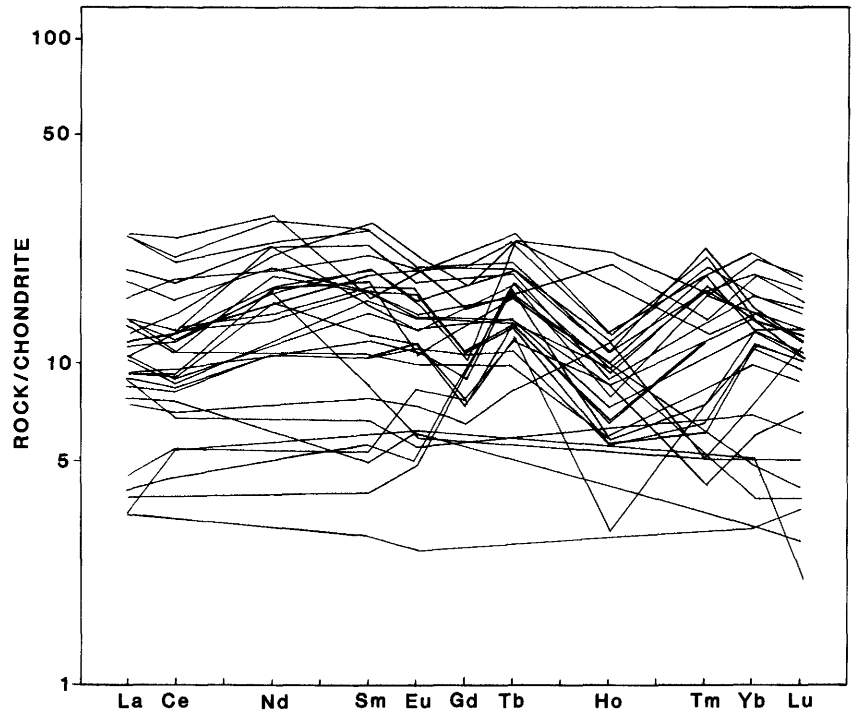
FIGURE 58.—Data from the Ropes Creek Metabasalt. ARC, volcanic-arc basalt; MORB, mid-ocean-ridge basalt; WPB, within-plate basalt; OFB, ocean-floor basalt. Captions for parts *A* through *P* are under each diagram.



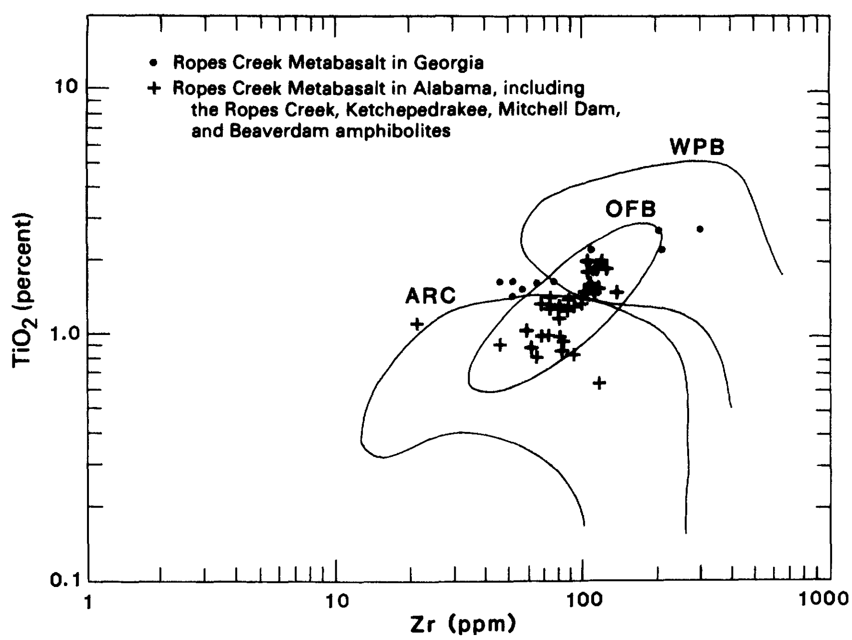
B, From rocks in Georgia and Alabama, including Ropes Creek, Ketchepedrakee, Mitchell Dam, and Beaverdam amphibolites (Stow and others, 1984). See *A* for explanation of TH/CA line.



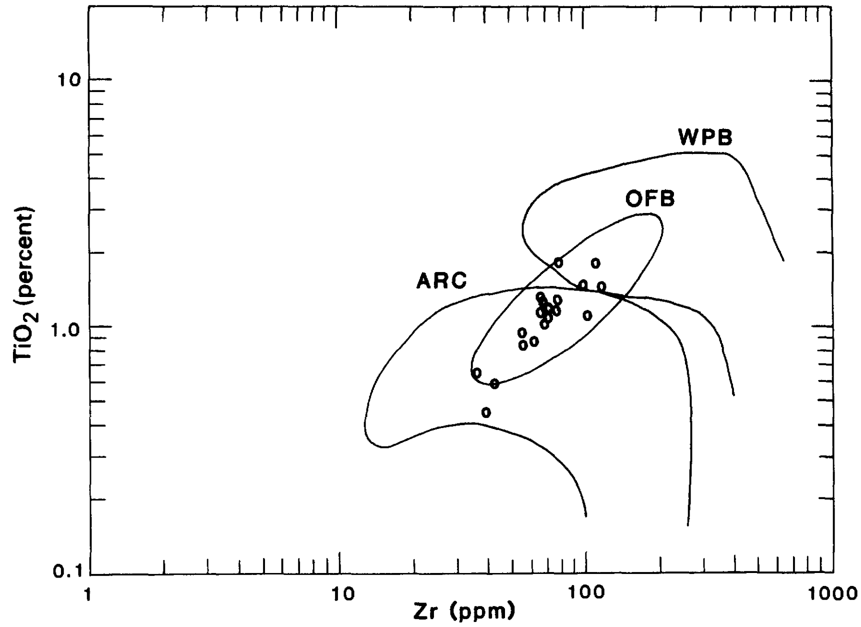
C, From the Hillabee greenstone in Alabama (Tull and others, 1978; Stow, 1982).



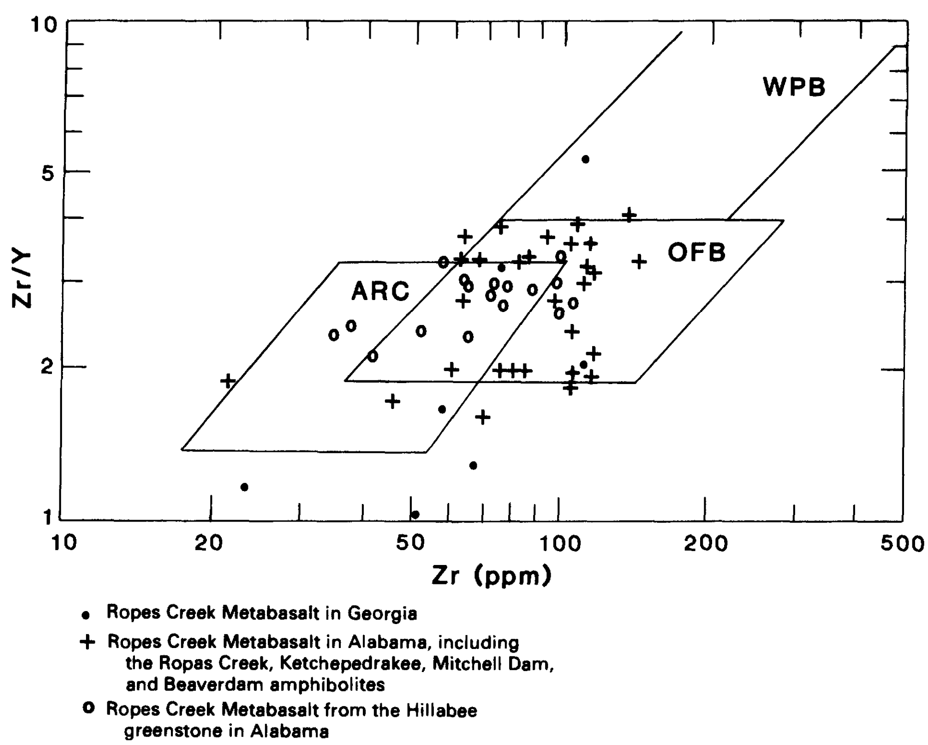
D, Chondrite-normalized rare-earth-element distribution patterns from rocks in Georgia (compare with Stow and others, 1984, p. 428).



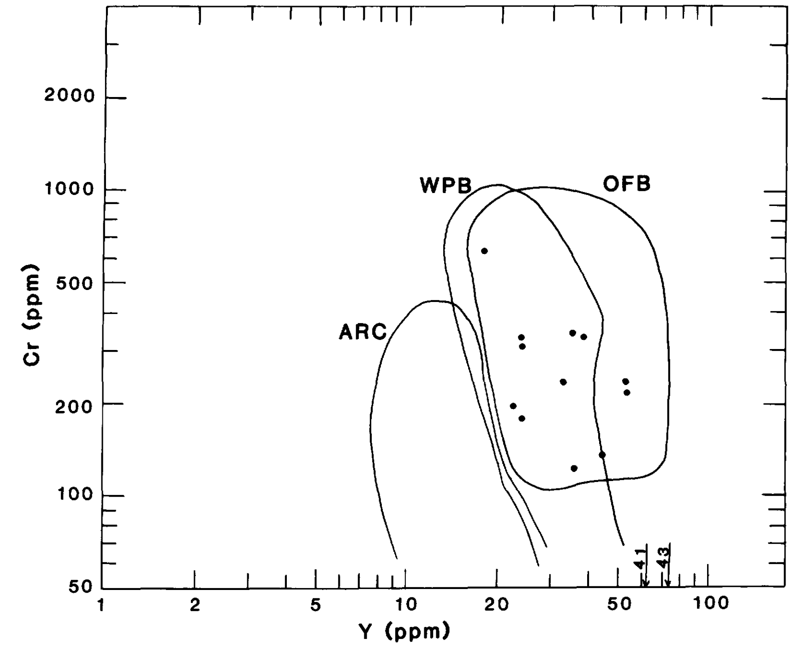
E, From rocks in Georgia and Alabama including the Ropes Creek, Ketchepedrakee, Mitchell Dam, and Beaverdam amphibolites (Stow and others, 1984), plotted on a TiO_2-Zr tectonomagmatic discrimination diagram (after Pearce, 1979).



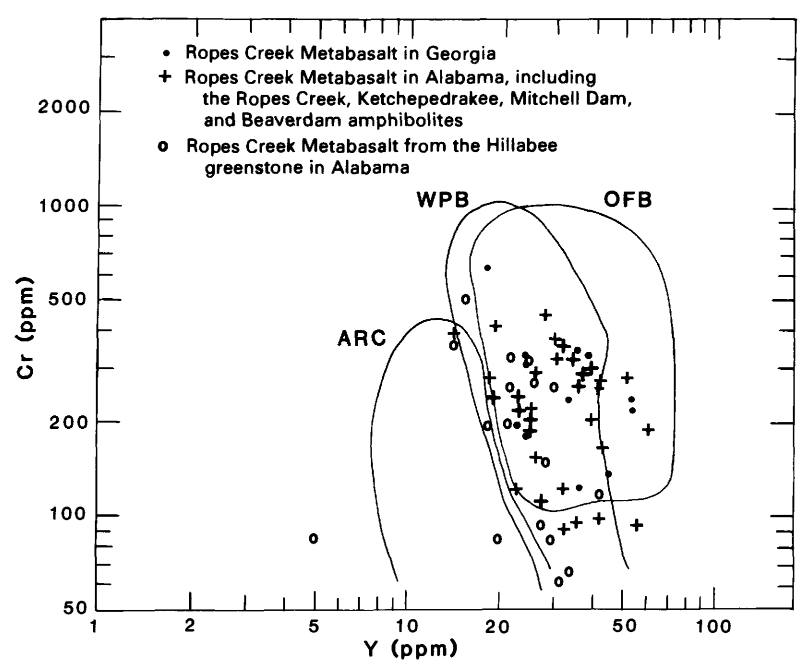
F, From the Hillabee greenstone in Alabama (Tull and others, 1978; Stow, 1982), plotted on a TiO_2-Zr diagram for tectonomagmatic discrimination (after Pearce, 1979).



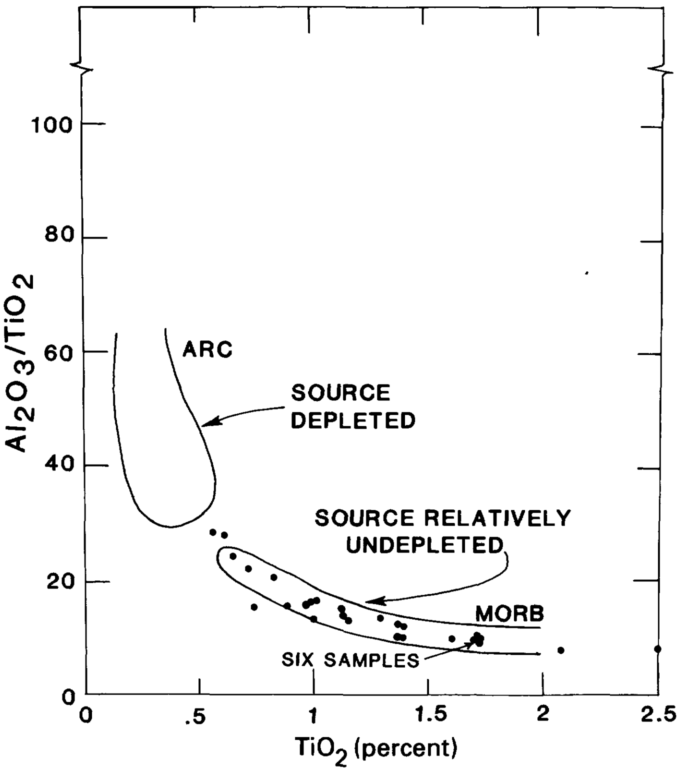
G, From rocks in Georgia and Alabama, including the Ropes Creek, Ketchepedrakee, Mitchell Dam, and Beaverdam amphibolites, and the Hillabee greenstone (Tull and others, 1978; Stow, 1982; Stow and others, 1984), plotted on a Zr/Y-Zr diagram for tectonomagmatic discrimination (after Pearce, 1979, and Pearce and Norry, 1979).



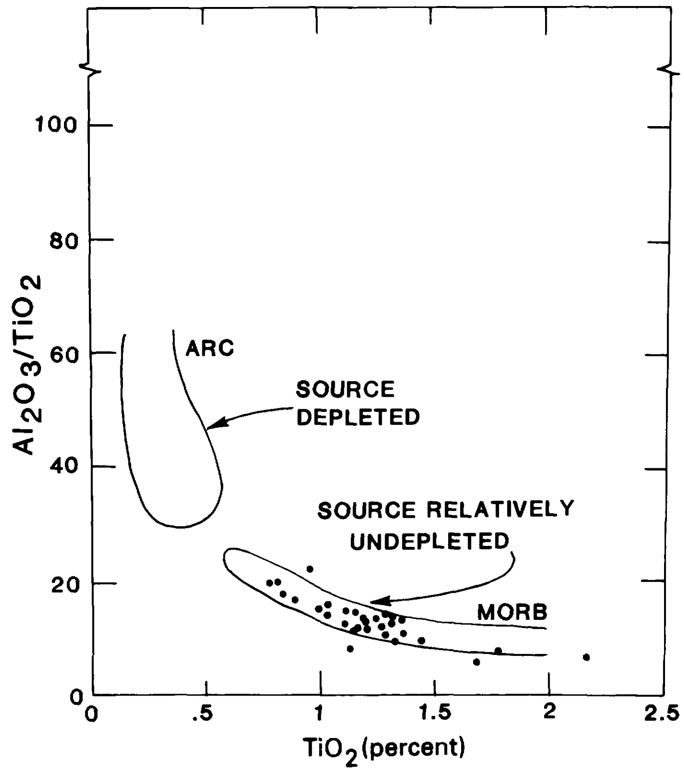
H, From rocks in Georgia, plotted on a Cr-Y tectonomagmatic discrimination diagram (after Pearce, 1979, and Gale and Pearce, 1982).



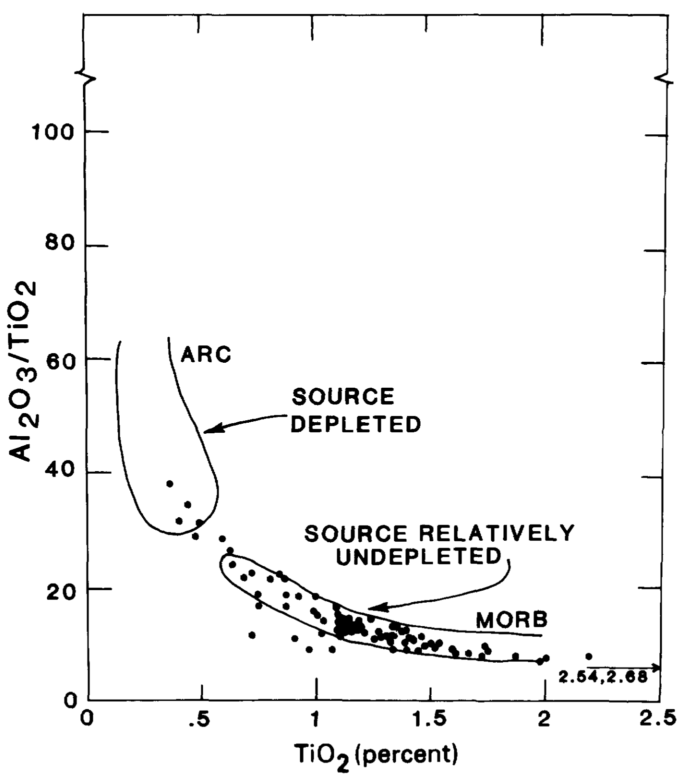
I, From rocks in Georgia and Alabama, including the Ropes Creek, Ketchepedrakee, Mitchell Dam, and Beaverdam amphibolites, and the Hillabee greenstone (Tull and others, 1978; Stow, 1982; Stow and others, 1984), plotted on a Cr-Y tectonomagmatic discrimination diagram (after Pearce, 1979, and Gale and Pearce, 1982).



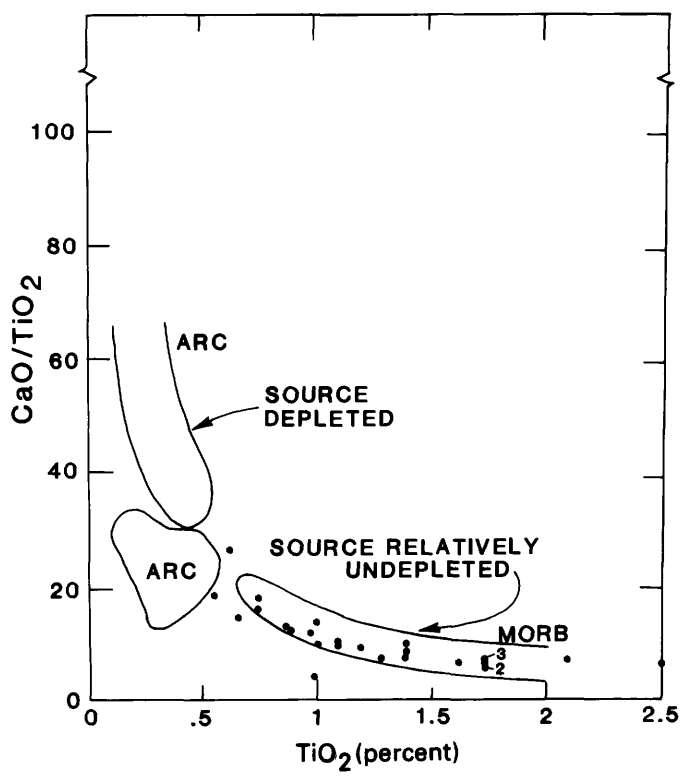
J, From rocks in Georgia, plotted on an Al_2O_3/TiO_2-TiO_2 tectonomagmatic discrimination diagram (as modified by Stow and others, 1984, after Sun and Nesbitt, 1978).



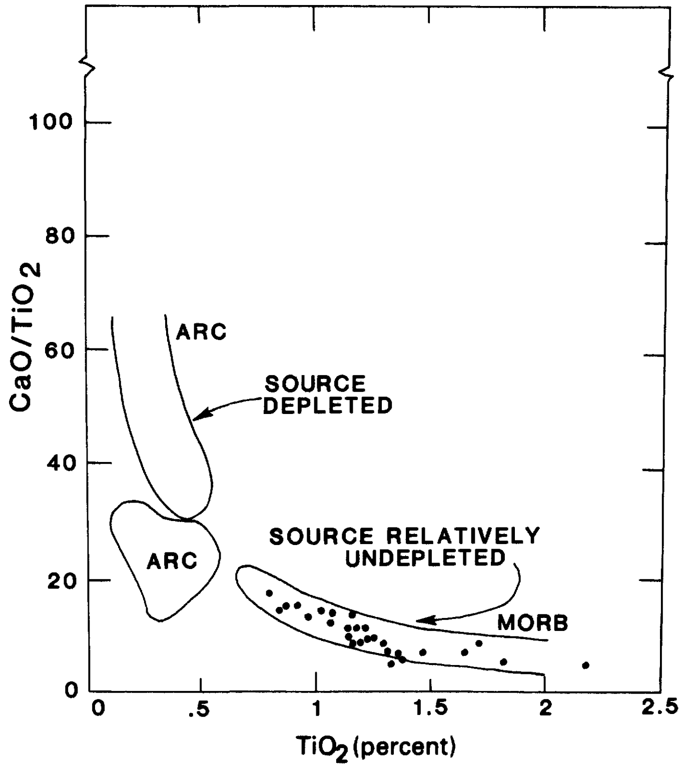
K, From rocks in Alabama (Stow and others), plotted on an Al_2O_3/TiO_2-TiO_2 tectonomagmatic discrimination diagram (as modified by Stow and others, 1984, after Sun and Nesbitt, 1978).



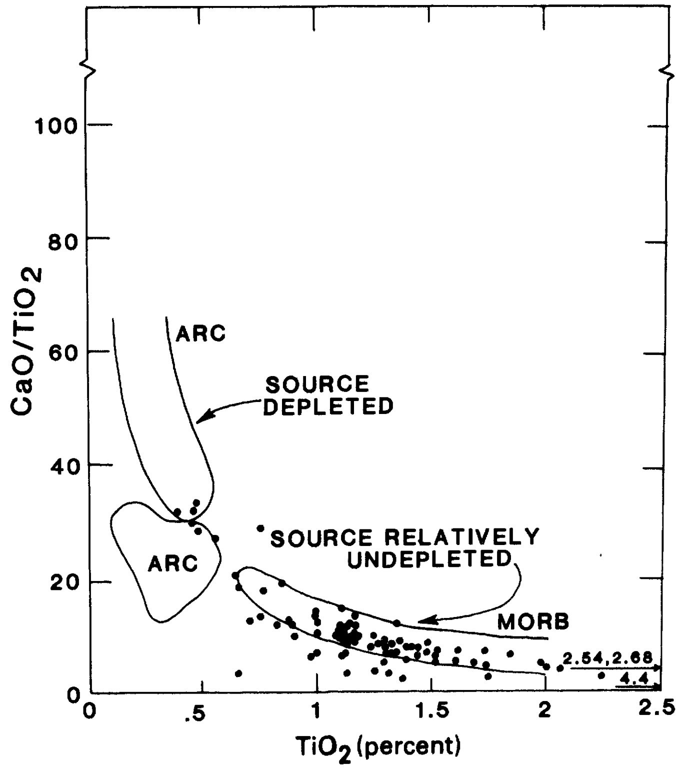
L, From the Hillabee greenstone in Alabama (Tull and others, 1978; Stow, 1982), plotted on an Al_2O_3/TiO_2-TiO_2 diagram (as modified by Stow and others, 1984, after Sun and Nesbitt, 1978).



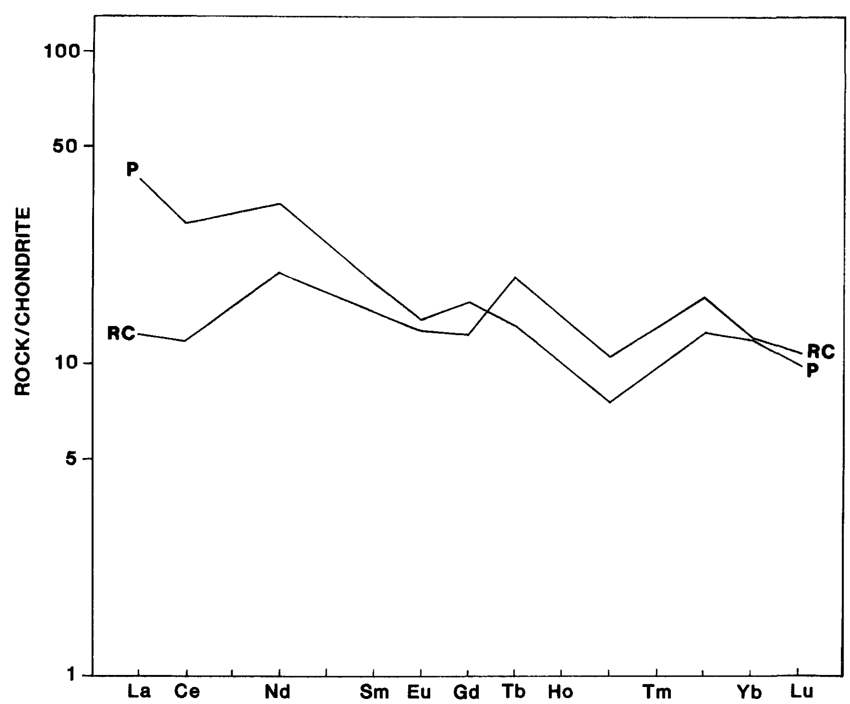
M, From rocks in Georgia, plotted on a CaO/TiO_2-TiO_2 tectonomagmatic discrimination diagram (as modified by Stow and others, 1984, from Sun and Nesbitt, 1978).



N, From rocks in Alabama (Stow and others, 1984), plotted on a CaO/TiO_2-TiO_2 tectonomagmatic discrimination diagram (as modified by Stow and others, 1984, from Sun and Nesbitt, 1978).



O, From the Hillabee greenstone in Alabama (Tull and others, 1978; Stow, 1982), plotted on a CaO/TiO_2-TiO_2 tectonomagmatic discrimination diagram.



P, Average chondrite-normalized rare-earth-element distribution patterns from the Ropes Creek Metabasalt in Georgia (RC) and the Paulding Volcanic-Plutonic Complex (P).

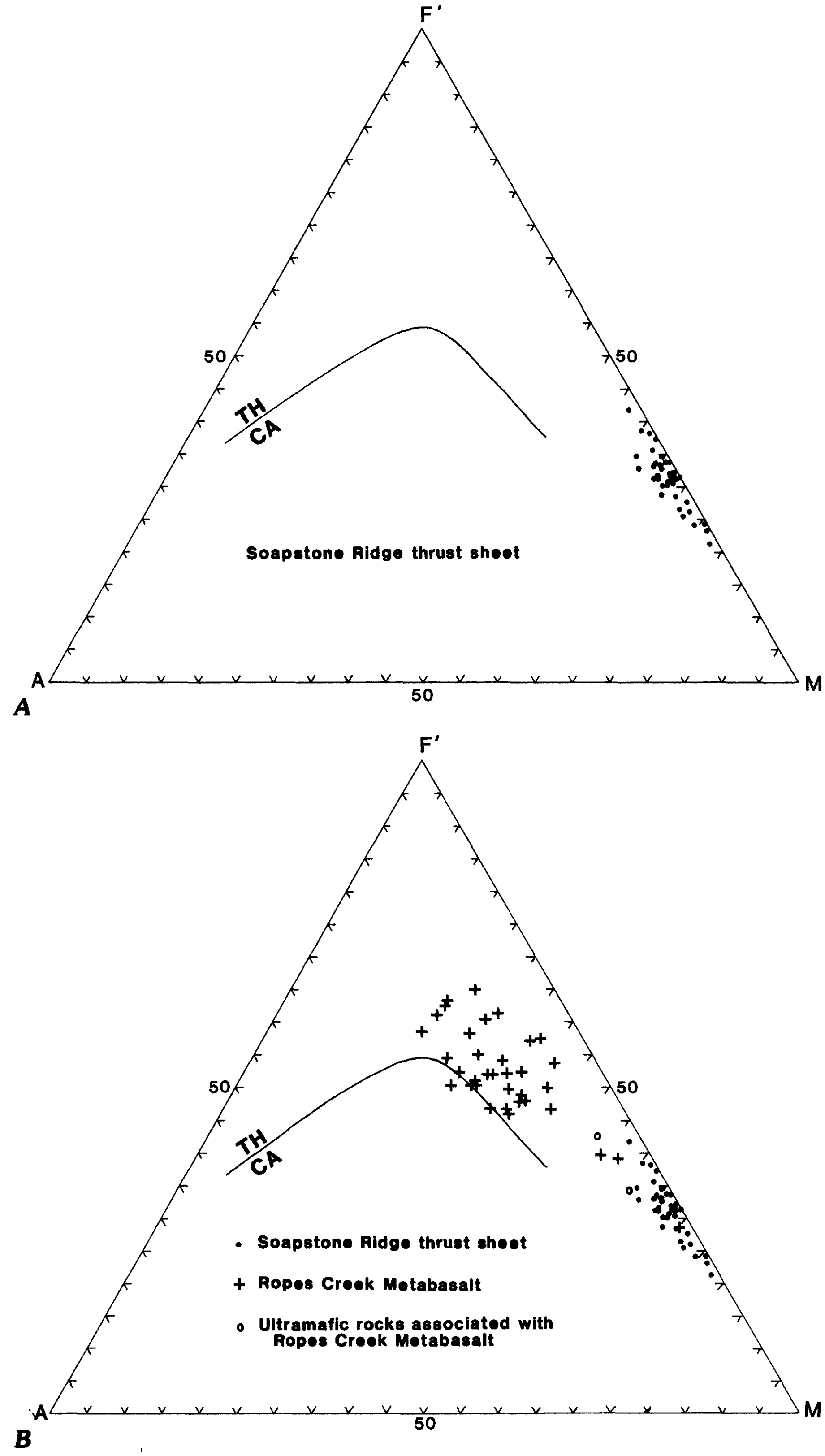


FIGURE 59.—Data plotted on F'-M-A diagrams (F'=total iron as FeO; M = MgO; A = Na_2O + K_2O). The line marked by TH/CA represents the boundary between tholeiitic and calc-alkaline rocks (after Irvine and Baragar, 1971; Stow and others, 1984). *A*, From rocks of the Soapstone Ridge thrust sheet. *B*, From rocks of the Soapstone Ridge thrust sheet, the Ropes Creek Metabasalt in Georgia, and ultramafic rocks associated with the Ropes Creek Metabasalt.

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