To the Graduate Council:

I am submitting herewith a thesis written by Roger C. Brewer entitled "Structure and Petrography of the Basement Complexes East of the Hot Springs Window, Blue Ridge Province, Western North Carolina." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Geology.

Nicholas B. Woodward, Major Professor

We have read this thesis
and recomend its acceptance:

Accepted for the Council

Vice Provost and
Dean of the Graduate School

STRUCTURE AND PETROGRAPHY OF THE BASEMENT COMPLEXES EAST OF THE HOT SPRINGS WINDOW, BLUE RIDGE PROVINCE, WESTERN NORTH CAROLINA

A Thesis

Presented for the

Master of Science

Degree

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Roger Clay Brewer

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ABSTRACT

Recent tectonic models of the Blue Ridge Province of western North Carolina correlate the contact between the Amphibolitic Basement Complex ("layered gneiss and migmatite" of Hadley and Nelson, 1971) and the structurally underlying Cranberry Granitic Basement Complex with the hypothesized Ordovician-Devonian Hayesville-Fries Fault. This study involves the detailed petrographic and structural study of these two basement complexes and the nature of the contact separating them. The study area is located in the area just east of the Hot Springs Window, central western North Carolina.

The Cranberry Basement is composed chiefly of biotite granitic gneisses and semischists intruded by small scattered bodies of weakly foliated granodiorite to quartz diorite. Other lithologies less typical of the complex include biotite hornblende granitic gneiss and calc-silicate rock. As is characteristic elsewhere in the Blue Ridge, the western edge of the granitic basement is marked by the presence of a pink, epidote-rich granite called the Max Patch Granite. Published radiometric ages from exposures of the Cranberry Basement to the north of the study area range in age from 1.8by to 870my.

Roughly three-fourths of the Amphibolitic Basement Complex is composed of locally migmatitic biotite hornblende granitic gneiss intruded by and complexly intermixed with amphibolite. Other intermixed lithologies typical of the complex include weakly foliated granitic rock, talc-rich ultramafic bodies (high in Cr and Ni), metapyroxenite, garnet chlorite schist, feldspar augen semischist, metabasalt porphyry, diopsidic marble, and calc-silicate rock. No stratigraphic order could be developed for the complex. Field observations in conjunction with geochemical analyses suggest that the bulk of the amphibolites represent tholeiitic, continental basalts. A single published Rb/Sr whole rock date on a granitic gneiss from just east of the study area yielded an age of 1.2by.

Based on: 1) the truncation of amphibolite units and deformation zones elsewhere along the contact and 2) the dominant restriction of amphibolites and ultramafic rock to the Amphibolitic Basement Complex, the contact between the Amphibolitic Basement Complex and the structurally underlying Cranberry Granitic Basement Complex is interpreted to be a fault. In the study area, granitic and gabbroic rocks correlated with the Crossnore and Bakersville plutonic suites intrude both Cranberry and Amphibolitic Basement complexes. The Crossnore-like

granite (Indian Grave Metagranite) appears to crosscut the contact between the two complexes. The Late Proterozoic (734-700my) age of the two plutonic suites establishes a minimum age for the fault contact separating the two complexes.

As in areas to the north, the Crabberry Granitic Basement Complex is interpreted to represent a Grenville-age granitic plutonic complex once attached to the eastern edge of the North American Craton. The Amphibolitic Basement Complex is interpreted to represent an intensely disrupted, melange-like complex composed chiefly of transitional crustal material. The complex is interpreted to have developed during Middle to Late Proterozoic incipient rifting of granitic crust, accompanied by the intrusion of tholeiitic basaltic magmas. Closure of the rift complex later during the Proterozoic resulted in the intense disruption of the transitional crust and the incorporation of blocks of lower crustal/upper mantle ultramafic rock and sedimentary carbonate into the complex.

Contrary to previous interpretations, the contact between the Amphibolitic Basement Complex and the structurally underlying Cranberry Granitic Basement Complex cannot be correlated with the hypothesized Ordovician-Devonian Hayesville-Fries Fault. If a single,

continuous "Hayesville-Fries" fault can be drawn in the Blue Ridge of western North Carolina, it must lie no further west than the upper contact of the Amphibolitic Basement Complex.

TABLE OF CONTENTS

CHAPTER		PAGE
1.	INTRODUCTION	1
	Location Of Study Area	1
	Purpose	1
	Geologic Setting	5
	Blue Ridge Province	5
	Nature Of Eastern-Western Blue Ridge Boundary	6
	Field and Analytical Methods	7
2.	MAJOR LITHOLOGIC UNITS	9
	Introduction	9
	Sandsuck Formation-Ocoee Series	11
	Max Patch Metagranite	12
	Introduction	12
	Megascopic Description	13
	Petrography	14
	Contact Relationships	16
	Age	17
	Cranberry Granitic Basement Complex	17
	Introduction	17
	Megascopic Description	18
	Petrography	22
	Biotite granitic gneiss (6)	22
	Biotite schist	23
	Granodiorite (322*)	23
	Quartz diorite (156a*)	24
	Calc-silicate (727*)	27
	Granite, quartz monzonite (101, 543)	27
	Quartz feldspar biotite gneiss/schist (228*)	28
	Biotite hornblende granitic gneiss (158*)	30
	Contact Relationships	31
	Age	32
	Amphibolitic Basement Complex	33
	Introduction	33
	Megascopic Description	35
	Petrography	39
	Biotite hornblende granitic gneiss (344*, 411)	39
	Biotite granitic gneiss (52)	41
	Amphibolite (702b*, 726*, 34*)	42
	Quartz feldspar biotite augen schist/ semi-schist (726)	43

CHAPTER PAGE

Kyanite garnet plagioclase quartz gneiss (408*). 44
Granite-quartz monzonite (673, 170). . 45
Granodiorite-diorite (55). 46
Marble (654a*, 669*) 46
Calc-silicate (654b*). 47
Ultramafic rock (650*) 48
Actinolite semi-schists (670*, 716). . 49
Chlorite schist (171). 49
Metabasalt porphyry (183*) 50
Contact Relationships. 51
Age. 53
Roberts Mountain Granitic Complex. 53
Introduction 53
Megascopic Description 54
Petrography. 55
Hypersthene metagranite (72*, 79*) . . 55
Granitic semi-schist/gneiss (59), epidote granite (62*). 55
Contact Relationships. 56
Age. 57
Indian Grave Metagranite 57
Megascopic Description 57
Petrography (166*) 58
Contact Relationships. 62
Age. 64
Bakersville Metagabbro And (?) Metapyroxenite 64
Introduction 64
Distribution/Description 65
Petrography. 67
Metagabbro (14*, 153*, 340b*, 667* (?)). 67
Metapyroxenite (18a*, 18b*). 68
Metadiabase (674*) 69
Contact Relationships. 69
Age. 70

3. GEOCHEMICAL ANALYSES 72

4. STRUCTURE. 80
Megascopic Structure 80
Regional Trends. 80
Folds. 81
Major Faults 82
Rector Branch Fault. 82
Amphibolitic Basement/Cranberry Granitic Basement contact. 89
Minor Faults 90

CHAPTER PAGE

Introduction 90
Brush Creek Fault. 93
Roberts Mountain Fault 94
Sweetwater Fault 96
Mesoscopic Structures/Deformational Events 97
Amphibolitic Basement Complex. 100
Introduction 100
D1-D3. 100
D4 103
D5 103
D6-D7. 104
D8 104
D9 105
D10. 105
D11 (?). 110
D12. 111
Cranberry Granitic Basement Complex. . . 112
Introduction 112
D1-D3. 112
D8 113
D9 114
D10. 114
D11. 115
D12. 115

5. DEVELOPMENT OF THE RECTOR BRANCH FAULT ZONE. 119

Introduction 119
Development Of The Rector Branch Ductile Shear Zone 120
Introduction 120
"Undeformed" Rock. 123
Stage 1. 125
Groundmass 128
Quartz 129
Feldspar 129
Augen development. 131
Mica 134
Amphibole. 134
Mesoscopic/megascopic development. . . 137
Stage 2. 137
Quartz 138
Feldspar 139
Mica 142
Amphibole. 142
Mesoscopic/megascopic development. . . 142
Stage 3. 143

CHAPTER PAGE

Calc-silicate Bodies 145

6. DISCUSSION AND SUMMARY 147

Metamorphic History. 147
Metamorphic Events 147
Timing Of Metamorphism 150
Recognition Of The Amphibolitic Basement Complex 151
Interpretations. 153
Middle To Late Proterozoic-Basement Protoliths (D1-D3) 153
Cranberry Granitic Basement Complex. . 153
Amphibolitic Basement Complex. 154
Middle To Late Proterozoic Closure Of Rift Complex(D4-D8). 155
Melange-like Features Of The Amphibolitic Basement Complex. 156
Late Proterozoic (D9). 158
Ordovician/Devonian (D10). 159
Later Devonian (D11 ?) 161
Carboniferous/Permian (D12). 161
Large-scale Intermixing Of The Basement Complexes 162
Conclusions. 163

REFERENCES CITED. 167

APPENDIXES. 175

Appendix A - XRF Methods. 176
Appendix B - Whole Rock Analyses Of Selected. . Samples. 182
Appendix C - Road Log And Description Of Stops. 187

VITA. 196

LIST OF FIGURES

FIGURE		PAGE
1.	Geographic location of study area, Madison County, North Carolina, Marshall (M) and Spring Creek (SC) 7 ½' quadrangles.	2
2.	Generalized geologic map of western North Carolina Blue Ridge Province showing major lithologic packages, major structures, and study area (modified from Brown, P. and others 1985).	3
3.	Generalized geologic map of the study area. .	10
4.	Partial geologic map of study area showing interlayered nature of Indian Grave Metagranite in Walnut Creek area.	59
5.	Xenolith (X) of Amphibolitic Basement Complex in float block of Indian Grave Metagranite (IGM), from Walnut Creek.	60
6.	Variation diagrams of Ti, Zr, and Y plotted against MgO/FeO + MgO	74
7.	AFM plot showing tholeiitic nature of amphibolites.	76
8.	Ti/100 - Zr - Y*3 discrimination diagram showing distribution of amphibolite samples from study area (after Pearce and Cann, 1973)	77
9.	Railroad cut exposure of ector Branch Fault just northwest of Barnard (Field Station 2) .	83
10.	Schematic cross section of study area showing three zones of Rector Branch Ductile Shear Zone (see text for discussion).	86
11.	Roadcut exposure of a possible horse of ultramylonitized Ocoee (Field Station 593). .	88
12.	Roadcut exposure of the Brush Creek Fault (Field Station 727)	91
13.	Railroad cut exposure of Roberts Mountain Fault (field stations 60 and 61).	91

FIGURE PAGE

14. Roadcut exposure of Sweetwater Fault (solid line) (Field Station 345). 91

15. Exposure of garnet-bearing amphibolite dike crosscutting S1 foliation in granitic gneiss (GG) (Field Station 704) 101

16. Disrupted (attenuated ?) amphibolite dikes (dark bands) within the Amphibolitic Basement Complex. 101

17. Exposure of Amphibolitic Basement in Walnut Creek showing migmatitic nature of complex (Field Station 750) 101

18. Complex deformation of migmatitic amphibolite bearing rock (Field Station 392). 101

19. Exposures of Bakersville metagabbro and Indian Grave Metagranite. 106

20. Photograph of polished slab from Field Station 179 108

21. Roadcut of Amphibolitic Basement Complex (Field Station 179) 108

22. Conjugate kink bands developed in ultramylonitized Max Patch Metagranite at Rector Branch Fault (Sample 1). 116

23. Photomicrograph of cataclasite (C) developed in Ocoee horse (?) in main Rector Branch mylonite zone (Sample 98) 116

24. Summary of proposed stages of development of Rector Branch ductile shear zone (see text for discussion) 122

25. Photomicrograph of relatively undeformed quartz diorite in Cranberry (Sample 322). . . 124

26. Microshear surfaces (MS) in Indian Grave Metagranite (Sample 166). 126

27. Extensive development of quartz ribbons (Q) by dislocation creep mechanisms (Sample 408). 126

28. Deformation of feldspar grains. 126

FIGURE PAGE

29. Near euhedral phenocrysts of plagioclase (P) enclosed in a moderately well foliated (S3 or S4 ?), amphibolitic groundmass (Sample 183). 132

30. Recrystallized tail (T) developed on feldspar augen (F) (Sample 166) 132

31. Deformation of mica 135

32. Brittle fracturing of actinolite (and/or hornblende) (A/H) along hinges of kink folds (Sample 34) 135

33. Feldspar augen (F) wrapped by ultramylonitic microshear zones and ribboned quartz grains (Sample 32) 135

34. Extensively recrystallized quartz ribbons (Q) (Sample 340). 140

35. Plagioclase porphyroclast (P) displaying extensive internal recrystallization (Sample 79) 140

36. Plagioclase porphyroclast (P) strongly internally disrupted (Sample 1) 140

37. Photomicrograph of Max Patch Metagranite ultramylonite (Sample 1) (see also Figure 22, page 116) 144

38. Regional map showing projected Paleozoic isograds in the Blue Ridge (after Hadley and Nelson, 1971; Butler, 1972) 148

39. Schematic drawing showing possible explanation for the presence of Amphibolitic Basement Complex-like lithologies (ABC) in the footwall of the Brush Creek Fault (BCF) . 164

40. Generalized geologic map of study area showing field trip route. 189

LIST OF TABLES

TABLE		PAGE
1.	Representative whole rock XRF analyses of selected samples (oxides in weight %, elements in weight %)	73
2.	Deformational events.	99

LIST OF PLATES

PLATE (IN POCKET)

1. Geologic Map Of a Portion of the Marshall And Spring Creek & 7 ½' Quadrangles, Madison County, North Carolina.

CHAPTER 1

INTRODUCTION

Location Of Study Area

The thesis area covers portions of the Marshall and Spring Creek 7 ½ ' quadrangles in Madison County, western North Carolina (Figure 1). The area is approximately 6 ½ miles long by 4 miles wide and covers approximately 27 square miles.

Purpose

This study involves detailed mapping across the Amphibolitic Basement-Cranberry Basement contact just southeast of the Hot Springs Window area, central western North Carolina (Figure 2). Prior to this study, only a small part of the contact between the Amphibolitic Basement Complex and the Cranberry Granitic Basement Complex had been mapped in detail (Merschat, 1977; unpublished mapping). Detailed lithologic descriptions of the Amphibolitic Basement Complex are limited to text accompanying Merschat's (1977) published map of the Mars

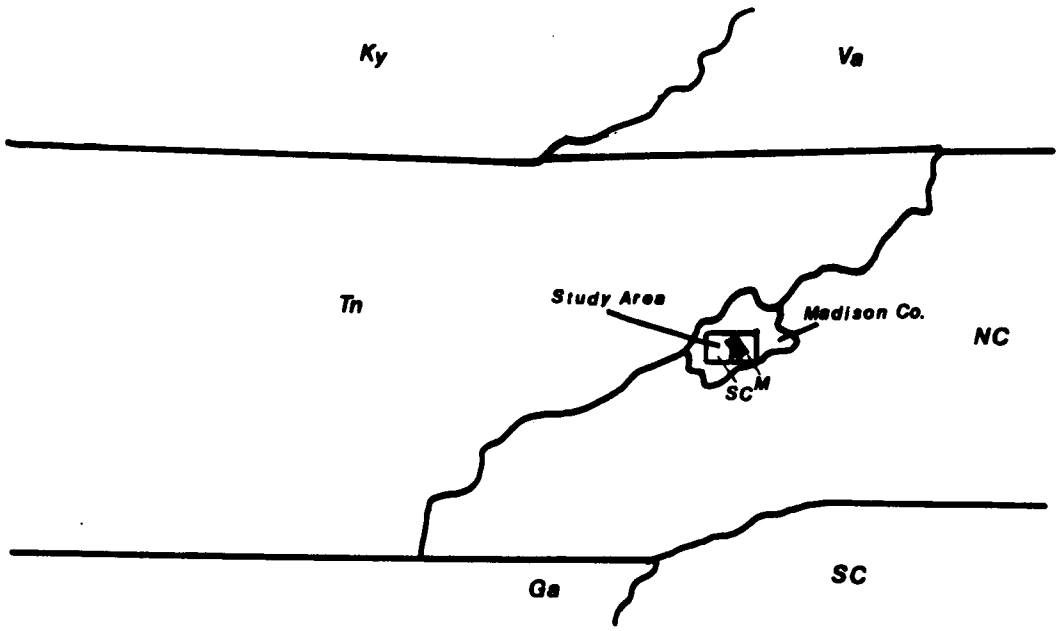


Figure 1. Geographic location of study area, Madison County, North Carolina, Marshall (M) and Spring Creek (SC) 7½' quadrangles.

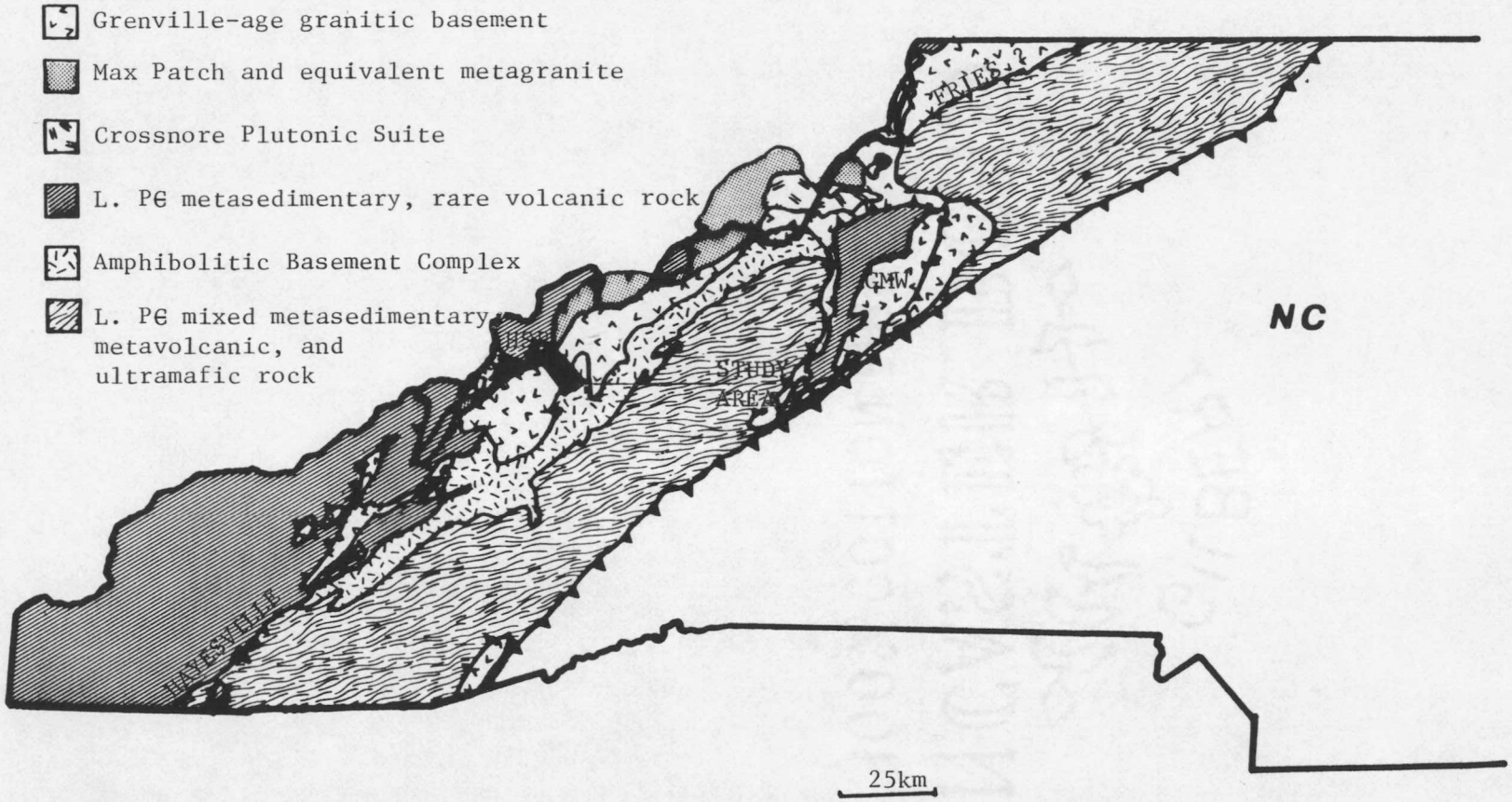


Figure 2. Generalized geologic map of western North Carolina Blue Ridge Province showing major lithologic packages, major structures, and study area (modified from Brown, P. and others 1985)

Hill 7 1/2' quadrangle and brief descriptions by Bryant and Reed (1970) of their "mixed rock" unit.

The primary concerns of this study are: 1) to provide detailed lithologic and structural descriptions of both basement complexes and 2) to provide detailed descriptions of the contact relationships between these two complexes. Secondary concerns of this study include 1) interpretion of the geologic evolution and deformational history of each complex, 2) discussion of the microscopic to megascopic development of the Rector Branch Ductile Shear Zone, and 3) discussion of the implications of this work to past regional modeling of the Blue Ridge Province of western North Carolina, particularly with respect to the placement of the hypothosized "Hayesville-Fries Fault".

Detailed mapping and lithologic descriptions are critical for validly correlating lithologic units and structures through the Blue Ridge. Such detailed work has been generally inadequate for the central portion of the Blue Ridge Province in North Carolina, making any correlations through this area speculative. This study represents the first in-depth description of the lithologies and structures associated with the Amphibolitic Basement Complex. This study also marks the first field-based interpretation of the Amphibolitic

Basement Complex-Cranberry Granitic Basement Complex contact.

Geologic Setting

Blue Ridge Province

Rankin (1975) and Hatcher (1978) divide the Blue Ridge Province in western North Carolina into two separate terranes (see Figure 2):

1) a western "continental" terrane composed of Grenville-age granitic basement intruded by Late Proterozoic granites and gabbros of the Crossnore and Bakersville Plutonic Suites and Late Precambrian metasedimentary rocks and rare metavolcanic rocks (Ocoee, Grandfather Mountain and Mt. Rogers),
2) an eastern "oceanic" terrane composed of complexly deformed Late Precambrian mixed metasedimentary, metavolcanic, and ultramafic rocks (Ashe, Alligator Back, Tallulah Falls, Coweeta groups).

Nature Of Eastern-Western Blue Ridge Boundary

The nature of the boundary separating the eastern and western Blue Ridge terranes has been a question of considerable debate over the past two decades. Recent work in the northwestern portion of the Blue Ridge suggests that the contact between the Ashe/Alligator Back Metamorphic Suite and the structurally underlying granitic basement is a major Devonian (Acadian ?) fault (see Figure 2) (Abbott and Raymond, 1984; Dietrich and others, 1969). The fault is commonly referred to as the "Fries Fault", although there is some debate over the use of this name (see Bartholomew and Lewis, 1984).

In the southwestern North Carolina Blue Ridge, Hatcher (1978) interprets the contact between the Tallulah Falls/Coweeta groups and the structurally underlying, generally volcanic-free, Ocoee metasedimentary rocks and local granitic basement to be a major Ordovician age (Taconic ?) fault (see Figure 2). This fault is referred to as the "Hayesville Fault".

Recent broadscale models of the Blue Ridge attempt to correlate the Hayesville and Fries faults as a single, Ordovician/Devonian-age structure referred to simply as the "Hayesville-Fries" Fault (Hatcher, 1980; Wehr and Glover, 1985). This major fault is inferred to separate the western "continental" terrane from the allochthonous

eastern "oceanic" terrane (see Figure 2). A major hinderance in validly correlating these faults is a lack of detailed mapping in central western North Carolina. Of special importance and the subject of this study is the appearance of the Amphibolitic Basement Complex southwest of the Grandfather Mountain Window (see Figure 2). Early models of the Blue Ridge Province grouped the Amphibolitic Basement Complex with the granitic basement complexes of the western terrane (see Rankin, 1975; Hatcher, 1978). Merschat (1977; unpublished mapping), however, recognized the widespread amphibolitic nature of the complex and the presence of ultramafic bodies. Later regional models of the Blue Ridge included the complex with the eastern "oceanic" terrane and correlated the Amphibolitic Basement Complex/ granitic basement contact with the hypothisized Hayesville-Fries Fault (Hatcher, 1980; Bartholomew and Lewis, 1984; Wehr and Glover, 1985). Bartholomew and Lewis (1984) and Gulley (1985) refer to the complex as Ashe equivalent.

Field And Analytical Methods

The study area was mapped during the summer of 1985. Mapping consisted of approximately 40 separate transects through the area. The ridge at Stafford Gap was not mapped because of land ownership problems. Other large

areas with a lack of data generally reflect a lack of outcrop in that area. The area was revisited several times after mapping. Early mapping of near continuous exposures in railroad cuts paralleling the French Broad River and exposures along State Highway 25/70 provided general structural and lithologic cross sections through the study area. After these transects were made, representative samples were slabbed and polished. These slabs were then used to describe more accurately and to correlate lithologies observed during the rest of the mapping of the study area. Thin sections were stained to distinguish between strained quartz and feldspar types. Selected hornblende amphibolite samples and metagabbro-metapyroxenite samples were analyzed by X-ray fluorescence methods (see Appendix A) to provide some quantitative data to support interpretations of the basement complexes.

CHAPTER 2

MAJOR LITHOLOGIC UNITS

Introduction

Seven major lithologic units are present in the study area (Figure 3, Plate 1): 1) Sandsuck Formation of the Ocoee Series, 2) Max Patch Metagranite, 3) Cranberry Granitic Basement Complex, 4) Amphibolitic Basement Complex, 5) Roberts Mountain Granitic Basement Complex, 6) Indian Grave Metagranite (Crossnore ?), and 7) Bakersville Metagabbro and (?) Metapyroxenite. Contacts between the units trend in a general northeast-southwest direction. The northwest part of the field area is occupied by Late Precambrian metasedimentary rocks of the Sandsuck Formation of the Ocoee Series. To the southeast, the Sandsuck is in fault contact with the structurally overlying Max Patch Metagranite or, where the Max Patch is absent, the Cranberry Granitic Basement Complex. The Cranberry Basement is structurally overlain to the southeast by the herein named Amphibolitic Basement Complex. Exposed within this complex is a mappable body of metagranite and granitic gneiss, herein reffered to as the Roberts Mountain Basement Complex. A narrow, linear, northeast-southwest trending belt of metagranite herein

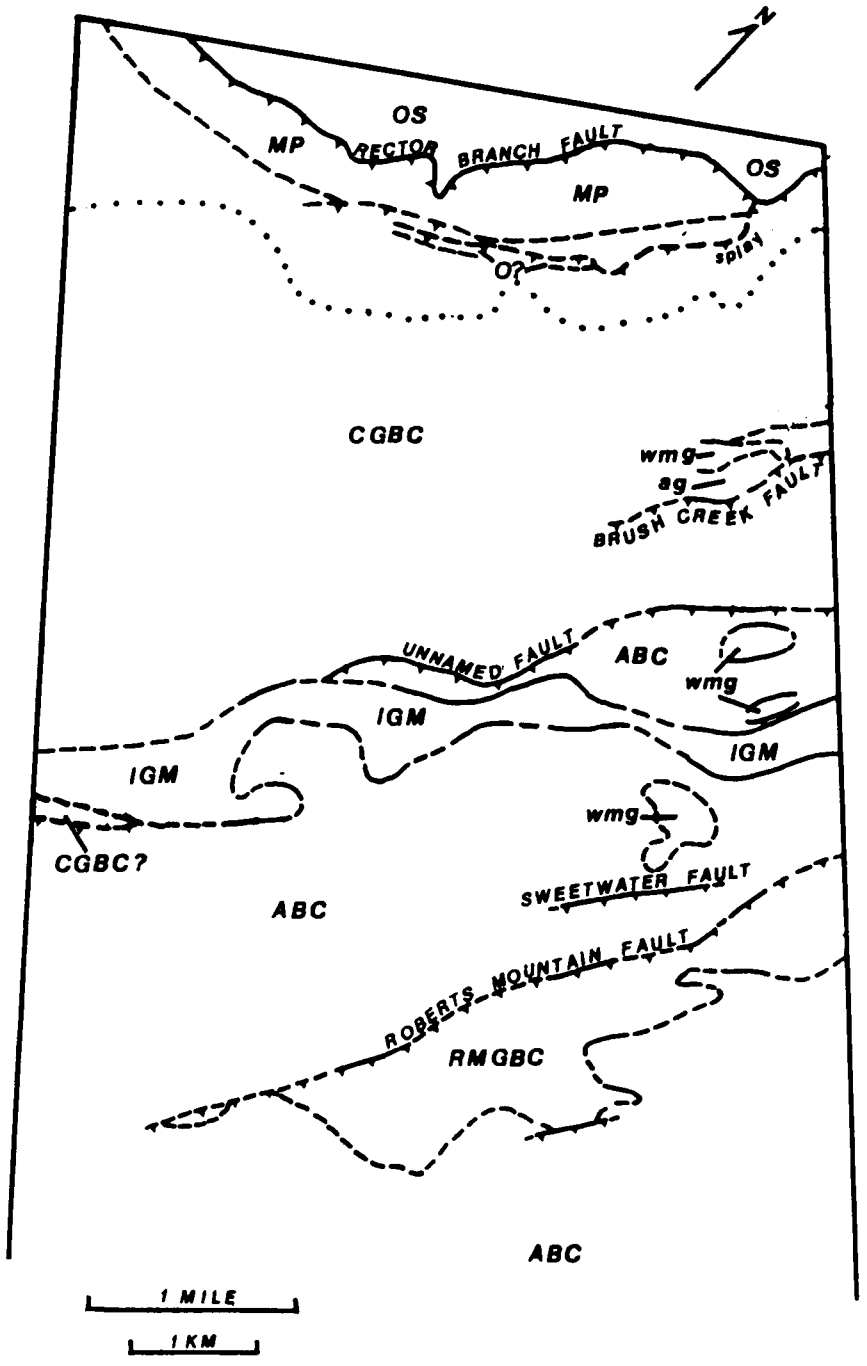


Figure 3. Generalized geologic map of the study area. The major lithologic units are: Sandsuck Formation-Ocoee Series (OS), Max Patch Metagranite (MP), Cranberry Granitic Basement Complex (CGBC), Amphibolitic Basement Complex (ABC), Roberts Mountain Granitic Basement Complex (RMGBC), Indian Grave Metagranite (IGM) and white mica granite (wmg).

named the Indian Grave Metagranite appears to crosscut the contact between the Cranberry Granitic Basement and the Amphibolitic Basement. Small, rare, irregular to dike-like bodies of metagabbro and metapyroxenite are exposed in the Cranberry and Amphibolitic basement complexes. These rocks are tentatively correlated with the Bakersville Intrusive Suite.

Descriptions of the major lithologic units recognized in the field area are discussed in 5 parts: 1) past work, 2) megascopic description, 3) petrography, 4) contact relationships, and 5) age. Emphasis is placed on describing the Cranberry and Amphibolitic basement complexes because it was interest in the contact between these two complexes that spurred this study. Sample numbers following specific rock types discribed under "Petrography" refer to field station locations (see Plate 1). Those samples which have an accompanying thin section are denoted by an asterisk.

Sandsuck Formation-Ocoee Series

Other than for mapping purposes, the Sandsuck Formation was not studied in detail. The intensely sheared contact between the Sandsuck and the overlying granitic basement complex was mapped by Oriel (1950, 1951) as the Rector Branch Fault. For detailed

information on the petrography and structure of the Ocoee metasedimentary rocks in the footwall of the Rector Branch Fault readers are referred to Oriel's work. The Sandsuck consists of greenish gray to gray, fine- to medium-grained metasandstones. Within a few meters of the fault, the Sandsuck metasedimentary rocks are ultramylonitic. Deformation rapidly decreases westward away from the trace of the fault and becomes locallized in a anastomosing array of ultramylonite zones crosscutting weakly mylonitized Sandsuck. The best exposures of the Sandsuck metasedimentary rocks occur in railroad cuts just northwest of the community of Barnard and in the lowermost extent of Brush Creek.

Max Patch Metagranite

Introduction

The Max Patch Metagranite was first mapped and named by Keith (1904) for a type location just southwest of the field area. Because of an abundance of orthoclase and epidote, the Max Patch and other similar granites (locally called "unakite") display a distinct mottled pink and green color and are easily recognized in the field. This suite of granites is conspicuously restricted to the westernmost portions of the Blue Ridge basement

complex (see Figure 2) (Keith, 1904; Sherkarcki, 1959; Bryant and Reed, 1970; this study). Sherkarcki (1959) and Bryant and Reed (1970) interpreted the Max Patch and similar granites to represent Middle to Late Proterozoic intrusives into the Cranberry Granitic Basement Complex.

Megascopic Description

Major exposures of the Max Patch Metagranite are restricted to the northwestern edge of the Cranberry Granitic Basement Complex in the Rector Branch Thrust Sheet. A few small lenses of mottled pink and green Max Patch-like metagranites crop out within the Cranberry complex. Like the Sandsuck, the best exposures of the Max Patch Metagranite occur in the lower extents of Brush Creek and in railroad cuts just west of Barnard. The Max Patch Metagranite is either absent or indistinguishable from Cranberry Basement ultramylonites in the northern part of the study area.

The Max Patch is a coarse-grained, equidimensional, pinkish-red and light-green metagranite. Local concentrations of biotite and magnetite enhance a distinctive mottled appearance. The Max Patch is completely converted to dark-green ultramylonite in approximately a 30 meter thick zone above the Rector Branch Fault. With the exception of a few isolated lenses

of relatively undeformed rock, the remainder of the metagranite is strongly mylonitized. Undeformed lenses of Max Patch range from a few meters to one hundred meters across and are elongate parallel to the foliation. The lenses are commonly dissected by small shear zones. Max Patch mylonites also display a distinctive mottled appearance due to patchy aggregates of dark greenish-gray ultramylonitic material, light-green epidote and white mica, pinkish orthoclase and microcline augen.

Calc-silicate lenses containing high concentrations of green epidote are scattered throughout the metagranite. The bodies range in size from a meters to a few tens of meters thick. Larger lenses are internally disrupted. The largest lense is exposed in a roadcut just south of Barnard (Field Station 556, see Plate 1). Smaller lenses are composed of dense, ultrafine masses of epidote. The calc-silicate lenses do not neccessarily parallel the dominant mylonitic foliation associated with the Rector Branch Fault Zone although they were clearly deformed by the mylonitization event.

Petrography

The Max Patch Metagranite is composed of equigranular, coarse, blocky grains of greenish plagioclase in a slightly finer groundmass of pink

orthoclase, microcline, quartz and local patches of biotite and/or magnetite (see samples 110*, 116). The composition varies from granite to granodiorite with granite being the most common.

Plagioclase (albite-oligoclase) has its greenish coloration because of saussuritization and sericitization. Grains average 2.5mm to 7mm in diameter. The cores of most grains are preferentially saussuritized. Some grains contain rounded inclusions of quartz and unaltered feldspar.

Pink orthoclase and rarer microcline grains average <5mm in diameter. In thin section grains are often weakly undulose. Like plagioclase, orthoclase grains typically contain rounded inclusions of quartz and feldspar. Unlike plagioclase, feldspar inclusions in K-feldspar grains are commonly intensely saussuritized. In rare cases, inclusions display myrmekitic intergrowths of quartz and feldspar.

Quartz composes an average of 10 % of the granite. In even the least deformed portions of the Max Patch, quartz is highly strained. In thin section, grains display very undulose, partially recrystallized, ribboned textures.

Small, patchy clusters of biotite up to a few millimeters across compose an average of 4 to 5% of the granite. In more mafic portions of the body, biotite may compose up to 20% of the rock. Magnetite occurs as

scattered grains and irregular masses in slightly lower concentrations than biotite. White mica (sericite) and epidote occur only as alteration products of feldspar grains. Epidote composes 4 to 8% of the granite.

Contact Relationships

The Max Patch metagranite is in fault contact (Rector Branch Fault) with the structurally underlying Sandsuck metasediment. Ultramylonitized Sandsuck versus Max Patch can be discerned in the field by the following criteria: 1) due to a higher quartz content, the Sandsuck displays an increased resistance to weathering, 2) the Sandsuck displays a olive-gray color in contrast to the dark-green color of the Max Patch, and 3) the Max Patch contains abundant, minute, pink, orthoclase augen not observed in the Sandsuck.

In the study area, the contact between the Max Patch and the granitic gneisses of the Cranberry Basement lies within the Rector Branch Fault mylonite zone and cannot be easily pinpointed in the field. The contact was approximated by marking the transition from dominantly pink feldspar typical of the Max Patch to dominantly white feldspar typical of the Cranberry gneisses and granites. In less deformed exposures of the basement complex to the northeast Sherkarchi (1959) and Bryant and

Reed (1970) interpreted the the same type of pinkish peralkaline granites to be intrusive with respect to the Cranberry Basement.

Age

A single published zircon analysis for a sample of the Max Patch Granite from Max Patch Mountain yielded an age of 880my (Carroll and others, 1957). Sherkarchi (1959) and Bartholomew and Lewis (1984) infer an age of Middle to Late Proterozoic for the pink, epidote-rich granites in the western portion of basement terrane.

Cranberry Granitic Basement Complex

Introduction

Keith (1904) named the extensive granitic gneissic unit exposed in the western half of the Blue Ridge "Cranberry Granitic Gneiss". More recent studies show the unit to represent a heterogeneous basement complex composed of Grenville or pre-Grenville-age gneisses intruded by slightly younger, less deformed, Grenville-age granitic plutons (e.g Bryant and Reed, 1970; Bartholomew and Lewis, 1984). Bartholomew restricts the name "Cranberry" to a layered granitic gneiss complex

in northwestern North Carolina and assigns this complex to the more regional scale "Elk River Massif". Detailed mapping of the basement southwest of the Grandfather Mountain Window is too incomplete to subdivide what Keith originally termed "Cranberry" into specific massifs. The name "Cranberry" is therefore retained in this study for exposures of a granitic complex in the western part of the field area.

Bryant and Reed (1970) described exposures of the Cranberry Basement north of the study area in the vicinity of the Grandfather Mountain Window in detail. Their descriptions are quite comparable with the gneissic-plutonic complex exposed in the study area.

Megascopic Description

In the study area, the Cranberry Granitic Basement Complex is composed of six distinct lithologies: 1) biotite granitic gneiss/semi-schist, 2) biotite schist, 3) non-foliated granitic rock (granodiorite, quartz-diorite, granite-quartz monzonite), 4) calc-silicate, 5) quartz feldspar biotite gneissic schist and 6) biotite hornblende granitic gneiss. Biotite granitic gneiss to semi-schist and nonfloiated granitic rock compose >85% of the exposed complex. All but the

biotite schist lithology occur as mappable units at least locally.

The Cranberry Basement Complex is characterized by light gray, moderately-to-intensely foliated biotite granitic gneiss with variable mafic content. In the study area, the term "gneiss" best describes compositional layering on the scale of meters rather than distinct banding observable in hand sample. In hand sample, the majority of the rock is best described as semi-schistose.

Biotite schists compose an average of 5% of the biotite granitic gneiss exposures. Schistose interlayers are rarely more than a few centimeters thick. Interlayered biotite schists become more prominent in progressively more deformed parts of the gneissic rocks. The best exposures of biotite granitic gneiss are in railroad and road cuts on the either side of the French Broad River between Walnut Creek and the community of Barnard.

A large, slightly elongate body of very mafic, locally migmatitic, quartz feldspar biotite gneissic schist is exposed just east of the community of Walnut. Feldspar grain size and mafic content is high enough in some areas to develop feldspar augen schists.

Very weakly deformed bodies of granodiorite to quartz diorite occur throughout the biotite granitic gneiss "country rock". Mappable bodies are exposed in the area

of the Highway 25/70-Brush Creek Road intersection and at the southern base of Barnard Mountain in fields to the west of Riddle Farm Road. Where exposed, the margins of these granitic bodies generally display a sharp increase in foliation intensity which grades outward into the foliation of the surrounding granitic gneisses.

A large quartz diorite body exposed near the Highway 25/70-Brush Creek Road intersection is structurally underlain by a 30 to 40 meter-wide zone of calc-silicate. This is the only calc-silicate interval mapped in the Cranberry in this study although they are apparently more common in other areas (see ex. Merschat, 1977).

The quartz diorite body and calc-silicate interval exposed on Highway 25/70 structurally overlie a narrow belt of very weathered horneblende amphibolite gneiss. This is one of at least two exposures of hornblende amphibolite gneiss interpreted to lie within the Cranberry Complex. The contact between the amphibolitic gneiss and the Cranberry granitic gneiss to the west is not exposed.

The Cranberry Basement Complex is intensely mylonitized within 1000 to 1200 meters of the Rector Branch Fault, well beyond the southeastern extent of the Max Patch Metagranite (see Figure 3-page 10, Plate 1). Mylonitic intensity progressively decreases to the southeast. Intensely mylonitized zones are generally very

weathered. Rare phyllonitic zones weather to distinct fish scale-like flakes of ultramylonite.

A very narrow, discontinuous band of odd, arkose-like rock is exposed within a second, less continuous, but distinct ultramylonite zone a few hundred meters to the southeast of the Rector Branch Fault (see Figure 3-page 10, Plate 1). Less mylonitized exposures of this rock resemble texturally mature, very feldspathic arkoses. Ultramylonite equivalents of the unit display a local calcite veining not observed in nearby Cranberry ultramylonites. The lithology is very tentatively correlated with the Ocoee metasedimentary rocks. Keith (1904) apparently recognized this same belt of rock and likewise correlated it with the metasedimentary rocks to the west. This unit is discussed again under "Rector Branch Fault-local splays" in Chapter 4.

Thin pegmatitic dikes a few centimeters to less than a meter thick crosscut the dominant foliation in a few exposures of biotite granitic gneiss. These dikes were too rare to determine their relationships with other units in the complex with any certainty.

Petrography

Biotite granitic gneiss (6)

Light brownish-gray biotite granitic gneisses to semi-schists range in composition from granite to granodiorite and average quartz monzonite. Biotite composes less than 5% of most samples and defines the foliation. Biotite grains are often kinked and display ragged grain boundaries. Minor amounts of epidote, sphene, and opaque oxides (magnetite or ilmenite ?) are concentrated in biotite-rich zones.

Leucocratic portions of the rock are composed of strained quartz and feldspar augen. Undulose, partially recrystallized quartz ribbons up to 1mm long typically wrap around the slightly larger feldspar augen and define the foliation. Quartz never composes more than 30% of the rock.

Orthoclase, perthite, and plagioclase (albite) augen compose an average of 65% of the rock. The augen range up to 7mm across and average 2-3mm. K-feldspar augen are typically inclusion-free. Plagioclase augen are locally sericitized and/or saussuritized. Feldspar augen display partially to intensely recrystallized or "mortared" grain boundaries and are commonly dissected by narrow bands of recrystallized material. Most augen are not large enough

to display well developed recrystallized "tails" in hand sample.

Biotite schist

Discontinuous layers and pods of brownish-black biotite schists are interlayered at all scales with the biotite granitic gneiss. Up to 90% of the schists are composed of fine-to-coarse, equigranular grains of biotite parallel to the enclosing gneissic foliation. Quartz and feldspar poryphyroclasts are scattered throughout the biotite layers.

Granodiorite (322*)

Exposures of non-foliated granitic rock are dominated by light-gray, coarse- to fine-grained, equigranular granodiorite. Twinned, white plagioclase grains (dominantly albite) average 2-4mm in width. Plagioclase is typically moderately sericitized and intensely saussuritized. K-feldspar commonly displays epidote-rich reaction rims with plagioclase. In even the least deformed samples, quartz grains are undulose and locally display intense subgrain development. Subgrains display serated to straight boundaries.

Dark greenish-brown, usually undeformed biotite grains up to a few milimeters across compose 4-8% of most

granodiorites. White mica composes less than 1% of the granodiotites.

Sphene is concentrated along biotite cleavage planes and the rims of opaque oxides (magnetite or ilmentite ?) grains. Sphene and opaque minerals compose less than 1% of the rock. Blocky epidote grains .1-.2mm across form trails across plagioclase grains and/or are concentrated in clusters of biotite. Magnetite-ilmenite grains are commonly partially altered to hematite.

Quartz diorite (156a*)

A large body of foliated-to-massive, medium- to coarse-grained, light bluish-gray and dark green quartz diorite is exposed in the northeastern part of the Cranberry complex. Local finer-grained diorites of a similar composition appear to crosscut the coarser-grained foliated to massive diorite. As discussed later, similar fine-grained diorites also appear to have intruded the Amphibolitic Basement Complex.

Light greenish-white, twinned plagioclase (albite-oligoclase) grains 3-4mm across compose at least 50% of the rock. Grains are strongly saussuritized. Most grains are isolated by rims of epidote, biotite, amphibole, and local white mica. Rounded quartz blebs are common inclusions in some grains. K-feldspar was not recognized in thin section or hand sample.

Bluish quartz composes 5% to 10 % of the rock. The quartz displays the bluish tint due to minute inclusions of rutile. Quartz grains in foliated areas of the quartz diorite are drawn out into partially recrystallized elongate ribbons.

Dark-green, subhhedral diopside grains averaging 1mm across compose up to 15% of the quartz diorite. Grains locally display cores of biotite, plagioclase, and epidote. Grains not in contact with other pyroxene grains are very irregular and partially rimmed by amphibole, quartz, and biotite. Some isolated pyroxene grains are completely replaced.

Light-green amphibole (hornblende and/or actinolite) composes up to 25% of the quartz diorite. Amphibole and pyroxene grains form a fishnet-like network with plagioclase filling in the gaps. Amphiboles form slightly elongate, subhedral grains <.2mm long or irregular flakes with locally abundant intragranular quartz. Coarse amphibole commonly coats plagioclase - plagioclase grain boundaries. Plagioclase - amphibole grain boundaries are often marked by coarse alteration rims of lath-like epidote growing perpendicular to the contact.

Minor amounts of greenish-brown biotite commonly rim amphibole and pyroxene grains or form discrete grains up to 1mm across. Trace amounts of zircon are associated with biotite grains. Clusters of biotite, amphibole, and

pyroxene define local mafic banding in compositionally layered portions of the quartz diorite.

Ilmenite-magnetite locally composes up to 10% of the quartz diorite. Sphene locally rims irregular .5-1mm grains of ilmenite-magnetite. Small grains of pyrite are randomly distributed throughout the rock.

The finer-grained intrusive (?) diorite differs from the coarser quartz diorite in that it contains only trace amounts of quartz and biotite and no pyrite. Epidote and amphibole reaction rims such as those described earlier are much better developed in the diorite. Like the quartz diorite unit, amphibole and subhedral pyroxene grains display a fishnet-like texture with plagioclase filling in the holes. The finer diorite also contains very minor amounts of intensely sericitized K-feldspar.

Calc-silicate (727*)

The bulk of the calc-silicate is composed of massive to fibrous actinolite and highly saussuritized plagioclase. Plagioclase grains display straight to sutured grain boundaries. Unaltered blebs of K-feldspar are scattered throughout the plagioclase. Coarse, pinkish, granitic migmatite crosscuts and is intermixed with the calc-silicate body.

Ragged, subhedral clinopyroxene grains are concentrated within patches of actinolite. The grains are

partially to completely replaced by actinolite. Biotite, sphene, and opaque oxides (ilmenite or magnetite ?) compose less than 1% of the calc-silicate. As discussed under the chapter entitled "Structure", the calc silicate is interpreted to represent the deformed, epidotized equivalent of the structurally overlying quartz diorite body.

Granite, quartz monzonite (101, 543)

Undeformed or weakly foliated granite and quartz monzonite bodies are rare in the Cranberry Complex. Where they are occur, exposures are usually highly weathered. Two types of granitic bodies occur.

Small lenses of white-to-mottled pink and white, very coarse-grained, granite display sharp contacts with well foliated biotite granitic gneiss (ex. sample 101). Light pink orthoclase and local microcline displaying cross-hatched twinning compose up to 70% of the rock. Greenish-white plagioclase (albite) grains are highly saussuritized and sericitized. Orthoclase and microcline often contain highly altered blebs of plagioclase. With the exception of trace amounts of opaque oxides (ilmenite or magnetite ?) these granites-quartz monzonites are almost completely lacking in mafic minerals. As in other granitic bodies, quartz is always highly strained and partially recrystallized.

A distinct, light-yellowish to pinkish-gray, fine- to medium-grained equigranular white mica granite is exposed in a highly weathered saprolite quarry at the southern extent of Price Mountain (sample 543). The granite displays sharp intrusive contacts with surrounding biotite granitic gneiss and hornblende biotite granitic gneiss. Light pink orthoclase composes up to 60% of the rock and plagioclase 10% to 20%. White mica composes 4-5% of the granite. Because of a general lack of white mica in the basement complexes, the granite is very distinct in the field. Biotite and Fe-rich opaques are present in only trace amounts. An identical lithology is exposed in the Amphibolitic Basement Complex.

Quartz feldspar biotite gneiss/schist (228*)

Plagioclase appears to the dominant feldspar in the mafic, schistose unit exposed just east of the community of Walnut. Feldspar content varies within the unit but averages 40%. Twinned plagioclase (albite) augen are typically moderately saussuritized and sericitized. The augen display bent twin lamellae and highly undulose inclusions of quartz. Feldspar augen are usually partially recrystallized at their boundaries and wrapped by biotite and local white mica.

Biotite composes 20% to 40% of the rock. Large biotite augen are often crosscut by a second generation

of finer-grained biotite defining the dominant foliation. The larger grains are locally altered to chlorite. Fine- to coarse-grained white mica composes up to 5% of the rock type and usually forms elongate aggregates enclosing plagioclase augen.

Quartz composes an average of 5 to 10% of the rock. Grains are drawn out into elongate, partially recrystallized, undulose ribbons up to 1cm long. Quartz is also present as less deformed blebs at triple junctions of plagioclase grains.

Calcite, rare in the Cranberry Complex as a whole, composes up to 4% of some samples. Calcite occurs as small blebs at triple points of feldspar grains or as more extensive sheets overprinting plagioclase and quartz augen. Opaque oxide (magnetite or ilmenite ?) grains compose less than 1% of most samples.

Local migmatite is composed of crystalline aggregates of very coarse, twinned plagioclase (albite) and highly strained, undulose quartz ribbons. In contrast to the enclosing rock, plagioclase within the migmatite is typically highly sericitized. Most plagioclase grains are isolated from each other by thin zones of minutely recrystallized, quartz-plagioclase material. Several plagioclase grains display well-developed myrmekitic intergrowths of quartz and feldspar at their grain

boundaries. Biotite and white mica are concentrated at the borders of migmatite.

Biotite hornblende granitic gneiss (158*)

The leucocratic portion of the biotite hornblende granitic gneiss is composed of essentially the same mineralogy as the the biotite granitic gneiss lithology that composes the major part of the Cranberry Complex. In addition to biotite however, mafic intervals of this gneiss locally contain significant amounts of hornblende.

Thin interlayers and pods of amphibolite are intermixed with the gneiss. 80% of the amphibolite is composed of elongate grains of hornblende which parallel the enclosing gneissic foliation. Generally untwinnned plagioclase subgrains fill interstitial areas between amphibole grains and compose most of the remainder of the amphibolite. Local patches of twinned plagioclase (albite-oligoclase) are intensely saussuritized.

Ilmenite-magnetite composes up to 5% of the amphibolite. Most grains are rimmed by sphene. Minor epidote-zoisite grains are scattered throughout the rock. K-feldspar (orthoclase ?)is present in trace amounts.

Contact Relationships

Contact relationships are difficult to establish in the Cranberry Complex. Nonfoliated granitic bodies commonly display sharp compositional differences with the enclosing biotite granitic gneiss. The majority of the nonfoliated granitic bodies probably represent intrusions into the gneissic complex rather than tectonic lenses of the same protolith. In a small saprolite quarry just to the north of State Highway 25/70, the white mica granite is in sharp intrusive contact with biotite granitic gneiss (Plate 1, Field Station 543). Xenoliths of the gneiss are present within the margins of the white mica granite.

The eastern and southern contacts of the large quartz diorite body partially exposed on State Highway 25/70 (see Plate 1) appear sharp but are poorly exposed. The quartz diorite body becomes increasingly foliated near its western margin. As discusssed in Chapter 4, the western margin of the pluton is interpreted to be fault bounded (Brush Creek Fault), with the basal calc-silicate lense representing a fault zone. It seems reasonable to infer that the quartz diorite body intruded the gneissic country rock of the Cranberry and was later tectonized along its western border.

The contact between the biotite granitic gneiss and the more mafic quartz feldspar biotite gneiss/schist unit (see Plate 1) appears gradational. Small lenses and interlayers of biotite schists display sharp contacts with the enclosing biotite granitic gneisses. The schists probably represent original mafic contrations in the older granitic complex, slightly younger mafic intrusions, and/or concentrations of mafic material due to shearing.

The contact between the biotite hornblende gneiss and the biotite granitic gneiss (see Plate 1) is somewhat arbitrary and was picked at the first occurance of widespread, intermixed hornblende amphibolite. This distinction is fairly sharp in the field and is also a major criteria for picking the contact between the Cranberry Granitic Complex and the Amphibolitic Complex.

Age

Published Rb/Sr whole rock radiometric ages of the Cranberry Granitic Basement Complex from exposures to the north of the study area average around 1.1by (see Fullagar and Odom, 1973). Rb/Sr whole-rock dating of gneisses in the Roan Mountain area just north of the study area yielded an age of 1.8by (Monrad and Gulley, 1983; Bartholomew and Lewis, 1984).

Amphibolitic Basement Complex

Introduction

The name "Amphibolitic Basement Complex" is used in this study to emphasize the distinctive amphibolitic character of the complex and recent work (including this study) which suggest a "Grenville" age of the complex. Prior to regional mapping by Hadley and Nelson (1971) the complex was not separated from the units on either side of it. Hadley and Nelson simply refer to the unit as "layered gneiss and migmatite", in contrast to the granitic gneiss of the Cranberry Complex. This name grossly oversimplifies the complex lithologic nature of the unit. Their brief description of the unit included with the map is very comparable to the lithologies described in this study. Keith (1904) lumped the more mafic portions of the Amphibolitic Basement Complex with his "Roan gneiss" unit.

Bryant and Reed (1970) delineate a "mixed rock unit" southwest of the Grandfather Mountain Window which they described as a transitional lithology between the structurally overlying Ashe Formation and the structurally underlying Cranberry granitic gneisses. Their mixed rock" unit was composed of heterogeneously interlayered amphibolite, calc-silicate, biotite

hornblende gneiss and schist, epidote plagioclase gneiss and schist, and granitic gneiss ranging from diorite to quartz monzonite in composition. The lithologic descriptions and structural position of their "mixed rock" unit are identical to the Amphibolitic Basement Complex delineated in this study.

Merschat (1977 and unpublished data) mapped adjacent areas of the Amphibolitic Basement Complex in and around the Mars Hill 7 ½' quadrangle. He refers to the complex as a light-brownish-to-pinkish gray, massive-to-well foliated, biotite hornblende migmatite. He specifically mapped the unit as separate from the Cranberry and Ashe complexes. Amphibolite, biotite hornblende gneiss, epidote-veined granitic gneiss, calc-silicate, magnetite granitic gneiss, magnetite biotite gneiss, biotite augen gneiss, biotite gneiss, hypersthene biotite hornblende gneiss, and hypersthene granitic gneiss are interlayered at all scales within the biotite hornblende migmatite. Merschat's map units are very similar to the units mapped as part of the Amphibolitic Basement Complex in this study. Feldspar "lenses, stringers, and cross cutting veinlets" described by Bryant and Reed in their "mixed rock" unit closely match the characteristic "migmatitic" texture of the biotite hornblende migmatite unit described by Merschat and the Amphibolitic Basement Complex described in this study.

Megascopic Description

The Amphibolitic Basement Complex composes twelve distinct lithologies: 1) biotite hornblende granitic gneiss, 2) biotite granitic gneiss, 3) amphibolite, 4) quartz feldspar biotite augen schist/semi-schist, 5) kyanite garnet plagioclase quartz gneiss, 6) nonfoliated granitic rock (granite-quartz monzonite, granodiorite-diorite), 7) marble, 8) calc-silicate rock, 9) talc-rich ultramafic rock, 10) actinolite semi-schist, 11) chlorite schist, and 12) metabasalt porphyry. No mappable stratigraphic order or and degree of internal continuity could be recognized in the Amphibolitic Basement Complex.

Local outcrops of the complex are distinctly migmatitic. The migmatitic nature is best exposed in stream beds. The granitic migmatite stands out over the more deeply weathered mafic portions of the rock. The migmatite crosscuts earlier gneissic foliation but is clearly effected by later folding and shearing events.

Biotite hornblende granitic gneiss with intermixed lenses and pods of amphibolite and biotite granitic gneiss compose >75% of the Amphibolitic Basement Complex. Only these lithologies and local, weakly foliated, granitic bodies were extensive enough to be mapped as

separate units (see Figure 3-page 10, Plate 1). Other lithologies are complexly intermixed within the biotite hornblende granitic gneiss. A single lens of kyanite-bearing gneiss was observed in the complex. In many exposures the biotite hornblende granitic rock is so intensely deformed and intermixed with lenses and pods of amphibolite and other lithologies that it is difficult to describe the rock simply as a "gneiss" or "schist".

Amphibolite pods and lenses generally compose no more than 20% of an exposure. On an outcrop scale, small amphibolite layers often crosscut the foliation in the enclosing biotite granitic gneiss. Larger lenses of amphibolite are elongate parallel to the regional foliation and gross compositional layering. Lenses of very coarse-grained psuedo-diorite are intermixed with the more well-foliated amphibolite. Small, nonmappable exposures of mafic augen schist are interlayered within the mafic gneissic rock.

A large belt of biotite granitic semi-schist containing only sparse amphibolite is exposed in the eastern part of the Amphibolitic Complex. This belt of rock is distinctly less mafic than the complex in general. The transition to the more mafic portions of the complex is gradational over a few tens of meters. This gradation is well exposed in roadcuts at the eastern edge

of the town of Marshall (Field Stations 211-214, 485-489).

Large exposures of non-foliated to weakly foliated granitic rock are much less common in the Amphibolitic Complex than in the Cranberry Complex. Three bodies of highly weathered, pinkish, white mica granite identical to the white mica granite exposed in the Cranberry complex are exposed in the northern corner of the Amphibolitic Complex. A small but mappable quartz monzonite body is exposed in the southernmost corner of the complex. Other small, rarely mappable bodies of nonfoliated granitic rock are scattered throughout the complex. The granitic bodies are irregular in shape and not neccessarily elongate parallel to the regional foliation. Small, nonmappable exposures of granodiorite-diorite are scattered throughout the complex. Local lenses of nonfoliated diorite are petrographically identical to the fine-grained diorite postulated to intrude the Cranberry Complex.

Narrow marble interlayers are restricted to a narrow belt of exposures near the Redman area. Individual interlayers are not large enough or continous enough to be mapped as separate units. According to local residents, marble was also encountered during drilling for the construction of the Redman Dam. The marbles locally grade into layered, siliceous calc-silicate

lenses. Calc-silicate lenses are also scattered throughout the complex.

A few small, talc-rich ultramafic bodies are scattered throughout the complex but they are not large enough to be mapped as separate units. These talc bodies were prospected during the early 1900's but were too small to have economic value. Locally mappable lenses of chlorite schist are scattered throughout the complex. Small, nonmappable lenses and pods of actinolite semi-schists (metapyroxenite ?) are also present throughout the complex. Where the margins of these amphibolites are exposed, the rock is completely enclosed within highly deformed biotite hornblende granitic rock.

The metabasalt porphyry lithology is very similar to a "metabasalt porphyry" unit described by Burton (1979) in the Cranberry Basement just north of the study area. Burton interpreted these lithologies as mafic dikes which intruded the Cranberry sometime during the Mid to Late Proterozoic. Unfortunately, this lithology was restricted to a single exposure in the Amphibolitic Basement Complex and its relationship to the enclosing rocks could not be determined with any certainty.

Quartz veins a few millimeters to a meter or more wide crosscut and/or parallel compositional layering. Most veins are in turn folded and broken and rotated into the dominant foliation plane. Vein quartz float is much

more abundant in the Amphibolitic Complex than the Cranberry Complex and commonly caps ridge tops. The peak of Star Mountain is held up by abundant large quartz veins. These quartz veins have been locally prospected for gold.

Petrography

Biotite hornblende granitic gneiss (344*, 411)

The biotite hornblende granitic gneiss is distinguished from Cranberry biotite granitic gneiss by the presence of hornblende in mafic intervals of the gneiss and as discrete amphibolite pods or lenses. Quartz, plagioclase, and K-feldspar compose an average of 90% of the leucocratic portions of the rock. Grains are very granoblastic and average <.25mm in size. Plagioclase (albite to oligoclase) is locally strongly sericitized. Quartz is always very undulose and partially recrystallized. Biotite content of the rock varies from 5% in gneissic intervals to > 70 % in more schistose intervals (see sample #30). Opaque oxides (ilmenite or magnetite ?), epidote, and sphene are commonly present in minor amounts and are usually concentrated in the more mafic portions of the rock.

Mafic intervals in the gneissic rock are composed of 50% to 70% elongate hornblende grains. The parallel

alignment of hornblende grains defines the dominant foliation of the rock. Hornblende grains often contain numerous rounded plagioclase inclusions. Local grains of hornblende appear to have grown oblique to the dominant foliation, possibly indicating two periods of amphibole growth. Plagioclase (albite-oligoclase) composes up to 45% of the amphibolites and is present as interstitial material between the hornblende grains. Biotite composes 1% to 10% of the amphibolites. Coarse flakes up to 2mm across define the dominant foliation.

Opaque oxides, sphene, epidote, and garnet compose up to 3% of the amphibolite. Epidote and garnet were never observed to co-exist in a single sample although they may both be present in different parts of a single large amphibolite body. Garnets are subhedral, 1mm to 2mm in diameter,and commonly contain moderate concentrations of plagioclse and quartz inclusions.

The granitic migmatite (see samples 179*, 747*) developed throughout the biotite hornblende granitic gneisses and biotite granitic gneisses of the complex. It appears to vary in composition from K-feldspar dominant to plagioclase (albite-oligoclase) dominant. No distinct distribution pattern of migmatite development was noted in the field. Feldspar and quartz grains composing the migmatite are distinctly coarser than grains in the enclosing rock. Grains in the migmatite display

crystalline to augen textures. Plagioclase grains are usually twinned and highly saussuritized. Plagioclase and K-feldspar grains typically contain abundant clear blebs of of quartz and untwinned feldspar. Quartz composes an average of 15% of the migmatitic material. Grains are usually strongly undulose and ribboned and partially to completely recrystallized.

Biotite granitic gneiss (52)

The biotite granitic gneissic to semi-schistsose lithology of the Amphibolitic Basement Complex displays a somewhat wider range of composition and texture in single exposures than the biotite granitic gneiss lithology of the Cranberry Complex does. The rocks range from granite to granodiorite in composition. All minerals in the rock are highly strained. Foliation is defined by elongate to platy quartz ribbons, sheet-like trails of feldspar augen, and phyllosilicates. Biotite composition ranges from 5 to 10% in granitic intervals to 70% in more schistose intervals. Other minerals commonly composing <1% to 3% of the rock include hornblende, white mica, epidote, clinozoisite, and sphene. A single sample contained 15% white mica and a possible garnet grade pelitic assemblage. Unfortunately this sample was not in place. Opaque oxides (ilmenite or magnetite ?), zircon, and apatite are common accessory minerals.

Amphibolite (702b*, 52b*, 34*)

Two distinct types of amphibolite are recognized in the Amphibolitic Basement Complex: 1) small pods and lenses to larger interlayers of fine-grained, foliated amphibolite (702b*, 52b*), 2) lenses of very coarse-grained hornblende actinolite plagioclase semi-schists ("psuedo-diorite") (34*). XRF analysis of selected amphibolites are discussed in the following chapter.

Moderately foliated, dark green amphibolites are composed of 70% to 90% stubby to elongate, subhedral grains of hornblende averaging .5mm in length. Hornblende grains commonly contain small rounded blebs of plagioclase and local concentrations of zircon. Untwinned plagioclase grains compose most of the groundmass of the rock. Plagioclase grains are locally saussuritized and/or sericitized. Small blebs of plagioclase often occur at hornblende triple points or common grain boundaries. Quartz grains are highly strained and partially recrystallized.

Amphibolites contain local concentrations of garnet or epidote. Neither were observed to coexist in thin section although they may both be present in the same outcrop. Subhedral garnet porphyroblasts (or porphyroclasts) average less than .5mm across and appear

synchronous-to-late, with respect to the dominant foliation. Sphene and opaque oxides (ilmenite or magnetite ?) grains commonly compose 1% to 3% of the rock. Both are somewhat concentrated at hornblende-hornblende grain boundaries.

Very coarse grained, mottled-green-and-white, moderately foliated, "psuedo-metadiorite" is present as discontinuous interlayers up to 75 meters thick. Hornblende/actinolite is present as large, blocky, slightly elongate grains averaging 5mm across. Grain boundaries perpendicular to the foliation are very ragged. Amphibole grains are partially enclosed in a fine grained, partially recrystallized groundmass of twinned plagioclase (albite-oligoclase). In slightly more mylonitic samples, dense concentrations of sphene form distinct light-greenish discontinous trails parallel to the foliation.

Quartz feldspar biotite augen schist/semi-schist (726)

Two types of augen schists-semi-schists are recognized: 1) those dominated by blocky or rounded, pinkish to murky-white K-feldspar augen and 2) those dominated by blocky subhedral to irregular white plagioclase augen. Rocks dominated by K-feldspar augen usually contain less than 10% biotite, giving them a semi-schistose to gneissic texture. The roundess of

K-feldspar augen increases with increasing mylonitonization displayed by the quartz feldspar biotite groundmass. Samples dominated by plagioclase augen typically have a much more biotite-rich groundmass and display more schistose textures. Increased biotite content in the groundmass is often accompanied by the presence of hornblende. Groundmass plagioclase content decreases dramatically in K-feldspar dominated augen semi-schists.

Plagioclase and feldspar augen contain numerous rounded blebs of weakly undulose quartz. K-feldspar augen generally display a much higher degree of border recrystallization and the development of "tails" of recrystallized material than do plagioclase augen. K-feldspar augen often contain a small, central inclusion of ilmenite-magnetite. Plagioclase augen often contain minute inclusions of hornblende and are locally altered to sericite and clinozoisite.

Kyanite garnet plagioclase quartz gneiss (408*)

Just north of the Redman Dam, a rare hornblende, kyanite, orthopyroxene (?), garnet, plagioclase, quartz gneiss is interlayered with the biotite ± hornblende granitic gneiss. Subhedral garnet porphroclasts compose 15% of the rock. Kyanite and orthopyroxene (?) grains compose 7% of the rock and are concentrated in

garnet-quartz-rich portions of the rock. Hornblende and plagioclase compose the more mafic intervals of the gneiss. Trace amounts of epidote-clinozosite occur at plagioclase-garnet and plagioclase-amphibole grain boundaries. Opaque oxides (ilmenite or magnetite ?) composes less than 2% of the rock.

Granite-quartz monzonite (673, 170)

Most exposures of non-foliated granitic rock in the Amphibolitic Complex are too weathered to collect samples for thin section study. The granitic rocks contain only minor amounts of mafic material. The medium-grained, equigranular quartz monzonite body exposed in the southern-most portion of the field area is composed of approximately 60% K-feldspar, 30% plagioclase and 5% to 10% quartz. Opaque oxides (ilmenite or magnetite ?) composes <1% of the rock. White mica is present in trace amounts.

Exposures of pinkish-white, equigranular, medium-grained, white mica (muscovite ?) granite appear identical to the white mica granite exposed in the Cranberry Complex. As in the Cranberry, the granite is highly weathered. The granite is composed of approximately 60% pinkish K-feldspar, 10% to 15% plagioclase, 10% to 15% quartz, 4% to 5% white mica, and

minor amounts of opaque oxides (ilmenite or magnetite ?) and biotite.

Granodiorite-diorite (55)

A single sample of granodiorite-diorite was collected in the northwestern portion of the Amphibolitic Complex. The lithology is present as small, discontinuous lenses throughout the complex. Clear-white plagioclase grains up to 1cm across compose approximately 80% of the rock. Dark green hornblende is distributed in patchy clusters and is the dominant mafic mineral. Quartz composes <10% of the rock.

Small, lenses of nonfoliated "diorite" (55) are scattered through the complex. Texturally and compositionally the rock appears identical to the fine-grained diorite of the Cranberry Complex and will not be redescribed here.

Marble (654a*, 669*)

Crystalline mosaics of fine to coarse, twinned, pinkish-to-white calcite compose an average of 65% of the marble. Scattered, subhedral, grains of dark green diopside averaging a few millimeters across compose up to 15% of the marbles. The diopside gives the rock a distinct spotted texture. Microcline and less common plagioclase (albite?) compose an average of 15% of the

marble. Feldspar is concentrated at calcite triple junctions and common grain boundaries and less commonly at calcite-diopside grain boundaries. Sphene, a common accessory mineral, is present as elongate grains preferentially concentrated at cacite-calcite grain boundaries. The occurrance together of pinkish calcite and whitish feldspar and quartz causes the marbles to display a striking resemblance to a non-foliated granite in the field.

Calc-silicate (654b*)

The marbles locally grade into mineralogically more diverse green and white, banded, siliceous, calc-silicate interlayers. The calc-silicate is composed chiefly of quartz, plagioclase (albite), microcline, and diopside with lesser amounts of amphibole, orthopyroxene (?), epidote, clinozoisite, sphene, calcite, biotite and local concentrations of garnet. Quartz and feldspar grains display sutured to granoblastic grain boundaries but little internal strain. Diopside grains locally reach up to 2-3cm across. The grains contain abundant blebs of feldspar and quartz. Orthopyroxene (?) is partially altered to light green amphibole (actinolite ?).

Local concentrations of subhedral-to-irregular garnet preferentially occur at K-feldspar-K-feldspar grain boundaries, or less commonly they rim diopside grains.

The garnets contain abundant, random inclusions of epidote and feldspar.

Epidote and clinozoisite are concentrated at plagioclase, amphibole, and less commonly diopiside grain boundaries and triple points. The finer fractions of some calc-silicate pods are extensively saussuritized. Calcite and locally sphene occur as discontinuous trails of fine grains parallelling compositional layering.

Local pods of calc-silicate within the amphibolitic gneisses and schists are composed of pyroxene, hornblende, microcline, plagioclase, garnet, and local masses of green epidote (see sample 668*). Extensely saussuritized plagioclase fills interstitial spaces between pyroxene and amphibole grains. Pyroxene is usually partially altered to actinolite and/or hornblende. Euhedral garnets averaging .2mm across are locally abundant.

Ultramafic rock (650*)

The ultramafic body exposed near Redman (see Plate 1, 650*) is composed of talc,Fe-rich carbonate (ankerite and/or siderite), anthophyllite and minor chlorite and chromite. Massive, grayish-green, fine-grained talc composes 40% to 90% of the bodies. Very coarse, light green talc fills local fractures throughout the talc bodies. Irregular masses of honey-colored ankerite up to

several centimeters across compose up to 40% of the rock. The patches readily oxidize, giving weathered parts of the talc bodies a spotted "rusty" appearance. Clusters of light greyish-tan anthophyllite neddles up to 1 centimeter long compose approximately 10% of the talc bodies. Rounded meshworks of chromite (± ilmenite or magnetite ?) a few millimeters across appear to be "ghosting" an earlier mineral which has since been replaced by talc, anthophyllite, and/or ankerite.

Actinolite semi-schist (670*, 716)

Most exposures of actinolite semi-schist (metapyroxenite ?) were too weathered to sample for thin section study. Blocky grains of actinolite and/or hornblende a few milimeters across compose 40 to 80% of the rock. Untwinned plagioclase and minor amounts of garnet and epidote compose the rest of the rock.

Chlorite schist/(171)

Exposures of chlorite schists were too weathered to get samples for thin section study. Chlorite schists in the road-cut at the Sweetwater Road-highway 25/70 intersection (Field Station 171) and in a small, mappable body near Redman (Field Station 278) contain abundant euhedral pyrope-almandine garnets up to several

centimeters across. Other chlorite schists exposed along Sweetwater Road do not contain garnets.

Metabasalt porphyry (183*)

The metabasalt porphyry is composed of excellently preserved, 1-2cm euhedral plagioclase "phenocrysts" to slightly more sheared augens. Plagioclase augenp are enclosed in a moderately well-foliated (sheared) amphibolitic groundmass composed of 25% hornblende, 15% biotite, 28% quartz and untwinned plagioclase, and 2% garnet with lesser amounts of sphene, epidote, and opaque oxides (ilmenite or magnetite ?).

Feldspar phenocrysts/augen compose 25 to 30% of the rock. The phenocrysyts/augen are composed of an interlocking mosaic of twinned albite-oligoclase subgrains less than .4mm across. The plagioclase aggregates contain needle-like inclusions of hornblende and small, irregular flakes of biotite. The grain boundaries of most augen are partially recrystallized. Local augen tails are composed of minutely recrystallized feldspar and local quartz.

Subhedral hornblende grains in the groundmass of the rock average <1mm long. Grains are randomly oriented in and define the plane of foliation. The grains contains local inclusions of quartz and feldspar. Thin trails of

minute biotite, sphene and Fe-oxides also define the foliation in the groundmass of the rock.

Small, subhedral, garnet porphyroclasts compose up to 2% of the groundmass. The garnets contain moderate amounts of randomly spaced inclusions.

Contact relationships

As previously mentioned, no mappable stratigraphic order could be developed for the Amphibolitic Basement Complex. Discontinous, gross compositional layering of the complex parallels the dominant northeast-southwest foliation of the area and is interpreted to be tectonic in origin. Contacts of larger amphibolite bodies and marble interlayers with the dominant biotite hornblende granitic gneiss are indistinct. The metabasalt porphyry and quartz feldspar augen schists/semi-schists exposed in the complex often appear to "grade" into the enclosing, intensely foliated mafic gneissic rock over a short interval. The immediately adjacent mafic gneissic rock may in many cases represent a sheared equivalent of the augen schist. The contacts of these lithologies could not be easily discerned in the field. Their disordered state suggests that most are fault bounded and/or at least highly attenuated. Small lenses of amphibolite locally crosscut the foliation of granitic gneisses and are

interpreted to be intrusive. Chlorite lenses often grade into the enclosing mafic gneisses over an interval several tens of meters wide.

Contacts of nonfoliated white mica granite with the enclosing biotite hornblende granitic rock are poorly exposed but appear fairly sharp and are probably intrusive. These granites appear to crosscut the dominant deformational fabrics of the complex. In contrast, small lenses of granodiorite to quartz diorite scattered throughout the complex appear to be wrapped by the dominant deformational fabrics. This suggests they represent plutonic bodies emplaced prior to the major disruption of the complex. The finer-grained "diorite" interlayers display fairly sharp contacts with enclosing well foliated mafic gneissic rock, similarly suggesting they may be intrusive.

The margins of the ultramafic body cropping out near Redman are not exposed but again appear fairly sharp. No zoning or contact aureole was recognized for the body. The lack of intrusive features and discontinuous nature of the body suggest that it was tectonically incorporated into (faulted into) the complex as a solid body of rock rather than a magma. This interpretation is consistant with past work suggesting most ultramafic bodies in the Blue Ridge Province were emplaced as cooled slabs of peridotite (see Misra and Keller, 1978).

Age

Hadley and Nelson (1971) inferred a Proterozoic age for their "layered gneiss and migmatite". Rankin (1975) similarly groups what I refer to as the Amphibolitic Basement Complex with the Grenville-age basement terrane structurally underlying the complex. A single published Rb/Sr whole rock date on a granitic gneiss from Merschat's (1977) study area yeilded an age of 1.2 by for that lithology, similarly suggesting a Grenville-age for at least the widespread granitic gneisses of the complex (Odom and Fullagar, 1984). As discussed later, the complex is intruded by granites and gabbros of correlated with the Late Proterozoic (734-700) Crossnore and Bakersville plutonic suites.

Roberts Mountain Granitic Complex

Introduction

A large, slightly elongate, granitic complex up to 4,000 feet wide is exposed entirely within the Amphibolitic Basement Complex (see Figure 3-page 10, Plate 1). The granitic rocks are referred to as the "Roberts Mountain Granitic Basement Complex" for type exposures in road and railroad cuts at the southwest end

of Roberts Mountain. The most extensive exposures of the complex occur in railroad cuts just east of Redman Dam. The complex was originally recognized by Hadley and Nelson (1971), who correlated it with the granitic basement terrane exposed to the west.

Megascopic Description

Roughly 80% of the Roberts Mountain Complex is composed of light-gray to pinkish-white, massive to intensely sheared, coarse alkaline metagranite. The granite is less mafic and less epidote-rich than the Max Patch Metagranite exposed to the northwest. The majority of the metagranite displays moderately well-developed augen structures. The northwestern margin of the complex is partially composed of locally epidote-rich, light gray, biotite granitic semi-schist and gneiss. A small body of highly weathered, whitish, coarse metagranite to quartz monzonite is exposed in the central portion of the complex. The northeastern part of the complex becomes interlayered with and is soon replaced by biotite granitic gneisses similar to gneisses in the Cranberry Granitic Basement Complex.

Petrography

Hypersthene metagranite (72*, 79*)

The pinkish metagranite forming the major portion of the complex is composed of 40% to 60% pinkish orthoclase and local microcline. Grains average 1 centimeter or less across. 10% to 30% of the rock is composed of whitish gray, twinned albite-to-oligoclase. Plagioclase grains are slightly smaller than potassic feldspar grains. Many of the feldspar augen are recrystallized to smaller, strain free subgrains. Plagioclase grains are locally saussuritized. The groundmass is composed of approximately 10% milky white-to-bluish quartz and finer feldspar. In all samples, quartz grains are strongly ribboned and partially recrystallized. Biotite, chlorite, white mica, and ilmenite-magnetite are minor constituents of the rock. Irregular orthopyroxene grains (hypersthene ?) locally compose 2-3% of the granite.

The foliation in sheared exposures of the metagranite is defined by anastomosing trails of biotite, chlorite, opaques, and local white mica. Thin interlayers of quartz feldspar biotite schists are present in some exposures.

Granitic semi-schist/gneiss (59), epidote granite (62*)

Granitic semi-schists and gneisses are generally quartz monzonite in composition and essentially identical

to granitic gneisses of the Cranberry Basement Complex. An interesting but rare exception is a weakly foliated pinkish white metagranite which contains patchy concentrations of bright green epidote. The epidote appears to be a primary phase rather than a replacement of some mineral.

Contact Relationships

The western margin of the Roberts Mountain Complex is in fault contact with the Amphibolitic Basement Complex. The fault zone is referred to in this study as the "Roberts Mountain Fault". The zone dips steeply to the southeast. As discussed later, the Roberts Mountain Complex is interpreted to represent an upthrown block of the structurally underlying Cranberry-Max Patch basement complex. A more detailed discription of this fault is discussed in the chapter entitled "Structure".

The eastern contact of the complex is difficult to interpret. It is much more irregular than the western contact and appears to be dipping at a shallower angle to the southeast. In exposures along Roberts Mountain Road, the contact is extensively sheared and difficult to pinpoint. Lithologies from both complexes are intermixed over a zone up to one-to-two hundred meters wide. In exposures on the south side of the French Broad River,

the contact appears to be much less sheared and the basement units less intermixed, if mixed at all. This contact may repeat the major contact between the Cranberry Granitic Basement Complex and the Amphibolitic Basement Complex to the northwest.

Age

As discussed later, the Roberts Mountain Complex is correlated to the Cranberry-Max Patch Granitic Basement Complex. All are interpreted to be Middle to Late Proterozoic in age.

Indian Grave Metagranite

Megascopic Description

A linear belt of distinct, coarse pink peralkaline metagranite appears to have intruded across the contact between the two basement complexes (see Figure 3-page 10, Plate 1). Exposures of the granite trend subparallel to the dominant structural trend of the basement complexes. The granite displays various intensities of protomylonitization. Outcrops in the southwestern portion of the belt are especially strongly mylonitized. The granite is in this study referred to as the "Indian Grave

Metagranite", after a type exposure at the intersection of State Highway 25/70 and Indian Grave Gap Road.

Rather than a single continuous body, the metagranite locally contains discontinous interlayers of the enclosing basement complex lithologies. This is best seen in exposures in Walnut Creek, where it is interlayered with the Amphibolitic Basement Complex (Figure 4). Interlayers of the Amphibolitic Basement Complex range from a few meters to a hundreds meters in width. To the southwest, the metagranite is interlayered with the Amphibolitic Basement Complex and the Cranberry basement only along its outermost margins. An apparent xenolith of highly epidotized quartz feldspar biotite complex is exposed in a large float block of Indian Grave Granite in Walnut Creek (Field Station 749, Figure 5).

Petrography (166*)

60% of the Indian Grave Granite is comprised of very coarse, pinkish orthoclase and microcline feldspar. Augen average 8mm across but range in size up to 3cm. Locally perthitic orthoclase comprises the major portion of the potassic feldspar. Whitish-gray plagioclase (albite-oligoclase) grains comprise approximately 5% of the granite. Plagioclase grains rarely exceed a few milimeters across. Feldspar augen commonly display

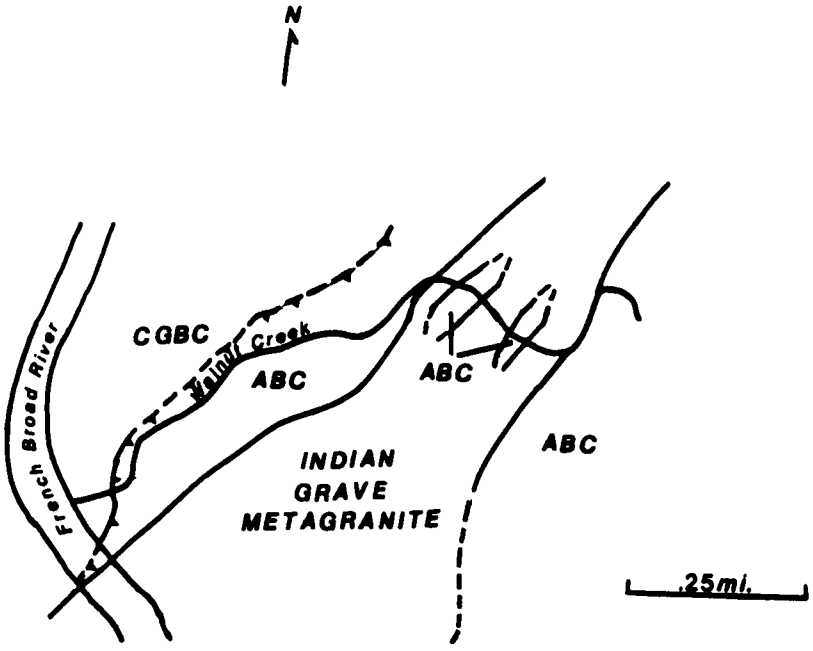


Figure 4. Partial geologic map of study area showing interlayered nature of Indian Grave Metagranite in Walnut Creek area. Amphibolitic Basement Complex (ABC); Cranberry Granitic Basement Complex (CGBC).

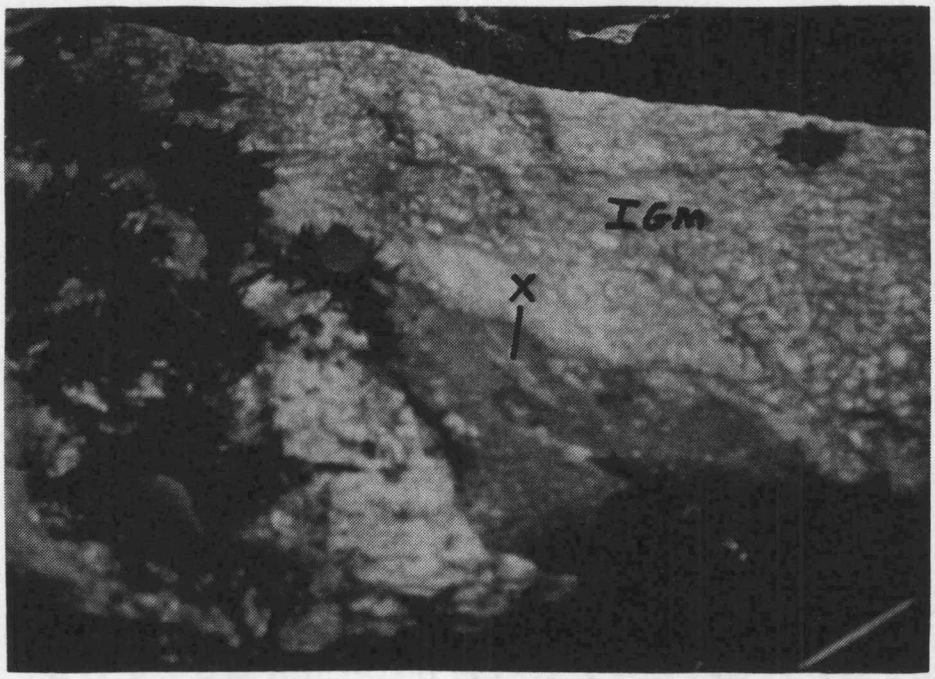


Figure 5. Xenolith (X) of Amphibolitic Basement Complex in float block of Indian Grave Metagranite (IGM), from Walnut Creek. Xenolith is a quartz feldspar biotite semischist similar to the Amphibolitic Basement lithologies bordering the metagranite.

well-developed tails of minutely recrystallized feldspar and local quartz. In less deformed samples, feldspar augens display little internal strain. Smaller augens generally do not display tail structures.

Quartz comprises 5 to 10% of the rock. In all samples of the granite, quartz is deformed into very elongate, undulose ribbons up to several millimeters long. Individual ribbons are bounded by narrow microshear zones of ultramylonite. Quartz ribbons wrap around feldspar augen and define the foliation in the granite. Some ribbons are partially recrystallized to subgrains averaging .1mm across.

Very fine grains of biotite comprise less than 5% of the granite. Biotite is concentrated in the finer parts of the feldspar augen tails and in microshears wrapping around the feldspar augens and defining the foliation in the granite.

White mica comprises less than 2% of the granite. Large augen of white mica are commonly concentrated above the hindward tails of feldspar augens. Most grains are deformed into broad open folds and partially recrystallized along their leading and trailing edges.

10 to 15% of the least sheared samples of the granite are comprised of microshear zones dissecting the rock. The zones are comprised of minutely recrystallized, ultramylonitic trails of quartz, feldspar, epidote,

biotite, white mica, and sphene. These microshears thicken as they wrap around and isolate individual feldspar grains or clumps of grains. Feldspar augen tails commomly merge into single, continous microshear zones. The glides zones are marked by the secondary growth of biotite ± white mica.

Small, blocky opaque oxide (ilmenite or magnetite ?) grains comprise less than 1% of the granite. Rutile and flourite (?) are common accessory minerals.

A single apparent xenolith of quartz feldspar biotite semi-schist was found in the Indian Grave Granite (sample 749*). The clast is highly epidotized. Other than this intense epidotization, the clast is lithologically identical to the bulk of the mafic Amphibolitic Basement lithologies intermixed with the granite in that area.

Contact Relationships

The Indian Grave Metagranite is interpreted to have intruded both the Amphibolitic Basement Complex and the Cranberry Granitic Basement Complex. The contacts of the Indian Grave Metagranite with the surrounding basement complexes are only exposed in Walnut Creek. As is characteristic of the entire study area, a late mylonitic overprint which affected all units in the study area makes any contact relationships difficult to interpret.

The xenolith exposed in Walnut Creek supports an intrusive relationship with the Amphibolitic Basement Complex. Discontinuous, scattered lenses of granitic rock similar to the Indian Grave Metagranite occur along the margins of the main belt of metagranite (see Plate 1). In Walnut Creek, the contacts of metagranite interlayers appear to be sharp with the more strongly deformed lithologies of the Amphibolitic Basement Complex. Mylonitization intensity does not dramatically increase at the contacts with the surrounding rock, as would be expected if the granite were faulted into the basement complex.

Larger exposures of the complex on the south side of the French Broad River do not appear to be as internally disrupted as the two basement complexes on either side of the exposure. The metagranite in this area is bounded to the northwest and possibly the southeast by granitic gneisses of the Cranberry Basement. A few small scattered lenses of what appears to be Indian Grave Metagranite are exposed to the northwest of the main contact. Exposure on the southeast side of the metagranite body are too poor to determine for certain that the gneisses do indeed belong to the Cranberry Basement. Due to the apparent absence of amphibolite in these rocks and the sudden appearance of amphibolite to the east, however, I feel fairly confident in mapping the Indian Grave Metagranite

in this area as lying completely within the Cranberry Basement. In turn I interpret the metagranite as having intruded across the contact between the Amphibolitic Basement and the Cranberry Basement.

Age

The Indian Grave Granite is in this study correlated with the Late Proterozoic Crossnore Plutonic Suite of the Blue Ridge Province. The granite is texturally and petrographically identical to the very distinct coarse, pinkish, Beech Granite of the Crossnore Suite. The age of the Beech Granite has been previously established at 700my (Odom and Fullagar, 1984). Crossnore granites are known to intrude the Cranberry Basement (Elk River Massif) to the north of the study area (see Bryant and Reed, 1970; Bartholomew and Lewis, 1984). Prior to this study, however, they had not been recognized as intruding the Amphibolitic Basement Complex.

Bakersville Metagabbro And (?) Metapyroxenite

Introduction

Widespread gabbroic intrusions in the basement terrane of the Blue Ridge are collectively referred to as

the Bakersville Intrusive Suite (Bryant and Reed, 1970; Rankin, 1975; Burton, 1977). The gabbroic rocks are present as narrow dikes or scattered, irregular bodies.

Bryant and Reed (1970) and Merschat (1977) mapped gabbroic intrusions that they correlated with the Bakersville Metagabbro as intruding both their respective "mixed rock unit" and "biotite hornblende migmatite" complexes (this study's Amphibolitic Basement Complex) and the Cranberry Granitic Basement Complex. Geochemical data and field observations by Goldberg and others (1986) support the intrusion of Bakersville Metagabbro in both basement complexes. Neither Bryant and Reed nor Merschat, however, mapped Crossnore Granitic Suite lithologies as intruding the Amphibolitic Basement Complex. If the Bakersville and Crossnore suites are related to the same tectonic event as Rankin (1975) suggested, the Crossnore Suite should also be found to intrude the Amphibolitic Basement Complex. This is, in fact, the probable case in the study area as discussed under "Indian Grave Metagranite".

Distribution/Description

A few scattered, nonfoliated, dike-like to irregular bodies of dark green to greenish-brown metagabbro, metapyroxenite and metadiabase are exposed in the

Cranberry and Amphibolitic basement complexes (see Figure 3-page 10, Plate 1, field stations 14,18,153,340b,667). All of the mafic bodies are altered to actinolite semi-schists. As discussed in Chapter 3, geochemically, these rocks are metagabbros and metapyroxenites. Geochemical data and field observations further support the interpretation of at least the metagabbro bodies as Bakersville equivalent (see Chapter 3). None of these bodies can be trace beyond single exposures and none appeared to be more than a ten to twenty meters wide.

In the Cranberry Basement Complex, lenses of dark green, dense metapyroxenite are poorly exposed in railroad-cuts just west of Walnut Creek (sample 18*). Pods of dense, massive metapyroxenite are locally enclosed in thin rinds of coarsely crystalline granitic material. A small lense of metagabbro is exposed in railroad cuts just west of the actinolite semi-schist to the west of Walnut Creek (sample 14*). A lense of metagabbro is exposed in roadcuts by Highway 25/70 just east of the community of Walnut (sample 153*). The rock is moderately mylonitized. Samples from this exposure were not analyzed but were petrographically identical to the metagabbro exposed in railroad cuts.

A dike-like body of very weakly foliated, dark green, metagabbro was briefly exposed during road work in the Amphibolitic Basement Complex at the intersection of

Sweetwater Road and Highway 25/70 (sample 340b). The lense crosscuts the dominant structural fabrics of the enclosing, complexly deformed biotite hornblende granitic gneiss and amphibolite. Unfortunately, continued work on the road soon covered a large part of the exposure. In hand sample, the rock is lithologically identical to the metagabbro lense exposed in railroad-cuts through the Cranberry Basement (sample 14*). A body of dark green, dense, metagabbro is exposed at the base of a roadcut on State Road 1114 Road (sample 667*). The contact relationships of this body could not be determined due to limited exposure.

A single 4 to 5 meter wide, dike-like body of metadiabase (sample 674*) exposed in cuts on State Road 1114 appears to truncate the complex fabrics in the enclosing gneissic rocks. The poorly exposed body was moderately weathered and not sampled for geochemical analysis. The relationship of the metadiabase with the metapyroxenites and metagabbros is uncertain.

Petrography

Metagabbro (14*, 153*, 344b, 667*(?))

The metagabbro sample from the railroad cuts in the Cranberry exposure is composed of 40% coarse actinolite (and hornblende ?) in a groundmass of small, twinned

plagioclase (andesine) subgrains and minor biotite, and opaque oxide (ilmenite or magnetite). >80% of the metagabbro sample from the Amphibolitic Basement complex is comprised of blocky actinolite grains averaging 1-3mm across. Many grains contain numerous blebs of untwinned plagioclase and quartz. Plagioclase and quartz comprises the interstitial material between amphibole grains. Plagioclase and quartz grains are noticeably less strained than feldspar and quartz grains in the enclosing rocks. Coarse biotite flakes up to several millimeters across comprise <1% of the metagabbro. Zircon inclusions are very common in the biotite.

Metapyroxenite (18a*, 18b*)

85 to 95% of metapyroxenites are comprised of light-to-dark green, coarse blocky grains of actinolite. In some of the coarser samples of the rock, blocky grains of actinolite averaged 5 to 10mm across. Moderately pleiochroic actinolite (and/or hornblende ?) often display slightly less pleiochroic rims of the same material.

Coarse, bronze colored flakes of biotite comprise an average of 8% of the metapyroxenites. Irregular to subhedral grains often rim actinolite grains. Very thin sheets of biotite are typically intergrown on cleavage

partings in actinolite grains. Clinozoisite is locally present as scattered grains through the rock.

Metadiabase (674*)

Twinned plagioclase (oligoclase-andesine) comprises 60% of the metadiabase. Local grains display a weak, possibly relict, poikolitic texture. Individual grains are irregular and recrystallized into subgrains less than .1mm across.

Light-green, elongate-to-blocky actinolite grains up to .5mm long comprise 20% of the rock and display a weak interlocking texture. The amphibole grains are intensely embayed by plagioclase and locally altered to chlorite. Weathered, blocky orthopyroxene (?) grains comprise 5% of the rock. Several pyroxene grains appear to have been completely replaced by actinolite.

Epidote and clinozoisite grains comprise 1-2% of the rock and are scattered throughout the finer-grained plagioclase-rich groundmass. Minor sphene overprints alteration fabrics in the rock. Rutile is present in trace amounts.

Contact Relationships

Where exposed, margins of the above described mafic bodies are in sharp contact with the adjacent gneissic

rocks of the two basement complexes. Dike-like bodies locally crosscut the complex structural fabrics of enclosing rocks. Even where contacts are not exposed, the mafic bodies do not display the complex internal deformation characteristic of the enclosing basement units. Like the Indian Grave Metagranite (Crossnore ?), these relationships suggest that the intrusion of the bodies-dikes postdated the dominant deformation of the Cranberry and Amphibolitic basement complexes. Thin granitic rinds surrounding pods of metapyroxenite in exposures in the Cranberry Basement may represent partial melts of the immediately adjacent granitic gneiss. The relationships of the metapyroxenite bodies to the metagabbro bodies is uncertain.

Age

The metagabbro and possibly the metapyroxenite and metadiabase bodies exposed in the field area are correlated with the Bakersville Gabbroic Intrusive Suite. The correlation of the metagabbros with Bakersville is supported by geochemical data discussed in the following chapter. The age of the Bakersville suite has recently been established at 734my (Goldberg and others, 1985).The intrusions of the Crossnore and Bakersville plutonic suites have been inferred to be related to crustal

thinning associated with the Late Proterozoic opening of the Proto-Atlantic (see Bryant and Reed, 1970; Rankin, 1975).

CHAPTER 3

GEOCHEMICAL ANALYSES

Although not a main topic of this study, geochemical analyses of the amphibolites in the study area can potentially be useful in interpreting the protolith of the Amphibolitic Basement Complex. Prior to this study, no such investigation had been made for the complex. 10 amphibolites, 1 talc-rich ultramafic rock, 1 actinolite (± hornblende) semi-schist, and 4 potential Bakersville equivalent metagabbro and metapyroxenite samples were analyzed. The results of the analyses are given in Appendix A. Representative analyses of each rock type are given in Table 1. Metamorphism may have slightly altered the original chemistry of the rocks. These data are not meant neccessarily to characterize the Amphibolitic Basement Complex as a whole but are merely a beginning of the geochemical study of the complex.

The locally recognized intrusive nature of the amphibolite and apparent major lack of intermixed aluminous metasedimentary rocks strongly support a basaltic protolith for the rock. Variation diagrams plotting Ti, Zr, and Y vs MgO/MgO + FeO suggest an igneous trend for the amphibolites (Figure 6). A number

TABLE 1. Representative whole rock XRF analyses of selected samples (oxides in wt%, elements in ppm). Amphibolite (702b); talc-rich ultramafic rock (650); actinolite semi-schist (716); Bakersville metagabbro (14); metapyroxenite (18a).

	702b	650	716	14	18a
Na_2O	3.44	0.35	1.07	3.41	1.14
MgO	4.93	28.00	11.76	5.46	14.88
Al_2O_3	14.41	2.48	6.56	14.53	6.31
SiO_2	46.17	52.17	50.74	49.73	50.83
P_2O_5	0.81	0.07	0.22	0.46	0.18
K_2O	0.63	0.08	0.58	0.87	1.77
CaO	9.41	0.02	12.20	7.91	10.95
MnO	0.18	0.13	0.29	0.19	0.35
Fe_2O_3*	17.56	7.53	14.48	13.81	11.29
TiO_2	3.58	0.01	0.61	2.39	0.51
V	210.00	17.00	355.00	215.00	274.00
Cr	165.00	1954.00	2640.00	153.00	2876.00
Ni	47.00	1568.00	551.00	44.00	221.00
Rb	10.00	3.00	9.00	25.00	78.00
Sr	209.00	21.00	48.00	295.00	35.00
Y	31.00	9.00	138.00	31.00	29.00
Zr	167.00	23.00	60.00	124.00	36.00
Nb	28.00	1.00	13.00	15.00	8.00
Total	101.21	91.19	98.89	98.85	98.57

*includes total Fe-oxide.

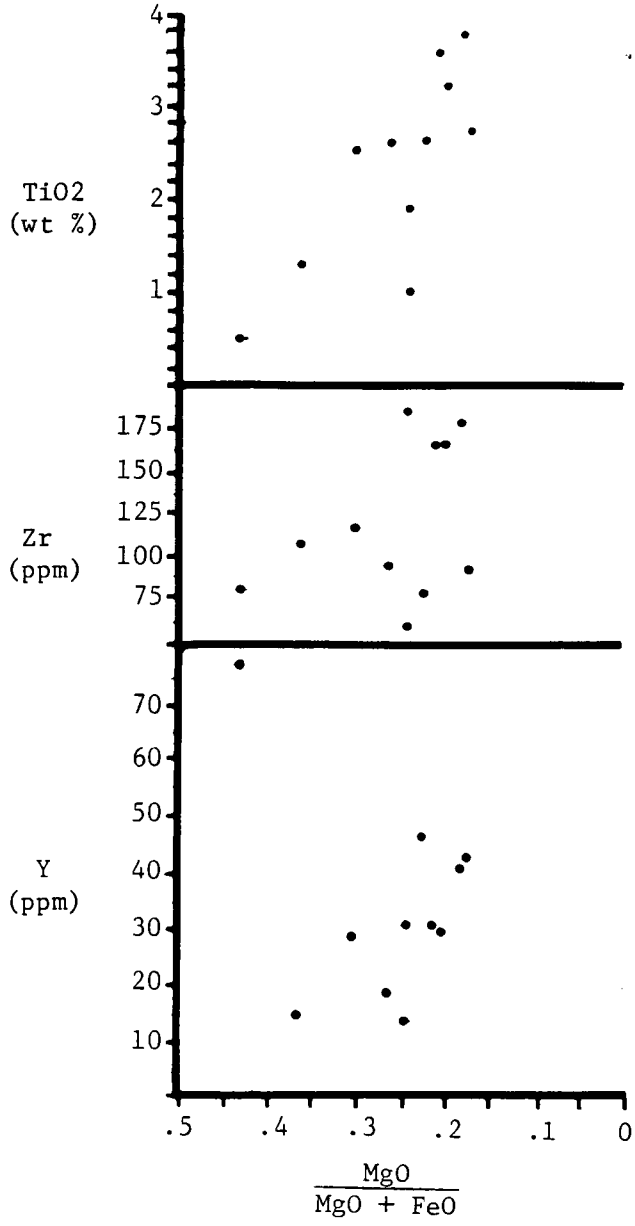


Figure 6. Variation diagrams of Ti, Zr, and Y plotted against MgO/FeO + MgO. FeO includes Fe^{+2} and Fe^{+2}. Plots suggest a general igneous trend.

of discriminant diagrams were developed to aid in distinguishing the tectonic setting of various types of basalts by Irvine and Barager (1971), Pearce and Cann (1973), Pearce and Norry (1979), and Shervais (1982). These diagrams have recently been applied to amphibolites in the Ashe Metamorphic Suite of the North Carolina Blue Ridge (Conte, 1986). Due to the uncertain metamorphic history of the complex, the discriminant diagram chosen for this study utilizes the presumably immobile trace elements Ti, Zr, and Y.

Geochemically, the amphibolites are tholeiitic (Figure 7). The discriminant diagram by Pearce and Cann (1973) plotting Ti/100-Zr-Y*3 suggests that seven of the ten amphibolites analyzed represent within-plate basalts (Figure 8). Two of the remaining samples fall in the field denoting tholeiitic volcanic arc basalts. Pearce and Cann define within-plate basalts as basalts which may have formed in either a continental setting or an ocean island (hot spot) setting not associated with MOR or island arc activity. Pearce and Cann were unable to chemically distinguish between ocean island basalts and continental basalts. The locally observed intrusive nature of hornblende amphibolites with enclosing biotite granitic gneiss and the abundance of probable Grenville-age granitic country rock within the Amphibolitic Basement Complex suggests a continental

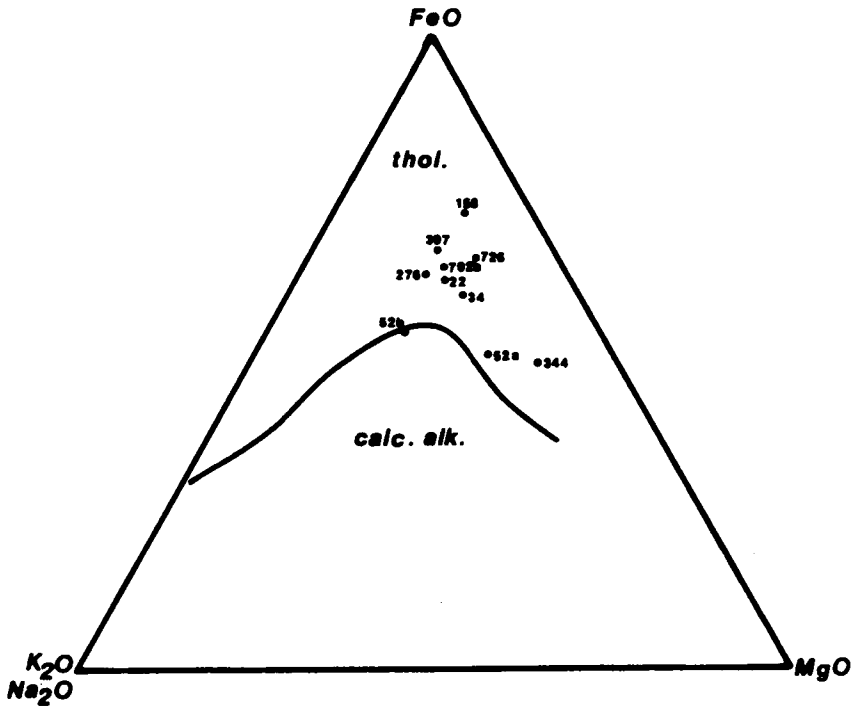


Figure 7. AFM plot showing tholeiitic nature of amphibolites. thol = tholeiites; calc-alk. = clc-alkaline. Tholeiite - calc-alkaline boundary after Irvine and Barager (1971).

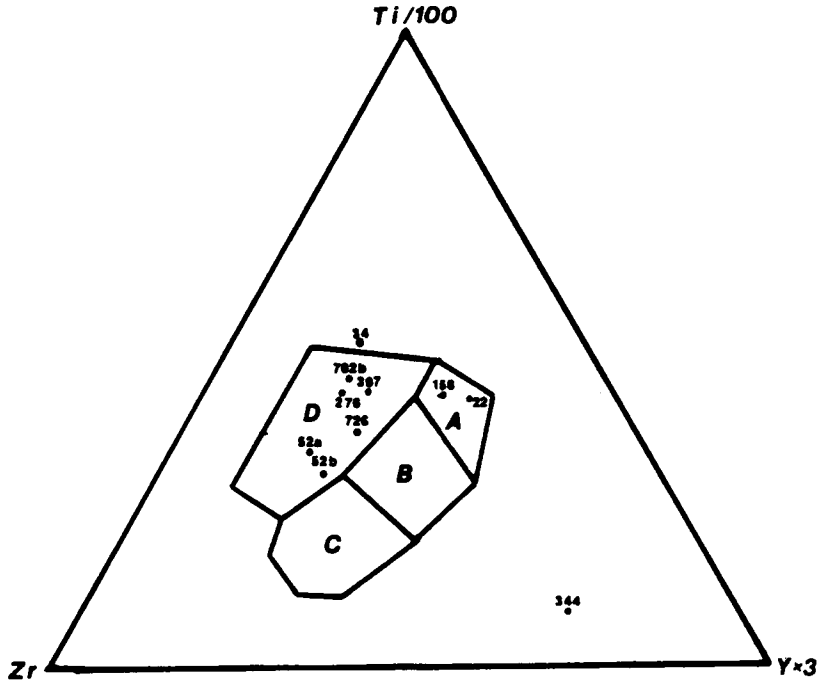


Figure 8. Ti/100 - Zr - Y*3 discrimination diagram showing distribution of amphibolite samples from study area (after Pearce and Cann, 1973). A = low potassium tholeiites (volcanic arc basalts); B = ocean floor and volcanic arc basalts; C = calc-alkaline basalts (volcanic arc basalts); D = within-plate basalts (ocean island or continental basalts).

rather than an ocean floor setting for the intrusion of the tholeiitic basalts.

A single sample from the talc-rich ultramafic body exposed near the community of Redman was also analyzed by X-ray fluorescence. High Cr and Ni values for the sample suggests that the rock is of igneous rather than sedimentary origin (see Table 1) and bulk chemistry suggest that the rock may represent a peridotite (Nockolds and others, 1979). Other talc-rich ultramafic bodies in the Blue Ridge of North Carolina have likewise been interpreted to represent highly altered blocks of lower crustal peridotite (Bohanan, 1975; Misra and Keller, 1978). Bohanan (1975) conducted several geochemical analysis on talc-rich "soapstone" ultramafic bodies in the central Blue Ridge of North Carolina, including at least two which probably lie within the Amphibolitic Basement Complex. As in this study, Bohanan concluded that the ultramafic bodies represent altered ultramafic plutonic rocks.

Small lenses and pods of massive actinolite (± hornblende) semi-schist enclosed within the complexly deformed amphibolitic rocks of the Amphibolitic Basement Complex geochemically represent metapyroxenites (e.g. sample 716) (see Table 1). Small lenses of metapyroxenite such as this are interpreted to represent blocks of lower

crustal material of similar origin as the talc-rich ultramafic bodies (see Misra and Keller, 1978).

Analyses of dike-like bodies of massive actinolite amphibolite interpreted potentially to be Bakersville equivalents suggest that two of the samples (both from same body) represent metapyroxenites (18a, 18b) and two represent metagabbros (14, 667) (Nockolds and others 1979). Again, post-emplacement metamorphism may have slightly altered the original chemistry of the rock. Geochemically, sample 14 is very similar to Bakersville metagabbro samples analyzed by Goldberg and others (1986). The correlation of the metagabbro sample #667 with the Bakersville is less clear. Metapyroxenite samples do not match the geochemistry of the Bakersville dikes. This suggests either: 1) they were derived from a different parental magma during the same event or 2) they are not associated with the same intrusive event.

CHAPTER 4

STRUCTURE

The interpretation of multiply deformed terranes, such as the basement complexes exposed in the Blue Ridge of North Carolina, can be difficult. It is vital in studying such complex terranes to establish a relative sequence of deformational events for the area based on the correlation of structural features between exposures (Williams, 1985). Once this sequence has been established, relative and absolute dating techniques can be incorporated to place the deformational events onto a geologic time scale. In areas of poor exposure such as in this study, mesoscopic-scale overprinting features are especially important.

Megascopic Structure

Regional Trends

Regional foliation, crude compositional layering, and major faults consistently trend northeast-southwest and dip steeply to the southeast in the study area (see Plate 1). No progressive megascopic changes in foliation trends

were observed across the area. In many exposures, foliations and lithologic layering were so chaotically variable that an "average" foliation for that exposure had to be recorded. Attempts to correlate these chaotically disturbed zones during mapping were largely unsuccessful because of their apparent sporadic nature and/or a lack of sufficient exposure.

Folds

No map scale folds were discernable within the basement complexes. As shown in larger scale studies, the Rector Branch Fault is folded by underlying duplexing/imbrication associated with the Hot Springs Window area (Witherspoon, 1981; Woodward, 1985). The folding of the Rector Branch was not a topic of this study. Readers are refered to the work of Oriel (1950, 1951) among others for detailed studies on the Hot Springs Window.

Megascopic folds may well be present in the basement complexes. Such folding, however, would be difficult to detect because of the internal complexity of the Amphibolitic Basement and the overall lack of contrasting lithologies in the Cranberry Basement (i.e. there are no good marker beds). Attempts to recognize megascopic fold generations utilizing stereonet plots of foliations are

inconclusive because of: 1) the common high variability of foliation attitudes within single exposures, 2) the complex overprinting of several generations of foliations, and 3) the absence of recognizable megascopic features in the field.

Major Faults

Rector Branch Fault

The trace of the Rector Branch Fault was used as the northwest boundary of the study area (see Figure 3, page 10, Plate 1). The fault places Max Patch and Cranberry Basement rocks over fine-grained clastics of the Sandsuck Formation of the Ocoee Series. This study concentrates soley on work in the overlying crystalline basement. The best exposure of the fault is in railroad cuts just northwest of the community of Barnard (Figure 9). Between the communities of Barnard and Walnut and south of the French Broad River the Rector Branch Fault dips 40 to 70 degrees to the southeast. Mapping of the fault by the North Carolina Geological Survey suggests that the fault plane is almost horizontal in the bed of the French Broad River (L. Weiner, personal communication). Water levels were too high during field mapping to recheck this observation.

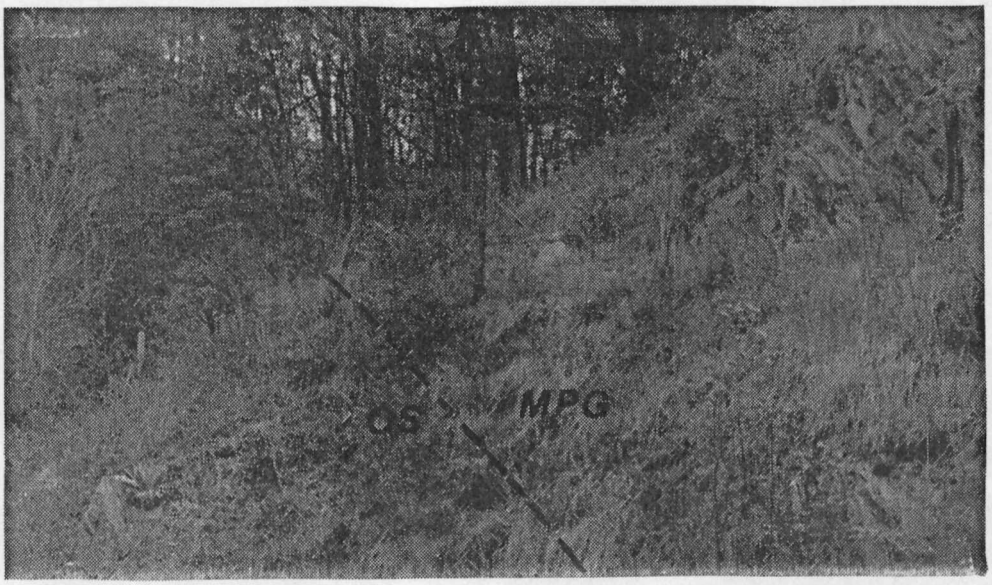


Figure 9. Railroad cut exposure of Rector Branch Fault just northwest of Barnard (Field Station 2). Max Patch Metagranite (MPG); Sandsuck Formation, Ocoee Series (OS). Both lithologies are ultramylonitized within a few tens of meters of the fault contact. Fault denoted by dashed line.

The age the Rector Branch is poorly constrained but cannot be older than Cambrian because it deforms Cambrian Honaker Formation in the Hot Springs Window area (see Oriel 1950, 1951). The fault is in turn folded by footwall duplexing associated with the Alleghanian development of the Valley and Ridge thrust belt (see Oriel, 1950, 1951; Witherspoon, 1981). For specific detailed work describing the deformation of the Ocoee metasediments in the footwall of the fault, readers are refered to Oriel's work.

A well defined, intense ductile shear zone is associated with the Rector Branch Fault (see Figure 3, page 10, Plate 1). The majority of the deformation is restricted to the overlying crystalline basement complexes. The main mylonite zone extends approximately 1,000 meters to the southeast of the trace of the Rector Branch Fault. A late, very widespread, mylonitic overprint of the basement complexes was also noted by Merschat (personal communication) east of the study. The emplacement of the Rector Branch Fault appears to have been the last major recognized mylonitization event to effect the basement rocks. This and the observation that the mylonites associated with the overprint roughly parallel the fault suggests that the overprint is related to the emplacement of the Rector Branch. Deformation associated with the emplacement of the Rector Branch

Fault can be divided into three zones (southeast to northwest) (Figure 10):

1) a widely spaced but locally intense mylonitic overprint developed throughout the remainder of the study area,
2) a 700 to 1000 meter wide zone of anastomosing proto- to ultramylonite enclosing scattered, relatively undeformed lenses of granitic rock,
3) a 10 to 20 meter thick zone of ultramylonite at the Ocoee-Max Patch/Cranberry contact.

This generalized scheme is complicated by the presence of major imbricates off of the Rector Branch Fault which duplicate and thicken parts of the main mylonite zone.

Both the basement rock and the Ocoee metasediments are ultramylonitized within 10 meters of the trace of the fault. Where Cranberry granitic gneiss is directly thrust over the Sandsuck metasedimentary rocks, the distinction between the respective ultramylonites is difficult to make and the fault trace was approximated within a zone a few tens of meters wide.

Several southeastward dipping faults, probably imbricates off the Rector Branch Fault, are mappable within the outer mylonite zone of the fault (see Figure 3, page 10 and Plate 1). The fault splays are marked by zones of intense ultramylonites trending parallel to the

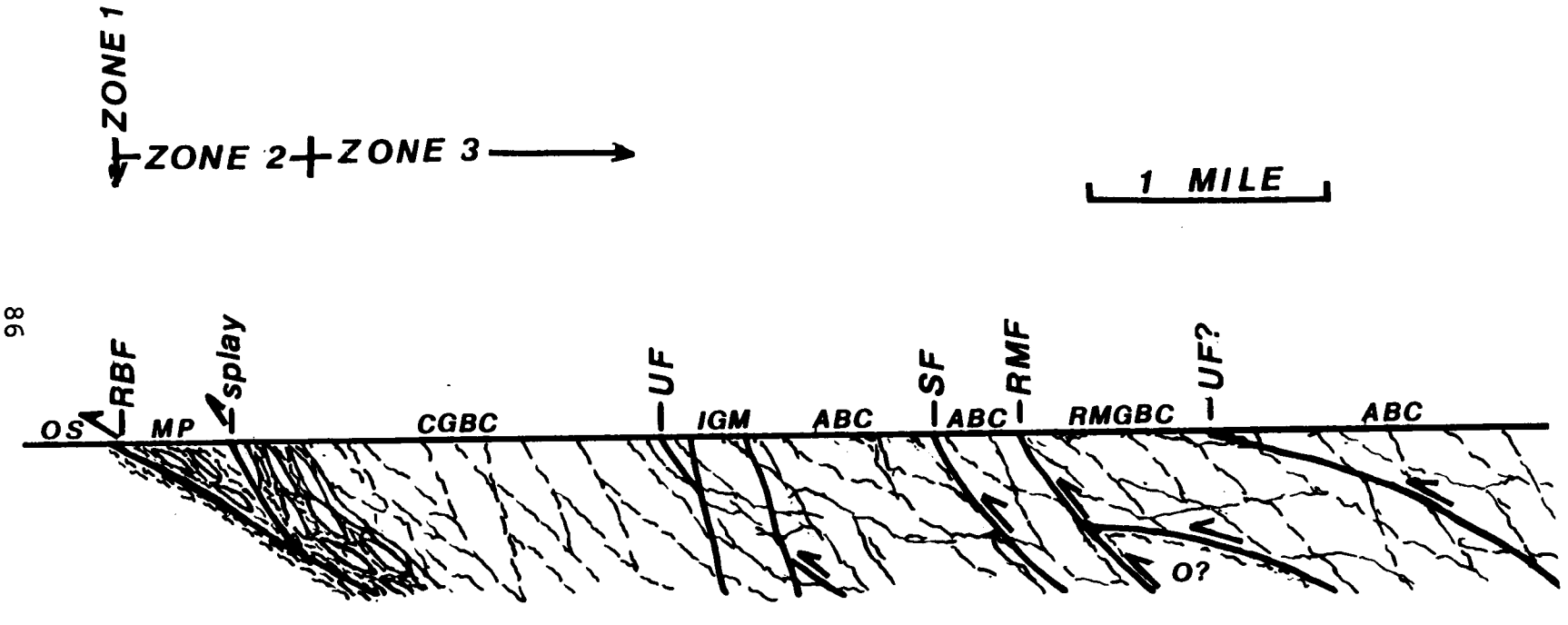


Figure 10. Schematic cross-section of study area showing three zones of Rector Branch Ductile Shear Zone (see text for discussion). Rector Branch Fault (RBF); unamed fault (UF); Sweetwater Fault (SF); Roberts Mountain Fault (RMF). Lithologic unit abbreviations same as for Figure 3 (see page 10).

trace of the Rector Branch Fault. A major imbricate diverges from the main Rector Branch ultramylonite zone just northwest of the community of Walnut. The splay is traceable to the Barnard area where it apparently divides into at least three separate branches. This system of faults could not be traced farther to the southwest due to poor exposure.

A very odd, sedimentary-looking rock is locally exposed in the hanging walls of these splays (see Figure 3, page 10, Plate 1). The rocks display coarse, "clastic" textures to ultramylonitic textures and are very distinct from the enclosing Cranberry lithologies. The rocks are tentatively interpreted to represent horses of Ocoee sediments incorporated into the Cranberry Complex during imbrication associated with the emplacement of the Rector Branch Fault. Less deformed samples of the rock could be interpreted as very coarse-grained, plagioclase-rich feldspathic arenites. Angular garnet fragments within these rocks are not common to the Cranberry. Ultramylonitic exposures on the southwest side of the French Broad River at Barnard are more siliceous than typical Cranberry mylonites and contain local microscopic vein fillings of calcite, also not typical of the Cranberry (Figure 11). These ultramylonites most closely resemble Ocoee ultramylonites observed directly beneath the Rector Branch Fault.



Figure 11. Roadcut exposure of a possible horse of ultramylonitized Ocoee (Field Station 593). This is one of several lenses exposed in a system of imbricate faults within the main Rector Branch mylonite zone (see Figure 3, page 10).

LANCASTER BOND
100% COTTON FIBER

This same zone of Ocoee-like rocks within the western margin of the Cranberry Complex was also noted by Keith (1904) and Oriel (1950). Keith interpreted them as tight synclines of Sandsuck metasedimentary rocks within the basement rocks. Oriel disagreed with the idea of tight synclines and dismissed the rocks as an odd lithology of the basement. My views are closer to the original views of Keith with the alternate explanation that the rocks represent horses of Ocoee incorporated into the basement mylonite zone by imbricate faulting rather than by folding.

Amphibolitic Basement/Cranberry Granitic Basement contact

There is no easily defined deformation zone separating the Amphibolitic Basement from the underlying Cranberry Granitic Basement. The contact between the two basement complexes is marked by the distinct, widespread appearance of complexly interlayered and intermixed amphibolite, scattered ultramafic bodies, and other lithologies previosly described as characteristic of the Amphibolitic Basement (see Figure 3, page 10, Plate 1). In the only other detailed mapping of the contact, Merschat (1977) shows amphibolite lenses and mylonite zones truncated at the contact. Based on this relationship and the dominant restriction of amphibolite and ultramafic bodies to the Amphibolitic Basement

Complex, the contact between the Amphibolitic Basement Complex and the structurally underlying Cranberry Granitic Basement Complex is interpreted to be a fault. The minimum age of major movement along the fault is constrained to Late Proterozoic by the apparent intrusion of the Crossnore Group-Indian Grave Metagranite across the contact and the general intrusion of Bakersville and Crossnore plutonic suites into both complexes (see also Bryant and Reed, 1970; Merschat, 1977; Goldberg, 1986).

The westward limit of ultramafic bodies shown on a regional map compiled by Larabee (1966) matches quite well with the contact between the basement complexes established in the study area. Prior to my field based adjustment, Hadley and Nelson's (1971) regional mapping appeared to place ultramafic bodies within the Cranberry Basement. This posed a misleading problem in interpretating the origin of the ultramafic rock with respect to the Cranberry Basement.

Minor Faults

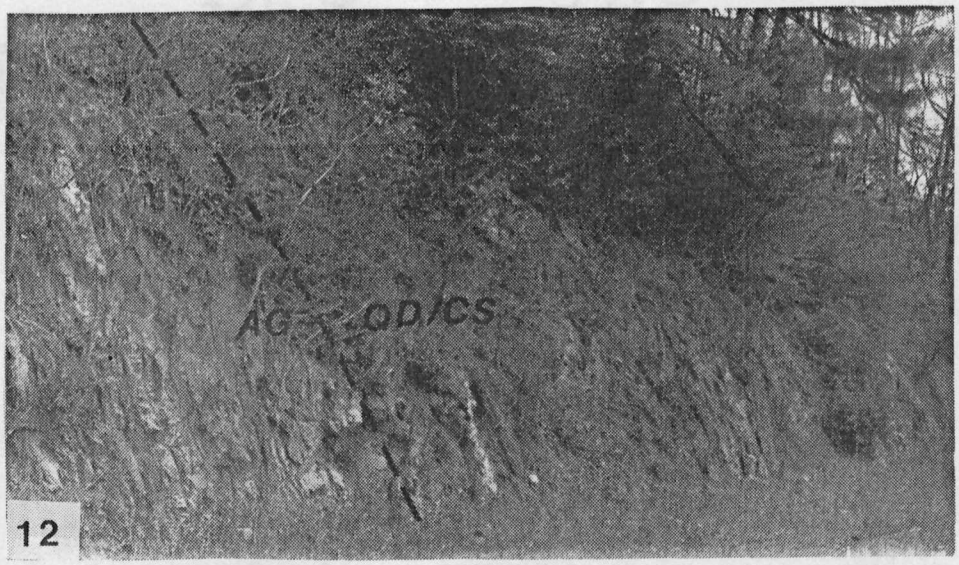
Introduction

Three mappable high-angle reverse faults are exposed in the two basement complexes (Figures 12-14 ,see Figure 3, page 10, Plate 1). The faults parallel the trend of the Rector Branch Fault mylonites. These mappable faults

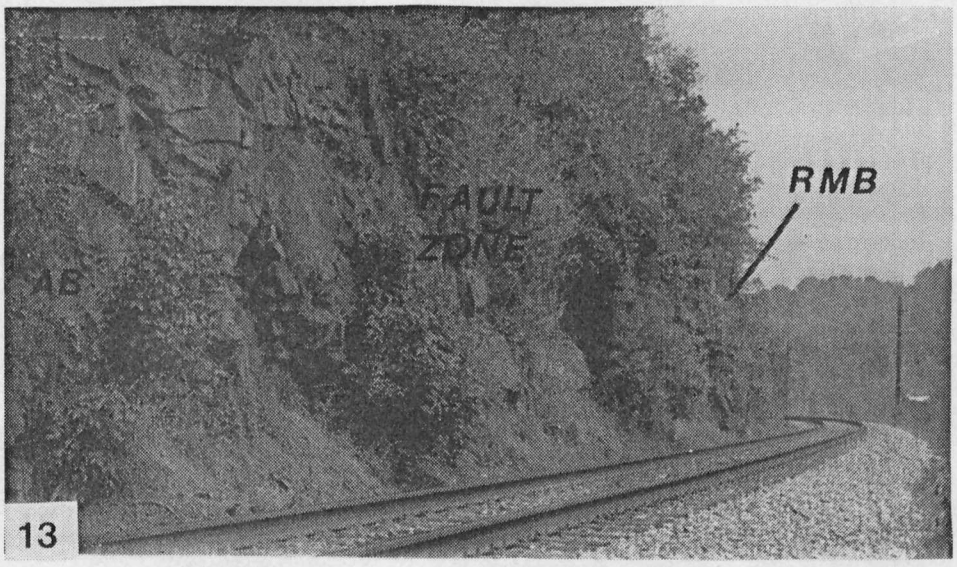
Figure 12. Roadcut exposure of the Brush Creek Fault (Field Station 727). Fault is marked by a 30-40 meter wide zone of strongly deformed, epidotized, actinolite-rich, calc-silicate and granitic rock (CSG). Amphibolitic gneiss (AB); quartz diorite (QD).

Figure 13. Railroad cut exposure of Roberts Mountain Fault (field stations 60 and 61). Fault zone is marked by 100 + meter wide zone of intensely disrupted, Amphibolitic Basement (AB) and Roberts Mountain Basement (RMB) lithologies.

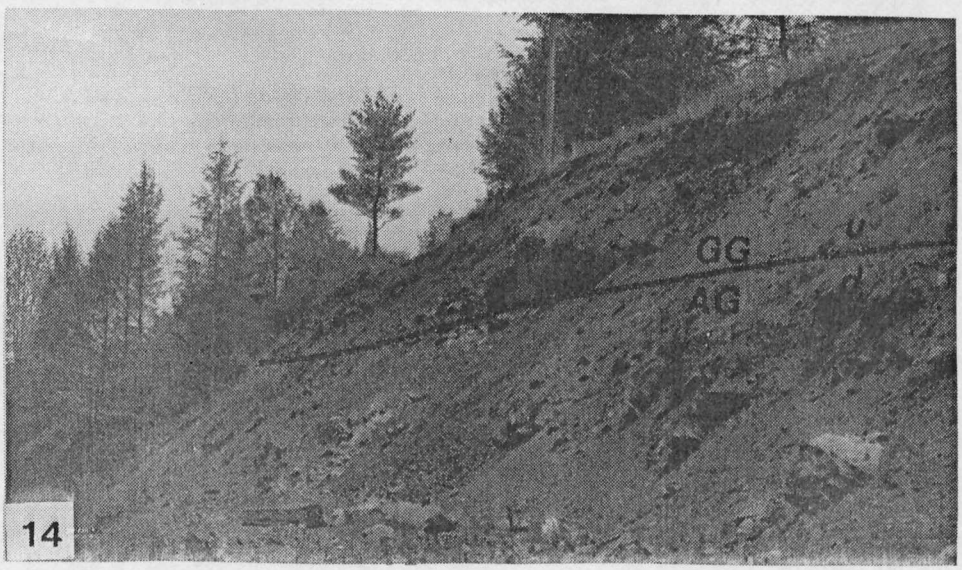
Figure 14. Roadcut exposure of Sweetwater Fault (solid line) (Field Station 345). At this locality the fault places granitic gneissic rock (GG) over amphibolite and amphibolitic gneisses.



12



13



14

and other zones of intense, late, ductile shearing variably developed throughout both complexes are interpretated to be related to the emplacement of the Rector Branch Fault and/or later deformation associated with folding of the fault. Extensive fault zones such as these would likely be very common in good exposures of both complexes but are difficult to detect due to poor exposure and a lack of good marker horizons.

Brush Creek Fault

The large quartz diorite body exposed in the eastern corner of the Cranberry Complex is at least locally bounded to the west by a 30 to 50 meter wide fault zone dipping steeply to the southeast. This fault is herein referred to as the "Brush Creek Fault" (see Figure 3, page 10, Plate 1). The best exposure of the Brush Creek Fault is in a roadcut .5 miles northwest of the intersection of Brush Creek Road and Highway 25/70 (see Figure 12). The fault zone is marked by lenses and pods of intensely epidotized, actinolite-rich calc-silicate chaotically intermixed with quartz diorite and granitic gneiss protomylonites. As described earlier under "Major Lithologic Units", parts of the calc-silicate lenses are mineralogically very similar to the overlying quartz diorite. The calc-silicate zone is traceable a short distance to the south to the presumed southern extent of

the quartz diorite body. Beyond this point exposure is too poor and lithologic contrasts too small to trace the fault zone into the Cranberry granitic gneisses.

The amphibolitic gneisses exposed just below (to the west of) the Brush Creek Fault may originally have been a extension of the Amphibolitic Basement onto the Cranberry Basement. Uplift of the Cranberry Basement and the quartz diorite body along the Brush Creek Fault isolated the extension of amphibolitic gneiss in the footwall of the fault. Subsequent erosion produced an isolated lense of amphibolitic exposed entirely within the Cranberry Basement (see Plate 1). If this is the case then the northwestern contact of the amphibolitic gneiss with the underlying granitic gneisses may repeat the contact between the Amphibolitic Basement and the Cranberry Granitic Basement. The white mica granite exposed in the same area may crosscut the contact between the two complexes. Unfortunately, the western margin of the amphibolitic gneiss unit is poorly exposed.

Roberts Mountain Fault

The Roberts Mountain Basement Complex is in contact with the Amphibolitic Basement Complex along a southeastward dipping reverse fault. The fault is herein refered to as the "Roberts Mountain Fault" (see Figure 3, page 10, Plate 1). The best exposure of the fault zone is

in railroad cuts directly above Redman Dam (see Figure 13).

The Roberts Mountain Fault is not a single plane but rather a hundred meter wide zone of mixed Amphibolitic Basement and Roberts Mountain Basement lithologies. Large folds within the zone are truncated by minor faults. A pegmatitic dike approximately 2 meters wide appears to have intruded the fault zone parallel to the dominant structural trend of the zone. The fault zone is poorly exposed away from the Redman Dam cut but easily traceable where the pinkish metagranites are still exposed in the hanging wall. To the southwest the Roberts Mountain Complex pinches out and the fault is only locally traceable by zones of intense folding and disruption within the Amphibolitic Basement.

The upper contact of the Roberts Mountain Complex is difficult to interpret. Ideally, this contact repeats the main contact between the Cranberry and Amphibolitic basement complexes to the northwest. In roadcuts on Roberts Mountain Road, on the soutwest slope of Roberts Mountain, the contact is distinctly intensely mylonitized. Mafic lenses of the Amphibolitic Basement-like lithologies are intermixed within mylonitized pinkish metagranites of the Roberts Mountain Complex. This suggests at least local faulting and mixing of the complexes along the contact. In exposures of the

contact across the French Broad River, the metagranite appears to be in sharper contact with the Amphibolitic Basement. Mylonitization does not appear to wrap around or be concentrated at the contact. An intrusive relationship cannot be ruled out for the pinkish metagranite. If this were the case then Amphibolitic Basement-like mafic lenses within the metagranite observed on Roberts Mountain Road may just as reasonably represent tectonized xenoliths.

The intense mylonitization-deformation along the upper contact of the Roberts Mountain Complex observed along Roberts Mountain Road is tentatively interpreted to be late with respect to original fault and/or intrusive juxtaposition of the two complexes becauses it does not appear to correlate with the contact south of that area. The contact between the Cranberry-like granitic gneisses in the northeastern portion of the complex and the structurally overlying Amphibolitic Basement is fairly sharp and potentially repeats the main contact to the northwest.

Sweetwater Fault

A minor reverse fault marked by a distinct, meter wide or less ultramylonite zone is mappable in the Amphibolitic Complex just to the northwest of the trace of the Roberts Mountain Fault. The fault is herein

refered to as the "Sweetwater Fault" due to its chance exposure in fresh roadcuts along the very northern extent of Sweetwater Road (see Figure 14, page ??, Plate 1). The Sweetwater Fault reasonably may represent either a minor footwall splay off the Roberts Mountain Fault or an earlier ductile shear zone. As do the previously mentioned faults, the Sweetwater Fault extends roughly parallel to but overprints the dominant deformational fabrics of the Amphibolitic Complex. Importantly, the fault truncates a metagabbro dike that in turn truncates the dominant structural trend of the complex (Field Station 340). This and other similar mafic dikes are correlated with the Late Proterozoic Bakersville Intrusive Suite.

Mesoscopic Structures/Deformational Events

This study marks the first attempt to describe mesoscopic structures in the Amphibolitic Basement Complex. Because of better exposure and wider contrasts in lithology, a more complete sequence of deformational events can be extracted from the Amphibolitic Basement Complex than can be from the Cranberry Granitic Basement Complex. A "deformational event" is defined as any structural, intrusive, and/or metamorphic event that affected the complex. These events are recorded by such

features as faults, folds, foliations (etc.), crosscutting plutonic rocks,and metamorphic mineral assemblages. Mesoscopic structures recognized in the study area provide the most valuable information for extracting and ordering the deformational events that affected the basement complexes. The mesofabrics recognized in the Amphibolitic Basement are described and assigned to specific deformational events. These events and associated structures are then used to catagorize structures recognized in the Cranberry Basement Complex. A summary of deformational/intrusive events affecting the two complexes is given in Table 2.

Correlating common deformational events between the two complexes may not be valid for events prior to D8. As discussed under "Interpretations", it is believed that before this event, the two complexes were not yet juxtaposed in their present structural position. However, the two complexes are believed to have been part of the same cratonic terrane during the Middle Proterozoic and were thus probably commonly affected by the early regional events. For reasons discussed in "Interpretations", the D3-D7 events probably did not directly affect the Cranberry Complex.

TABLE 2. Deformational events.

EVENT	FOLDS	FOLIATION	CRANBERRY COMPLEX	AMPHIBOLITIC COMPLEX
MIDDLE TO LATE PROTEROZOIC				
D1		S1	foliation	foliation
D2	F1		folded S1	folded S1
D3			granitic intrusions (prior to ABC D3 ?)	rifting, mafic intrusion
D4/M1		S2		metamorphic foliation
D5	F2		Cranberry complex not	deformation of rift complex
D6			affected ?	migmatitization
D7				quartz veins
D8	F3	S3	dominant foliation, two complexes, late	accretion of quartz veins ?
734my to 690my				
D9			intrusion of gabbro, granite (Bakersville and Crossnorre suites)	
ORDOVICIAN and/or DEVONIAN ?				
D10/M2	F4	S4	metamorphism ?, Rector Branch Fault mylonitization, late kink folds further disruption, late faults	
LATER DEVONIAN ?				
D11			rare pegmatite dikes	
PERMIAN ?				
D12	F5	S5	rare late cataclastic, further disruption, folding of RBF	

Amphibolitic Basement Complex

Introduction

Several generations of mesoscopic structures are present in the Amphibolitic Basement Complex. Although some outcrops of the complex appear hopelessly chaotic at first glance, by correlating structures between outcrops a distinct sequence of deformational events can be extracted for the complex (e.g. figures 15-18). The deformational events developed for this complex are summarized in Table 2. It is advisable to skim Table 2 briefly.

D1-D3

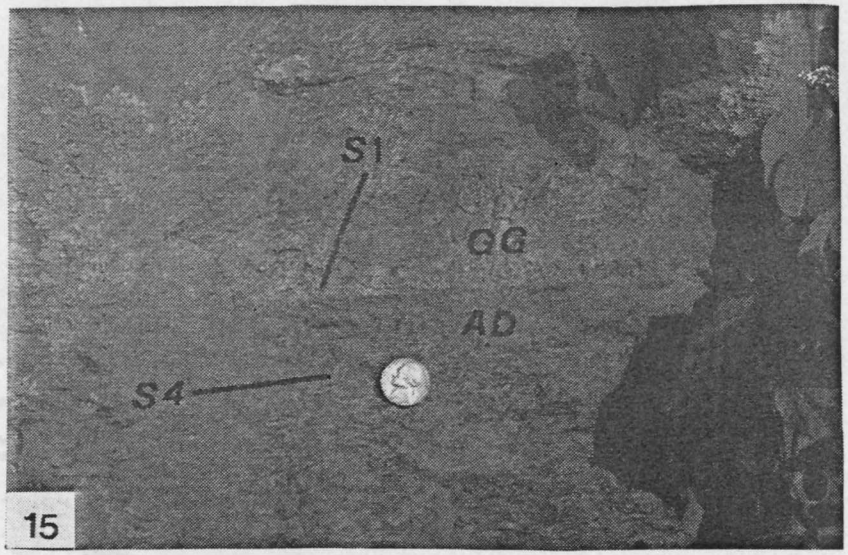
S1 is defined by an early foliation present in granitic gneisses and semi-schists. In a few rare outcrops, folded S1 foliation planes are truncated by amphibolite dikes (see Figure 15). The event that folded the S1 foliation is designated D2 and the fold generation F1. The event responsible for the intrusion of the basaltic dikes is designated D3. The intrusion of granodiorite to diorite plutons into the gneissic basement country rock is tentatively correlated with D3 although they may have been intruded earlier or slightly later.

Figure 15. Exposure of garnet-bearing amphibolite dike crosscutting S1 foliation in granitic gneiss (GG) (Field Station 704). Note S2 foliation in dike.

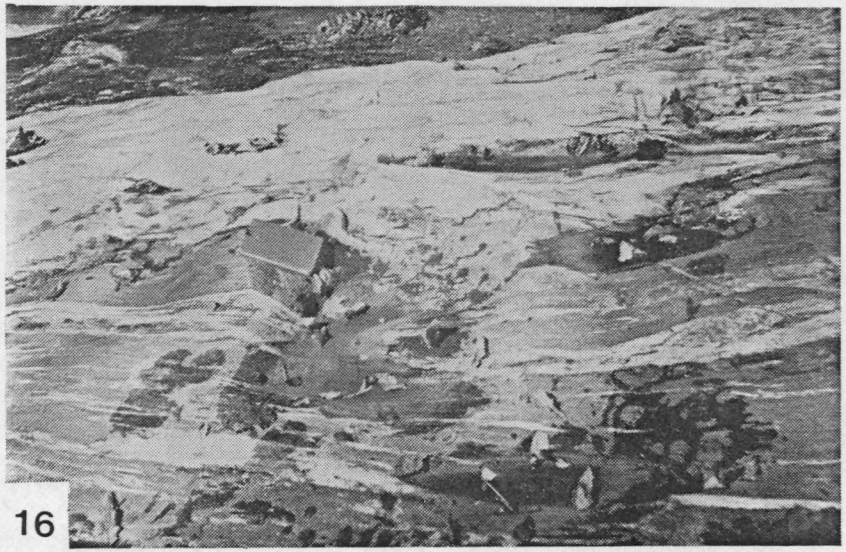
Figure 16. Disrupted (attenuated ?) amphibolite dikes (dark bands) within the Amphibolitic Basement Complex. From exposure in Walnut Creek (Field Station 734).

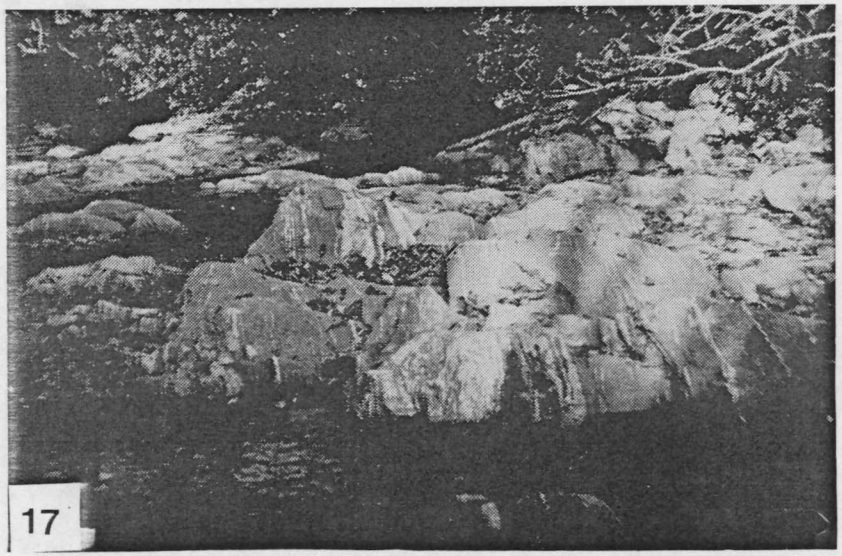
Figure 17. Exposure of Amphibolitic Basement in Walnut Creek showing migmatitic nature of complex (Field Station 750).

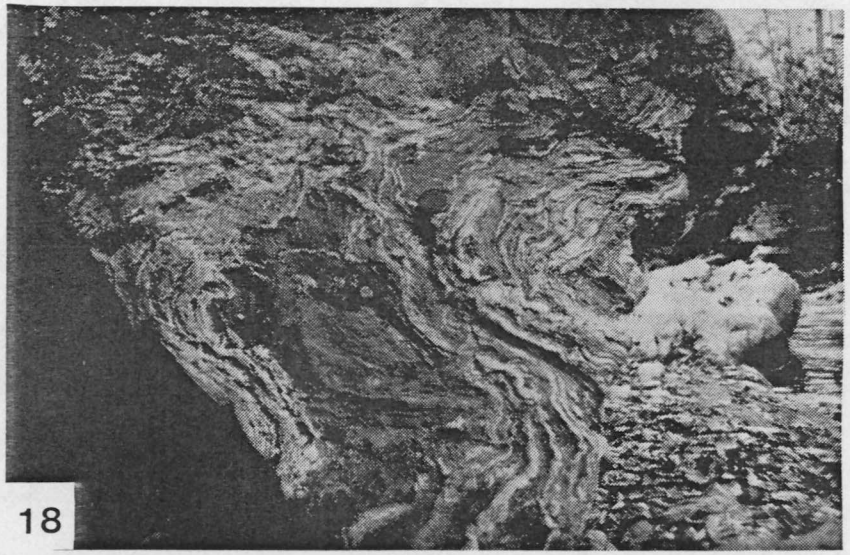
Figure 18. Complex deformation of migmatitic amphibolite bearing rock (Field Station 392). Deformation is related to D8 event. Folds are assigned to F3.



15


16


17


18

D4

The metamorphic foliation defined by the parallel alignment of hornblende grains in the amphibolite dikes/lenses is tentatively assigned to S2 of a D4/M1 deformation/metamorphic event (see Figure 15). The metamorphic history of the basement terranes is quite likely very complex and difficult to fit into the presented scheme of deformational events without broader-scale work. Amphibolite facies or higher metamorphism of the complex may have actually occured at any time before D8. Later deformational overprints make a more exact timing of metamorphism difficult to establish. The timing of metamorphism is discussed in Chapter 6.

D5

The amphibolite interlayers and dikes and the enclosing granitic gneisses are complexly disrupted. Lenses of amphibolite often appear highly attenuated or complexly interfolded with the enclosing granitic rock (see Figure 16). This major deformational event is designated D5 and, as later discussed, is believed to be related to a major dismemberment of the complex. Local tight to isoclinal folds associated with the D5 event are assigned to F2.

D6-D7

Thin vein-like to irregular masses of granitic migmatite characteristic of the complex locally crosscut F1 and F2 folds and S1 and S2 foliations (see Figure 17). Where migmatitic material is not present, F2 folds are very difficult to impossible to separate from later fold generations. Numerous origins are possible for the migmatite, including localized partial melting of the complex during the later part of the D5 event. This is briefly discussed in Chapter 6. The episode of migmatization is designated D6/M2. The migmatite is locally crosscut by quartz veins. The intrusion of the quartz is designated as D7.

D8

The entire complex displays an intense tectonic flattening which disrupts quartz veining and all previously described mesofabrics. This event is designated D8 and the resulting regional foliation/gross lithologic layering S3. The foliation is defined by the planar alignment of biotite grains in the mafic gneisses and interlayered schists. Most foliation measurements made in the Amphibolitic Basement during mapping were of S3 foliations. Intense, locally chaotic folding (F3) of the complex which occured during the D8 event is especially distinct in stream bed exposures in Walnut

Creek (see Figure 18). Deformation attributable to D5 versus D8 is very difficult to distinguish where migmatitic material and amphibolites are absent.

D9

Metagabbro, metapyroxenite, and metadiabase dikes and irregular bodies (Bakersville ?), the Indian Grave Metagranite (Crossnore ?), and the white mica granite bodies locally crosscut D1-D8 mesofabrics (Figure 19, Plate 1). The intrusion of these units is designated D9.

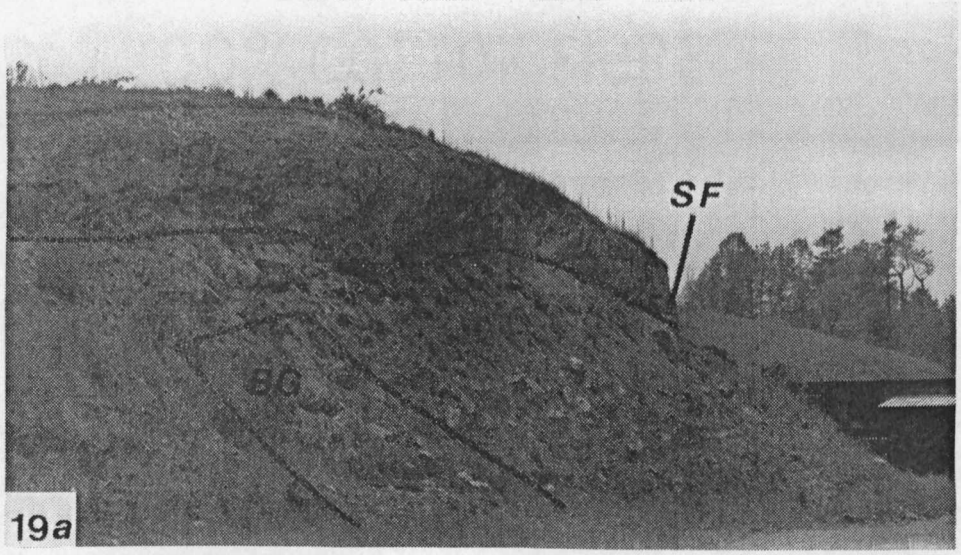
D10

The last major deformational event which strongly affected both basement complexes was associated with the emplacement of the Rector Branch Fault. This D10 event is recognized by intense ductile shearing associated with the Rector Branch Fault and the sporadic development of ultramylonites throughout both complexes. Minor faults such as the Sweetwater and Brush Creek faults are interpreted to be related to this event. The mylonitic foliation developed during D10 is assigned to S4. S4 often roughly parallels but clearly overprints S1-3 and all previously described mesofabrics (figures 20-21). S4 overprints the unnamed white mica grantite and the Indian Grave Metagranite (Crossnore ?). D10 ductile shear zones

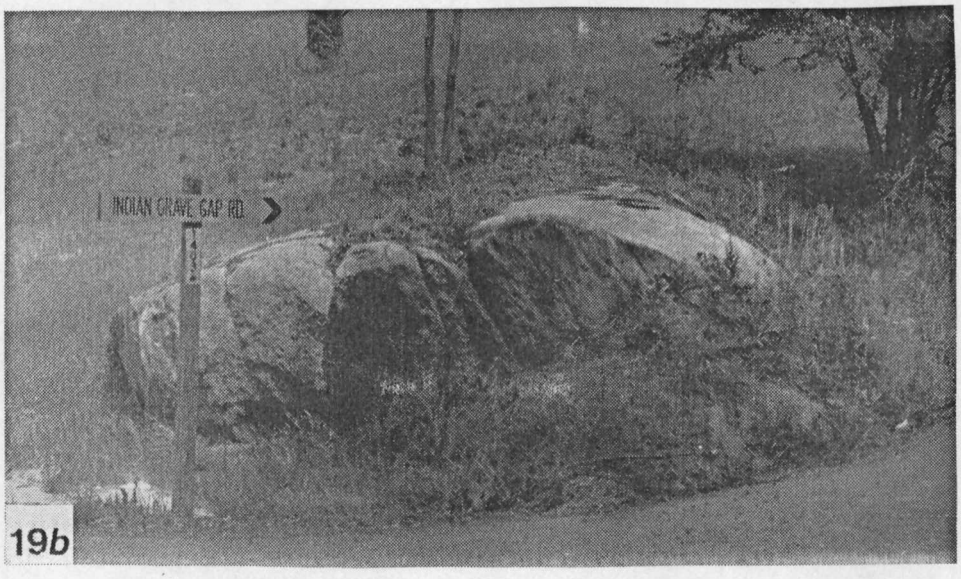
Figure 19. Exposures of Bakersville metagabbro and Indian Gap Metagranite.

a. Exposure of Bakersville Metagabbro (BG) at base of Sweetwater Fault (SF). The dike was exposed during road work on Sweetwater Road (Field Station 340).

b. Exposure of Indian Grave Metagranite (Crossnore ?) (Field Station 166). Granite is moderately mylonitized.



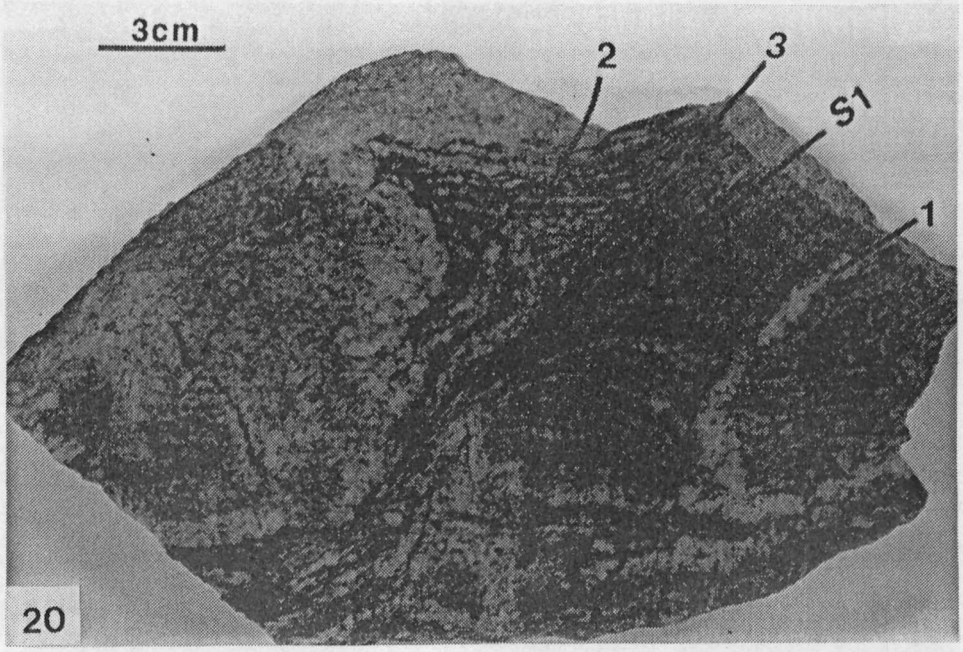
19*a*



19*b*

Figure 20. Photograph of polished slab from Field Station 179. 1 = granitic migmatite (D6) crosscutting folded (F1) S1 (D1) foliation in granitic gneiss; 2 = folded granitic migmatite (F3) (D8); 3 = truncation of all fabrics by S4 (D10) mylonitic overprint.

Figure 21. Roadcut of Amphibolitic Basement Complex (Field Station 179). In this exposure the D1 (S1), D2 (F1) or D5 (F2), D6, D8 (F3, S3), and D10 (S4) events can all be recognized (see also Figure 20).



20



21

LANCASTER BOND
100% COTTON FIBRE

locally truncate Bakersville metagabbro dikes.

Because S4 roughly parallels S3, any further folding and disruption of the complexes related to the emplacement of the Rector Branch Fault is very difficult to separate from the intense D8 event. The locally intense mylonitization of the Indian Grave Metagranite suggests that a great deal of shortening may have occured within the basement complexes during the D10 event. A detailed discussion on the progressive develpment of the Rector Branch Ductile Shear Zone is given in the following chapter.

The metamorphic mineral assemblage of the metagabbro bodies locally appear to be deformed by the D10 mylonitic overprint. This suggest that the metamorphic event that affected the gabbros occured prior to the emplacement of the Rector Branch Fault. Details of this "M2" event, however, are too sketchy to warrent separating the metamorphism as an unrelated event.

D11 (?)

Thin pegmatitic dikes were locally observed in large float blocks of the Amphibolitic Basement Complex where road construction was underway on Sweetwater Road (Field Station 345) and at Field Station 668. These dikes dikes did not appear to be overprinteed by S4. Exposures were too rare, however, to determine this with any certainty.

As discussed later, similar dikes exposed in the Cranberry likewise do not appear to have been overprinted by S4. The intrusion of the dikes is very tentatively assigned to D11.

D12

A late, very weakly developed cataclastic foliation is locally recognized in thin sections of Ocoee horses (?) within the Rector Branch Fault Zone (Sample 98). The Roberts Mountain Fault may have also been emplaced during this event. This late brittle event is very likely responsible for some of the intense disruption of the basement complexes.

The entire suite of deformational events is impossible to pick out in a single outcrop. In a road cut exposed just west of the Walnut Creek Road-Highway 25/70 intersection it is possible to pick out the D1, D2 and/or D5, D6, and D8 and/or D10 events (Field Station 179) (see figures 20-21) Unfortunately no amphibolite lenses where present in the exposure. Quartz veins not present in the slab sample were observered in outcrop to locally crosscut the migmatitic veins. As more megascopic and mesofabric data are accumulated for the Amphibolitic Basement Complex, in the future it may be possible to approach a single outcrop and pick out a more complete

sequence of the mesofabrics recording deformational events.

Cranberry Granitic Basement Complex

Introduction

The probable complex nature of mesofabrics in the Cranberry Basement Complex appears oversimplified in the field due to a lack of contrasting lithologies and a lack of large exposures. For this reason, correlatable mesofabrics recognized in the Cranberry are assigned to the more complete sequence of deformational events established for the Amphibolitic Basement. The Cranberry Basement is interpreted not to have been affected by the D4-D7 events recognized in the Amphibolitic Basement Complex.

D1-D3

Granitic gneisses of the Cranberry Complex are strongly foliated. The earliest foliation developed in the complex is designated S1 and the deformational event which caused this foliation D1. This early foliation is difficult to determine in intensely deformed portions of the complex. Average S1 foliation trends northeast and dips steeply southeast. Foliation is defined by the parallel allignment of biotite and/or platy ribbons of

deformed quartz. Folding of S1 is assigned to the D2 event and the folds to F1. The intrusion of the scattered bodies of granite to granodiorite into the gneissic country rock is assigned to D3.

Mafic portions of the Cranberry Complex are locally migmatitic. The migmatites crosscut the S1 foliation and are themselves folded and disrupted. The timing of migmatism is difficult to establish. Exposures of migmatitic gneisses in the Cranberry were too scarce to validly correlate the event with the D6 event recognized in the Amphibolitic Basement.

D8

The dominant foliation-layering of the Cranberry gneisses and semi-schists is correlated with the intense D8 flattening event recognized in the Amphibolitic Complex. S3 foliations are difficult to impossible to separate from the primary S1 foliation of the Cranberry on a mesoscopic scale. Progressive shearing of biotite-rich granitic rocks appears to accompanied by the thickening and coalescence of biotite rich S1 foliation planes, ultimately giving rise to a well-layered gneissic rock dominated by S3 (or older ?) foliation/compositional layering.

D9

As in the Amphibolitic Basement Complex, the intrusion of Bakersville gabbroic and (?) pyroxenite dikes, the Indian Grave Metagranite (Crossnore ?), and the white mica granite into the basement complex appears to post-date major D8 deformation but pre-date the strong S4 mylonitic overprint. Again, the intrusion of these bodies is assigned to D9.

D10

The late mylonitic overprint of the Cranberry Complex associated with the emplacement of the Rector Branch Fault is designated S4 and correlated with the D10 deformational event recognized in the Amphibolitic Basement Complex. As in the Amphibolitic Basement Complex, S4 mylonitic foliation roughly parallels but clearly overprints S1-S3. Away from the main Rector mylonite zone, the overprinting mylonitic S4 foliation and mesoscopic-scale ultramylonite zones become very widely spaced and sporadically developed. A detailed discussion of the progressive microscopic to megascopic development of the Rector Branch D10 mylonites is given in the following chapter.

Ultramylonites exposed along the trace of the Rector Branch Fault display a unique, late development of conjugate kink folds. The conjugate sets are roughly

bisected by the general trend of the ultramylonitic foliation (Figure 22). Local displacement along kink folds deforming the mylonitic foliation suggests they occured during the waning stages of movement along the Rector Branch Fault (see Sample 1). The folds are designated F4.

D11

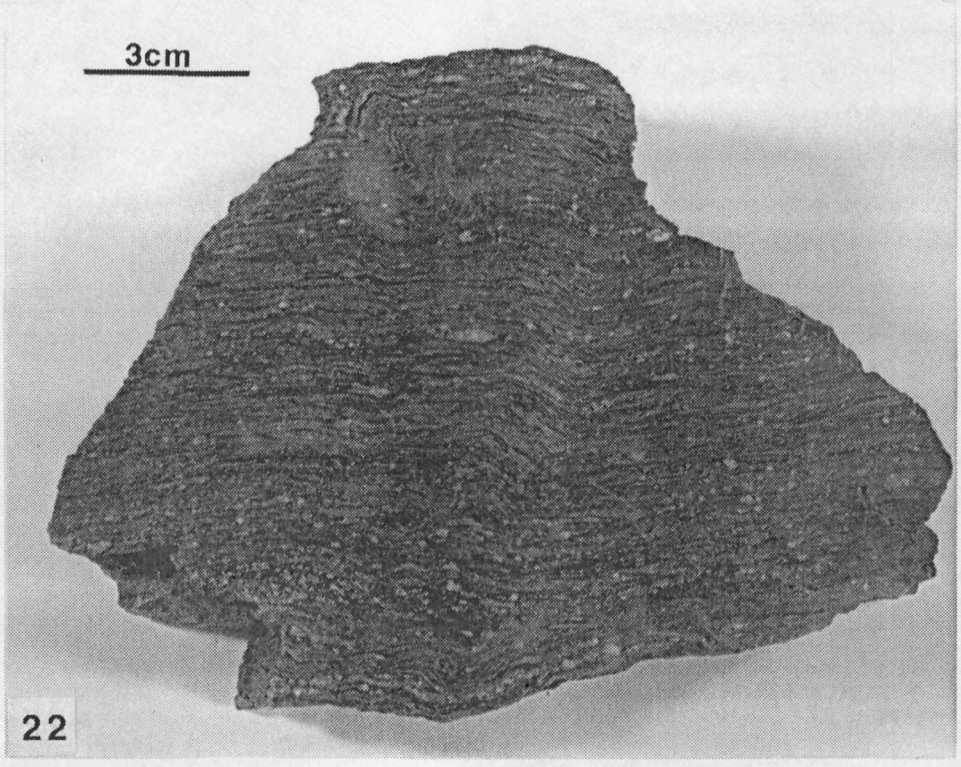
Rare, pegmatitic dikes a few centimeters across locally crosscut the D8/S3 foliation of the Cranberry Basement and likewise appear unaffected by the late S4 mylonitic overprint. No larger bodies of similar granites are exposed in the area, This intrusive event is tentatively assigned to D11 although the dikes are too rare to interpret very accurately. The pegmatites may be related to the emplacement of Devonian-age pegmatite bodies just northeast of the study area in the Spruce Pine district (see Butler, 1972, 1973). They may likewise be related to the D9 (Late Proterozoic) intrusion of gabbros and alkaline granites.

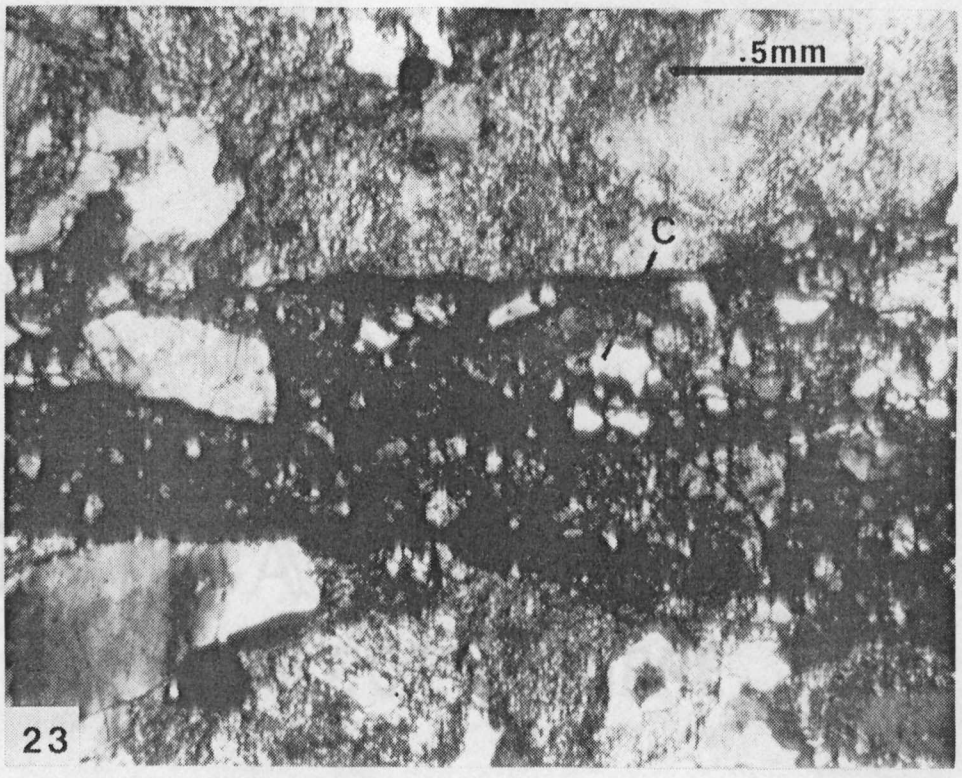
D12

An event which caused a very localized, weakly-developed cataclastic overprint of the Rector Branch S4 mylonites is designated D12 and the resulting foliation F5 (Figure 23). The foliation is best developed

Figure 22. Conjugate kink bands developed in ultramylonitized Max Patch Metagranite at Rector Branch Fault (Sample 1).

Figure 23. Photomicrograph of cataclasite (C) developed in Ocoee horse (?) in main Rector Branch mylonite zone (Sample 98).


3cm
22


.5mm
C
23

in horses of Ocoee-like rocks exposed in the hanging walls of Rector Branch splays (Field Station/Sample 98). This more brittle event is interpreted to be associated with very late movement along the Rector Branch Fault and/or the event that folded the Rector Branch Fault (FS).

Movement along the Roberts Mountain Fault may also be related to this event. As previously discussed, the fault does not display a distinct mylonite zone as do the Brush Creek and Sweetwater faults. This suggests that it developed at a shallower level under less "ductile" conditions. Uplift of the Roberts Mountain Complex may be related to imbrication associated with the Alleghanian (?) deformation recognized in the Hot Springs Window (see Figure 10, page 86).

CHAPTER 5

DEVELOPMENT OF THE RECTOR BRANCH FAULT ZONE

Introduction

Good exposure of the main mylonite zone associated with the Rector Branch Fault and the related less well developed mylonitic overprint developed in both complexes affords one the oppurtunity to study the progressive development of ductile shear zones at lower to upper greenschist facies conditions. Mylonites are defined as fault rocks in which the reduction of grain size was dominated by syntectonic, intracrystalline, "ductile" dynamic recovery and recrystallization processes (see Sibson, 1977; Bell and Etheridge, 1973; White, 1976). Mylonitization occurs in narrow zones of intense heterogenous shear or "ductile shear zones" (Ramsey, 1980).

As discussed below, whole rock deformation of the quartz and feldspar-rich rocks of the basement complexes cannot be classified simply as "ductile" or "brittle". The various mineral constituents of the rocks behave differently under the same deformation conditions. Rather than an ill-defined "ductile-brittle" transition in the deformation of a rock, Sibson (1977) suggests an

"elastofrictional-quasiplastic" transition marked by the point where quartz begins to deform by intracrystalline glide rather than brittle fracture. Sibson suggests that this transition takes place at temperatures around 300° C or, at normal P-T gradients, at depths of 10 to 15km.

Development Of The Rector Branch Ductile Shear Zone

Introduction

The Rector Branch Fault is an excellent example of a regional-scale ductile shear zone displaying advanced stages of deformation. The microscopic to megascopic development of the Rector Branch Fault Zone is very comparable to published work on ductile shear zones by Simpson (1983, 1985). The following is a slightly idealized model describing the progressive microscopic to megascopic development of the fault zone. The descriptions/interpretations were taken from my field-based zonation of the Rector Branch Fault zone combined with various published literature on deformation within ductile shear zones. Because they represent the most common rock type within the two basement complexes, emphasis is placed on the progression of deformational mechanisms operating in quartzo-feldspathic rocks.

Based primarily on microscopic to megascopic observations of deformation associated with the emplacement of the Rector Branch Fault, the development of the Rector Branch Ductile Shear Zone is subdivided into three stages (Figure 24). The development of the fault reflects inhomogeneous strain across the ductile shear zone (see Ramsey 1980). Each stage represents the progressive concentration of strain within a narrowing zone of deformation. These stages are recorded in the field by the present zonation of the Rector Branch Fault Zone (see Figure 10-page 86). Stage 1 correrlates to Zone 1 of the Rector Branch Fault Zone. This stage is characterized by the widespread but sporadic development of minor ductile shear zones on a microscopic to mesoscopic scale. As compressional stresses imposed on the basement continue to build, strain becomes concentrated in a narrowing, more centralized zone within the deforming body of rock. This second stage is characterized by an increased mylonitization of the rocks and the development of an anastomosing system of mesoscopic scale ductile shear zones within a centrallized part of Zone 1 (see Figure 24). This zone is denoted by Zone 2 of the Rector Branch Fault Zone. As strain becomes concentrated in Zone 2, the outer margins of the developing megascopic ductile shear zone (Zone 1) are essentially abandoned, recording only the early

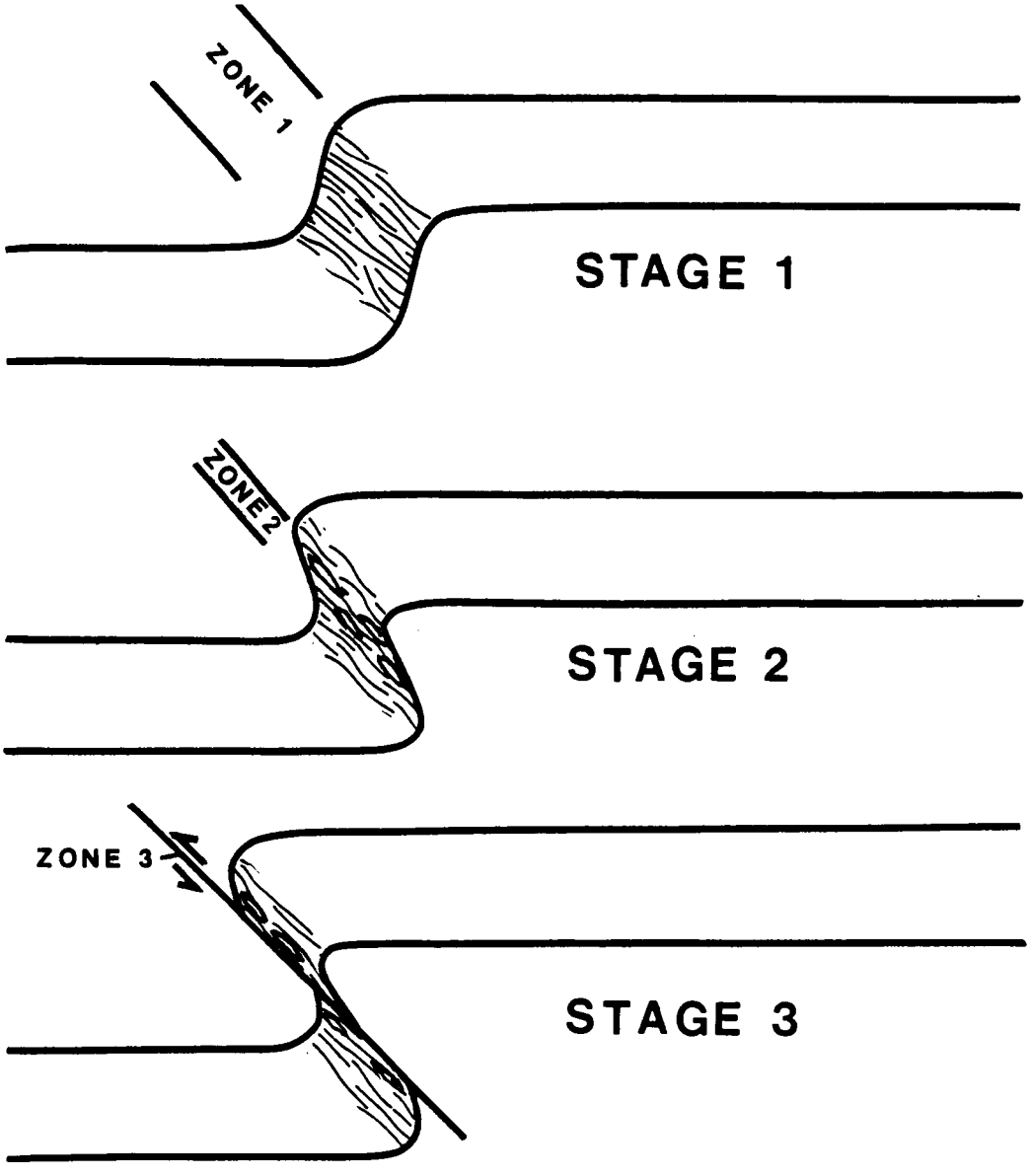


Figure 24. Summary of proposed stages of development of Rector Branch ductile shear zone (see text for discussion). Stage 1 (Zone 1): extensive, widely spaced development of microshears and mesoscopic ductile shear zones; Stage 2 (Zone 2): concentration of strain within an anastomosing system of coalescing ductile shear zones; Stage 3: concentration of strain in a single ductile shear zone and major movement within the fault zone.

stages of deformation. In Stage 3, as compressional stresses continue to be imposed on the granitic basement, strain ultimately becomes preferentially concentrated in 10 to 20 meter wide zone of highly strain-softened ultramylonite. Major movement of the over-riding thrust sheet occurs within this zone, denoted by Zone 3 of the Rector Branch Fault Zone.

In the above model, I suggest that the Rector Branch Fault Zone grew inward with progressive deformation. An alternative model may be that the deformation began as a single fault and grew outward, progressively incorporating more rock (Mitra 1978). The interior of the fault zone becomes the most deformed and the edges effected only by late mylonitization. In Mitra's model, my ordering of stages 1-3 would be reversed, with the ultramylonite at the Rector Branch Fault representing the whole period of deformation. Because both models produce the same map pattern of deformation, it cannot be proven whether the Rector Branch Fault Zone grew inwards or outwards with progressive deformation.

"Undeformed" Rock

In even the least deformed rocks in the study area, quartz displays deformation by dislocation glide and creep processes (Figure 25). This is



Figure 25. Photomicrograph of relatively undeformed quartz diorite in Cranberry (Sample 322). In thin section quartz (Q) displays undulose extinction and local subgrain development. Feldspar (F) is not deformed.

evident from such features as undulose extinction and the localized in-situ recrystallization of the grain to minute subgrains. Some "subgrain" boundaries may reflect local grain boundary sliding. Local diffusion-migration of quartz along subgrain boundaries is evident by seriate or lobate grain boundaries (Bell and Etheridge, 1973; Voll, 1961). The operation of these mechanisms suggests initial strain at no less than lower greenschist facies conditions (Tullis, 1979; Simpson, 1985).

Feldspar grains in the same rock display little deformation at this stage aside from localized brittle crushing or very localized recrystallization (see Figure 25). Biotite and white mica (if present) are similarly relatively undeformed at low early stresses.

Stage 1

As compressional forces acting on the basement began to intensify and strain rates began to increase, the basement rock begins to deform under lower-to-middle greenschist facies conditions. Deformation is first evident as an extensive zone of sporadically developing, widely spaced, microscopic and mesoscopic ductile shears (Figure 26). In thin section, all minerals display some degree of deformation (figures 27-28). Elongate quartz

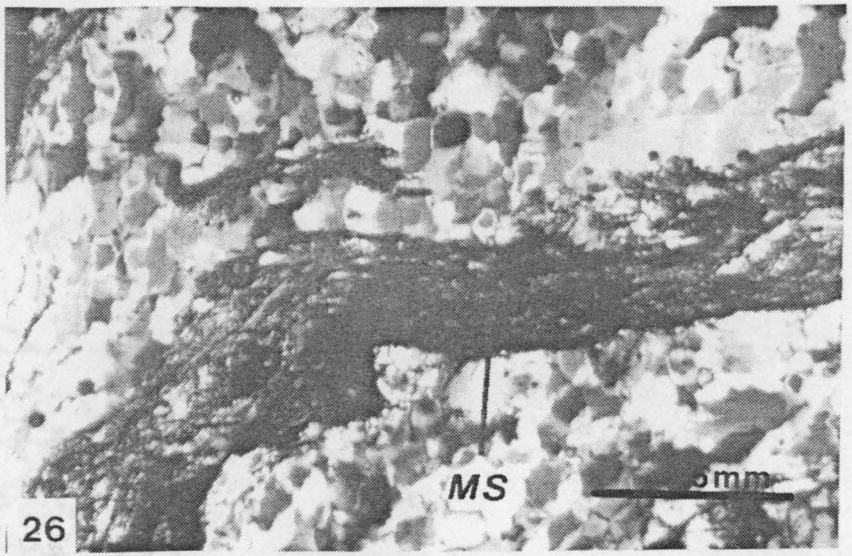
Figure 26. Microshear surfaces (MS) in Indian Grave Metagranite (Sample 166). Microshear surfaces are comprised of ultramylonitic feldspar + quartz + biotite + sericite + epidote ± sphene.

Figure 27. Extensive development of quartz ribbons (Q) by dislocation creep mechanisms (Sample 408). Ribbons wrap garnet porphyroclasts.

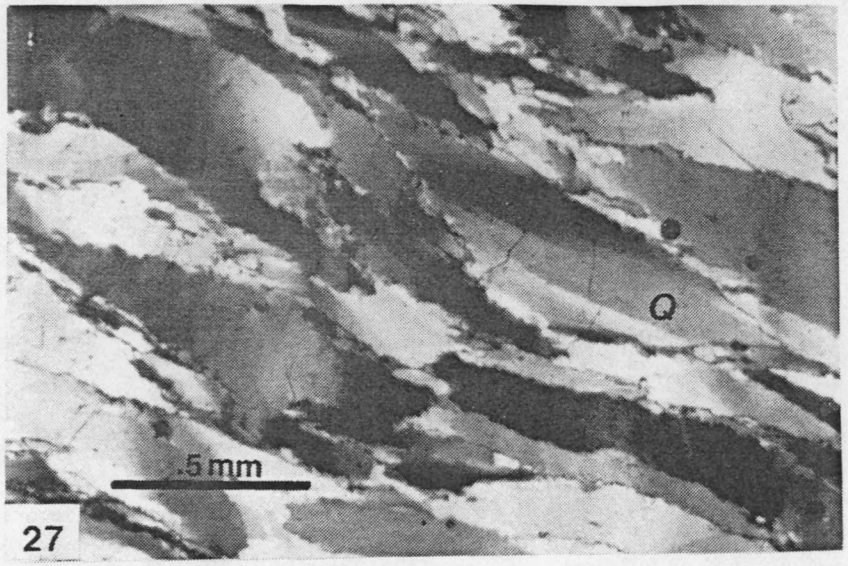
Figure 28. Deformation of feldspar grains.

a. Brittlely fractured plagioclase grain (P) (Sample 98). Note offset twin lamellae. Undulose, ribboned quartz grains (Q) partially wrap the feldspar grain (pressure shadow ?).

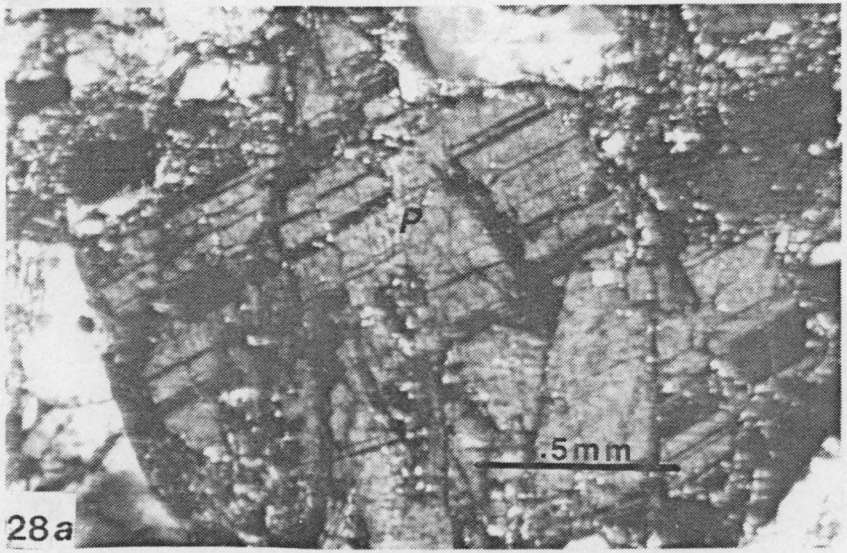
b. K-feldspar porphyroclast (F) displaying early stages of "tail" development (T) (Sample 513). Note subgrain development at margins of porphyroclasts oblique to shear direction (denoted by arrows).



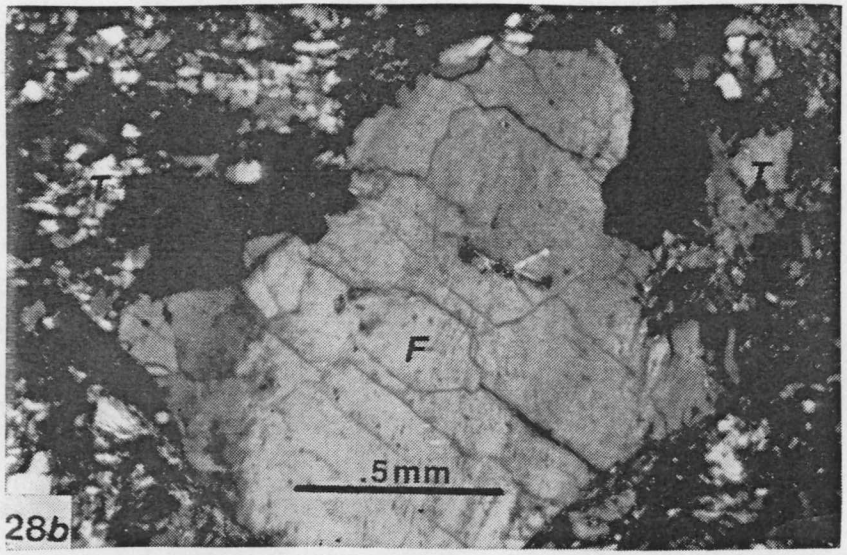
26



27



28a



28b

ribbons typically wrap more rigidly deforming feldspar grains.

Groundmass

Fine quartz and feldspar grains composing most of the groundmass readily begin to reduce in grain size by ductile dislocation glide and creep processes. At some critical grain size the groundmass begins to deform predominantly by grain boundary sliding and mass diffusion creep processes (Sibson, 1977). Microshear surfaces develop in preferentially strain-softened zones in the groundmass parallel to the overall sense of regional shear (see Figure 26) (Simpson and Schmid, 1983; Lister and Snoke, 1984). Microscopic shear surfaces define a deveolping widely spaced, discontinuous, mylonitic foliation in the granitic rocks. The microshear surfaces are composed of minutely recrystallized, ultramylonitic quartz, feldspar, and mica commonly accompanied by increased concentrations of epidote, opaques, and, especially in mafic rocks (e.g. amphibolite), sphene. Mica and epidote-rich shear surfaces may represent the local dissolution of feldspar within the microshear zone due to increased stress and temperature gradients (Simpson, 1977). "C" and "S" surfaces were only noted in rare phyllonites.

Quartz

With increasing deformation quartz grains begin to strain by dislocation dlide and creep processes. Grains ductilely deform into extremely elongate, flattened, undulose "ribbons" alligned parallel to the dominant shear direction (see Figure 27) (White, 1976; Simpson, 1985). Extension of quartz grains tends to orient their C axes parallel to the direction of shear (Voll, 1961; Wilson, 1975). Undulose deformation lamellae develop perpendicular to the elongate walls of the ribbons (Simpson, 1985). In areas of especially high strain (e.g. grain boundaries, tight packs of dislocations), quartz ribbons display minor recovery by dislocation creep recrystallization processes (White, 1976). This is characterized by scattered patches of recrystallized subgrains. Quartz generally begins to recrystallize at 100° to 300° C (Voll, 1961). Common grain boundaries between adjacent quartz ribbons are typically seriated, suggesting increased mobility of quartz (Voll, 1961; Bell and Etheridge, 1973).

Feldspar

At higher total strains, large feldspar grains are forced to deform with the strain-softening quartz. At low greenschist facies conditions, feldspar grains tend to remain as large "augen", deforming by brittle crushing

and fracturing (see Figure 28a) (Sibson, 1977; Simpson, 1985). At slightly higher strains but with lower volumes of augen, feldspar augen rigidly rotate within the more ductilely deforming quartz, feldspar, and finer grained feldspar matrix without much large-scale intracrystalline deformation (Vidal and others, 1980; Debat and others, 1978).

When feldspar augen concentration reaches 30 to 40% and/or with total strain, augen rotation becomes increasingly difficult. At some critical stress, an augen will "lock" in place and no longer rigidly rotate within the ductilely deforming groundmass. Stresses become concentrated at grain boundaries and especially at the leading and trailing edges of the augen (Debat and others, 1978; Vidal and others, 1980). Highly strained areas of potassic feldspar augen first deform by dislocation glide processes, producing a distinct undulatory extinction. With increasing strain, undulose margins of the augen aligned perpendicular to the direction of shear begin to brittlely of at higher stresses, deform by dislocation creep processes. The margins of the grain recrystallize into 5-15um strain-free subgrains (see Figure 28b) (Mitra, 1978; Simpson and Schmid, 1983; Simpson, 1985).

Plagioclase augen tend to remain euhedral during early stages of deformation, despite ductile shearing in

the groundmass (see Figure 29) (Debat and others, 1978). The first signs of internal strain are kinking and bending of twin lamellae. With increasing strain, plagioclase augen tend to first deform by brittle fracture rather than by more ductile processes as observed for potassic feldspars (Debat and others, 1978).

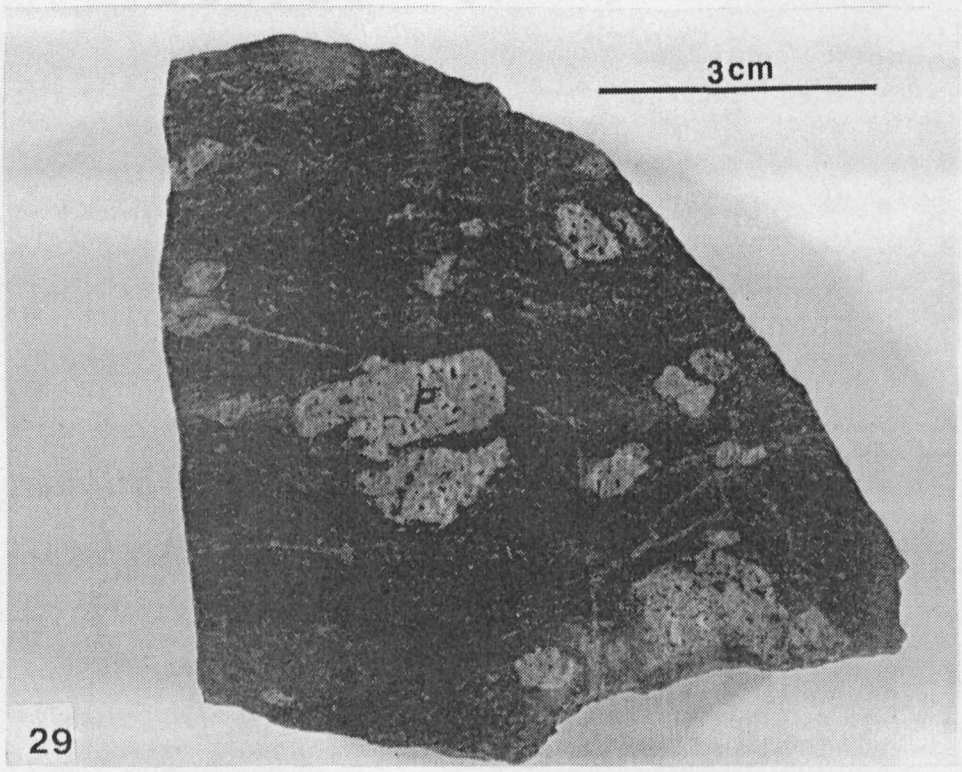
Augen development

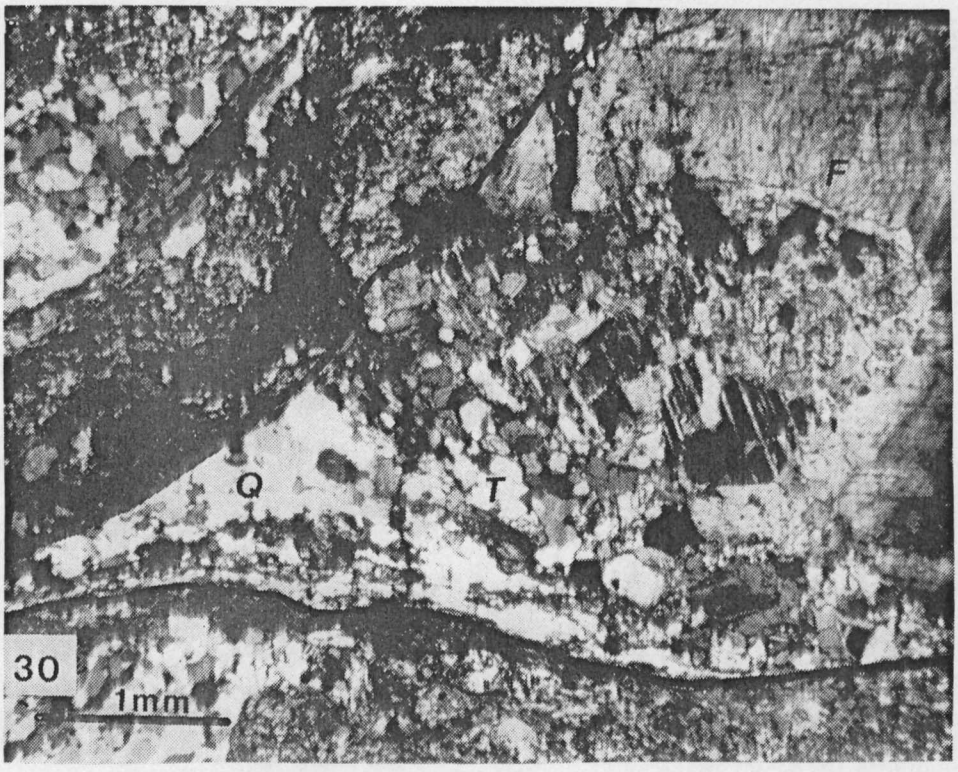
As the groundmass continues to deform, the brittlely fractured or recrystallized edges of the feldspar augens are progressively dragged into the ductilely deforming groundmass, generating elongate, asymmetrical "tails" of feldspar extending parallel to the overall shear direction (Figure 30) (Simpson and Schmid, 1983; Simpson, 1985). Increased quartz content in some feldspar augen tails may be related to the incorporation of early quartz-filled strain shadows into the tails during later deformation (see Figure 30) (Debat and others, 1978).

Subgrains in the augen tails continuously recrystallize and reduce in size as they are pulled away the margin of the augen and into the ductilely deforming, strain-softened groundmass. Recrystallizing subgrains ultimately approach the smallest grain size produceable by dislocation creep processes. Below this grain size, deformational mechanisms acting on feldspar grains change from dislocation creep to diffusion creep and grain

Figure 29. Near euhedral phenocrysts of plagioclase (P) enclosed in a moderately well foliated (S3 or S4 ?), amphibolitic groundmass (Sample 183). Phenocrysts are comprised of minute subgrains with scattered inclusions of hornblende and biotite (A/B).

Figure 30. Recrystallized tail (T) developed on feldspar augen (F) (Sample 166). Increased concentration of quartz (Q) in tail may reflect the early development of quartz-filled pressure shadows.


3cm
P
29


F
Q
T
30
1mm

boundary sliding processes. This is accompanied by a pronounced strain-softening and ultramylonitization of the outer margins of the augen tails (see Figure 30) (Sibson, 1977; Tullis, 1979).

Mica

Under lower to middle greenschist facies conditions, biotite augen (porphyroclasts) in the rocks readily deform by continuous dissolution and recrystallization, forming patchy sheets of platy, strain-free grains growing on the foliation planes defined by quartz ribbons and microshear zones (Figure 31(a)) (Wilson and Bell, 1979; Etheridge and Hobbs, 1974). Larger relict augen are kinked, fractured, and locally undulose. Muscovite grains deform by broad open folding and local fracturing parallel to fold axes with local slip on (001) cleavage planes (Figure 31(b)) (Wilson and Bell, 1979). Mica-rich ultramylonitic planes typically wrap large feldspar augen (Figure 32).

Amphibole

Amphiboles deform during this stage by brittle (to ductile ?) bending and fraying (Figure 33) (Spry, 1969). Mylonitization produces foliated aggregates which are very difficult to distinguish from a foliation produced by metamorphism. With increasing strain, amphibole grains

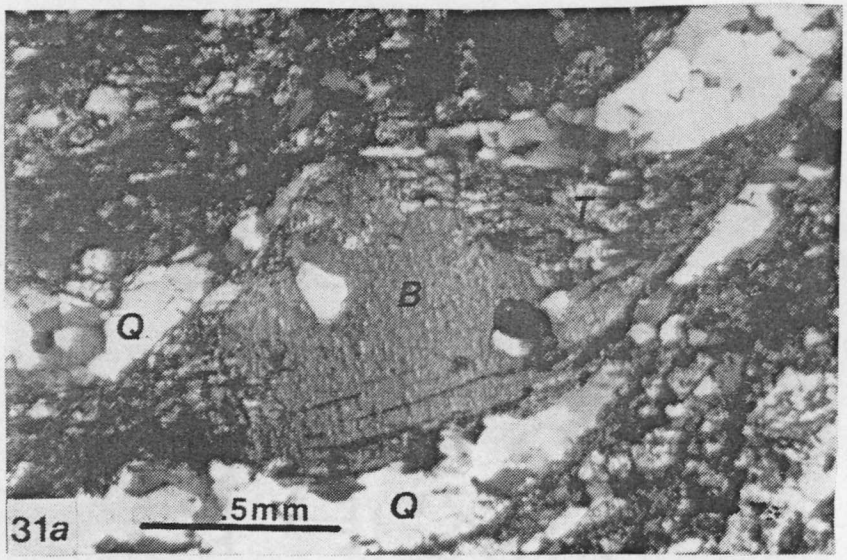
Figure 31. Deformation of mica.

a. Biotite porphyroclasts (B) displaying partially recrystallized tails (T) (Sample 166). Porphyroclast is wrapped by partially recrystallized quartz ribbons (Q).

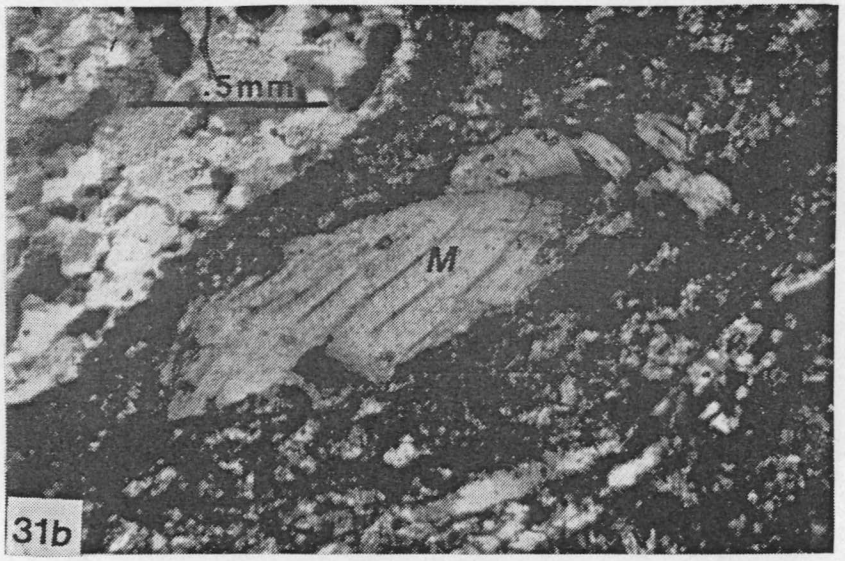
b. Brittlely deformed muscovite porphyroclast (M) (Sample 513). Note initial broad, open folds, fracturing of fold hinges, and possible local recrystallization (?).

Figure 32. Brittle fracturing of actinolite (and/or hornblende) (A/H) along hinges of kink folds (Sample 34).

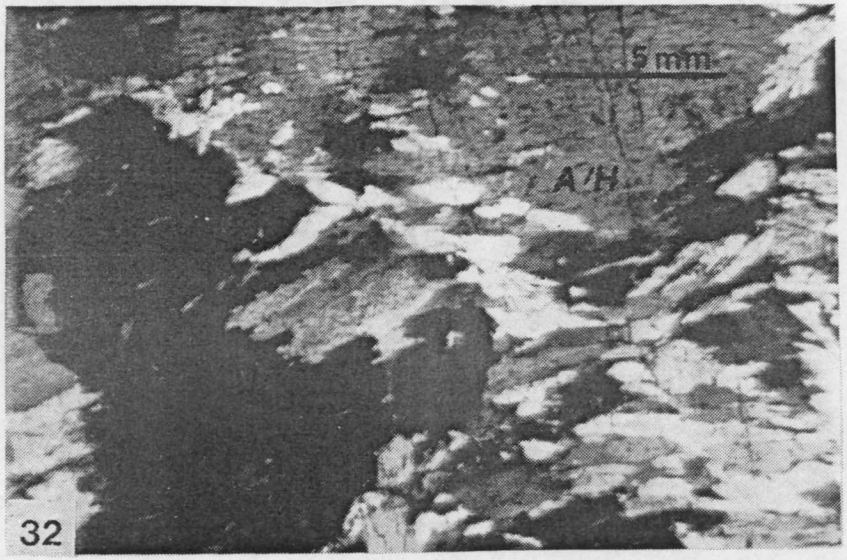
Figure 33. Feldspar augen (F) wrapped by ultramylonitic microshear zones and ribboned quartz grains (Sample 32). Arrows denote apparent sense of shear.



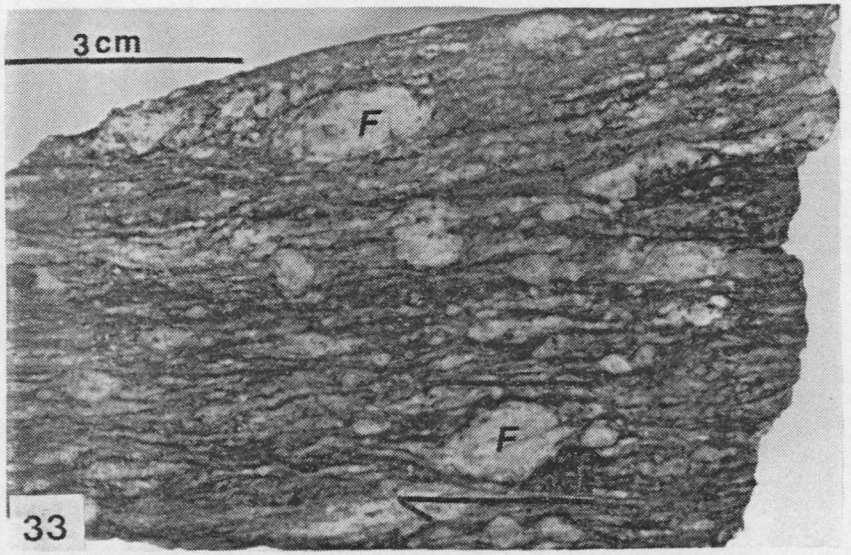
31a



31b



32



33

display local recrystallization into smaller aggregates of strain-free subgrains (Jenson and Starkey, 1985).

Mesoscopic/megascopic development

Mesoscopically, the rocks at this stage begin to sporadically develop a widely spaced mylonitic foliation which crosscuts other fabrics (see Figure 20, page 108). The foliation is defined by the parallel alignment of recrystallized biotite, quartz ribbons, and microshear surfaces composed of ultramylonitized material. In hand sample, feldspar augen are rounded and asymmetrically wrapped by the foliation (see Figure 33). As reviewed by Simpson and Schmid (1983), asymmetrical tails on augens are the most reliable structures for obtaining the sense of shear in a sample (see Figure 33). Most augen structures observed in the study area support the generally accepted northwest sense of regional shear in the basement complexes. This stage is comparable to Zone 1 of the present Rector Branch Fault Zone where the complexes display a locally intense mylonitic overprint.

Stage 2

During Stage 1, most of the deformation within the rock was taken up by widespread but sporadic ductile shearing of the finer grained quartz-feldspar groundmass.

Because of the discontinuous and widely spaced nature of the shear zones, only minor regional-scale displacement probably occured along the developing ductile shear zone during this stage (see Figure 24-page 122). During Stage 2, temperatures within the core of the developing ductile shear zone may have increase because of frictional heating, progressively pulling isotherms upwards into the shear zone (Sibson, 1977). Increasing total strains possibly accompanied by locally increased temperatures raised conditions of deformation to middle to upper greenschist facies.

Quartz

At increased strain rates and P-T conditions, quartz can no longer sufficiently recover from imposed stresses by dislocation glide alone. Highly strained parts of the ribbons recrystallize by dislocation creep processes. Numerous crosscutting bands of minutely (5-15um) recrystallized, strain free subgrains, split the ribbons into isolated parts. With continued strain the ribbons ultimately completely recrystallize. Diffusion creep processes may eventually lead to a polygonal mozaic of strain-free, recrystallized grains with high angle grain boundaries (Spry, 1969; White, 1976; Bell and Etheridge, 1973). Recovery to this extent may also be caused by thermally induced "annealing" during a later metamorphic

event (Figure 34) (Tullis, 1979; Tullis and others, 1982).

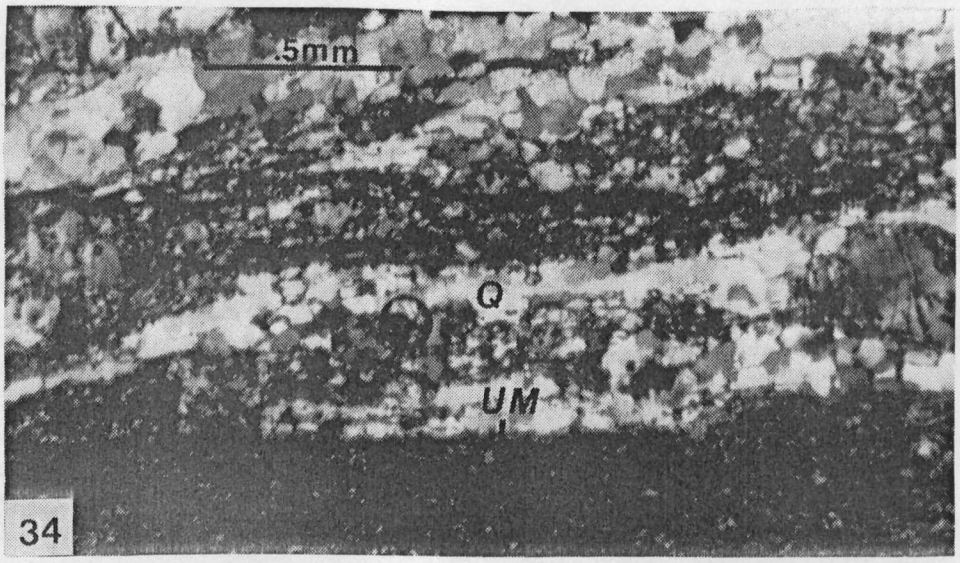
Feldspar

At the same increased strain rates and PT conditions, feldspar augens begin to recrystallize internally (Figure 35). The growing number of microshears in the groundmass begin to terminate and focus stresses against the margins of the augens, eventually leading to their dissection along narrow bands of brittle fractured material (Mitra, 1978). No displacement initially occurs across these bands. With further shearing within the groundmass, movement occurs along the cracks and the augens are progressively internally disrupted (Figure 36). Displacement along these zones and continued recrystallization and growth of the augen tails eventually reduce the feldspar augens to sheet-like masses of intensely sericitized and saussuritized quartz-feldspar ultramylonite with scattered, minute augen of completely recrystallized feldspar. Plagioclase tends to preferentially survive as small scattered augen. Rapidly increasing strain rates possibly accompanied by increasing temperatures accentuate diffusion creep processes within the ultramylonite and lead to superplastic flow of the material (Mitra, 1978; Sibson, 1977).

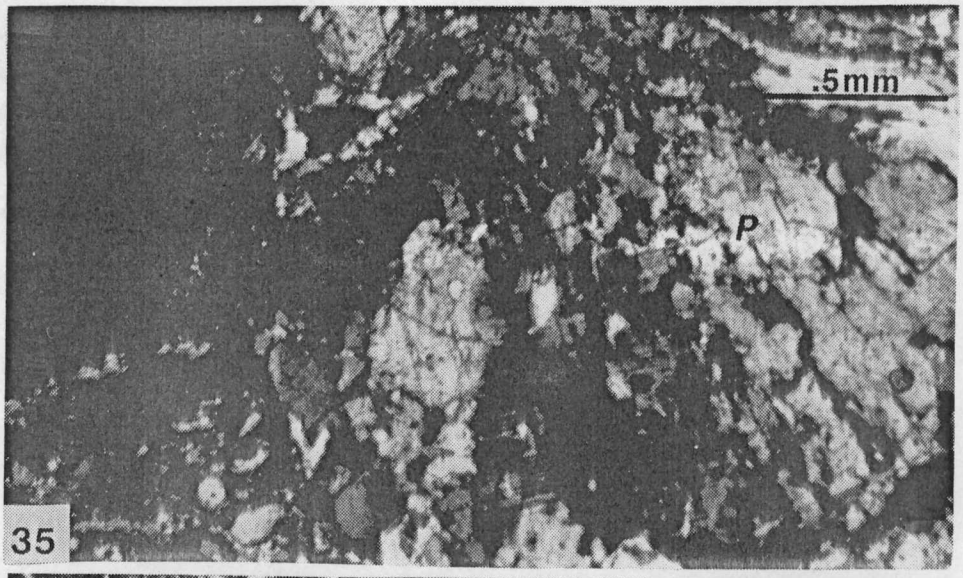
Figure 34. Extensively recrystallized quartz ribbons (Q) (Sample 340). Note sharp contact with feldspar quartz mica ± epidote ± sphene ultramylonite (UM) associated with the Sweetwater fault.

Figure 35. Plagioclase porphyroclast (P) displaying extensive internal recrystallization (Sample 79).

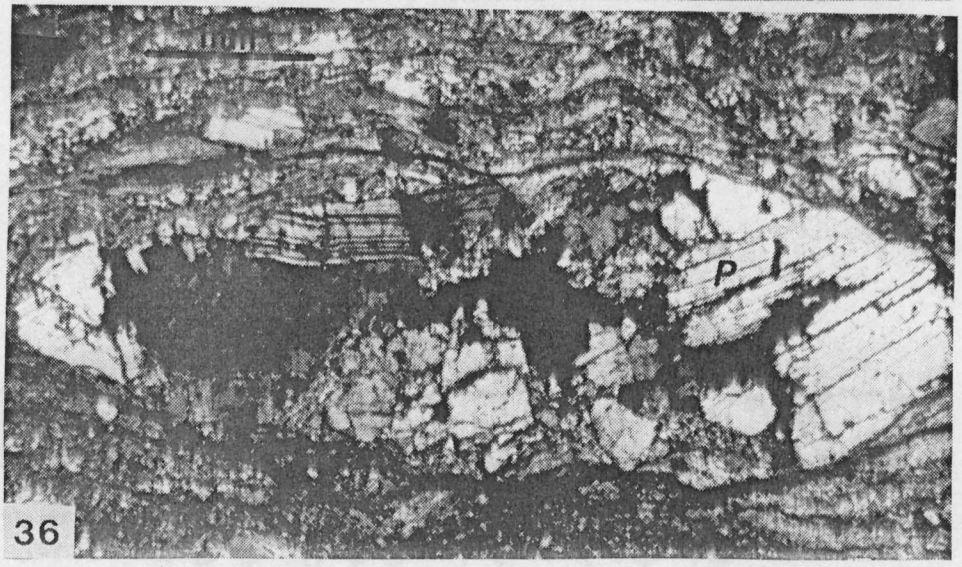
Figure 36. Plagioclase porphyroclast (P) strongly internally disrupted (Sample 1). Porphyroclast is completely enclosed in ultramylonite (UM). By this stage, quartz and most K-feldspar grains have been reduced to trails of ultramylonitic material.



34



35



36

Mica

At this stage, mica augen (porphyroclasts) completely recrystallize and are incorporated into the ultramylonite. Biotite recrystallizes as scattered trails of grains less than 1mm across. Relict white mica is less common in the ultramylonite. The appearance of sericite may be related to the breakdown and recrystallization of white mica.

Amphibole

No samples were collected which contained ultramylonitized amphibole grains. Amphibole deforms similarily to white mica during deformation at upper greenschist facies conditions (Jenson and Starkey 1985).

Mesoscopic/megascopic development

As compressional stresses continued to be imposed on the basement complex during this stage, strain became preferentially concentrated in widely spaced concentrations of strain-softened microshears. As strain continued to be concentrated in these zones the microshears coalesced and the zones thicken into mesoscopic scale ductile shears. With increasing shearing, ductile shear zones begin to thickened and become more extensive. Mesoscopic ductile shear zones

locally began to merge into a megascopic system of anastomosing ultramylonites, enclosing and ultimately engulfing comparatively undeformed lenses of the basement complex (see Figure 24-page 122). Deformation of the basement began to be preferentially concentrated in a narrowing megascopic zone of strain-softened rock. Further stresses imposed on the basement complex were compensated for by preferential shearing and ultramylonitization within this narrowed zone of strain-softened rock. At this time major regional displacement along the Rector Branch Fault Zone began. This stage of development is correlative to Zone 2 of the present Rector Branch Fault Zone.

Stage 3

At some time after the development of Zone 2, deformation and movement within the Rector Branch Fault Zone was preferentially concentrated in a ductile shear zone developed within the Max Patch Granite (see Figure 24-page 122). The concentration of strain within this ductile shear leads to the progressive development of the present 10 to 20 meter thick zone of intense ultramylonite (Figure 37). The regional persistence of epidote-rich, peralkaline granites along much of the extent of the western portion of the allochthonous

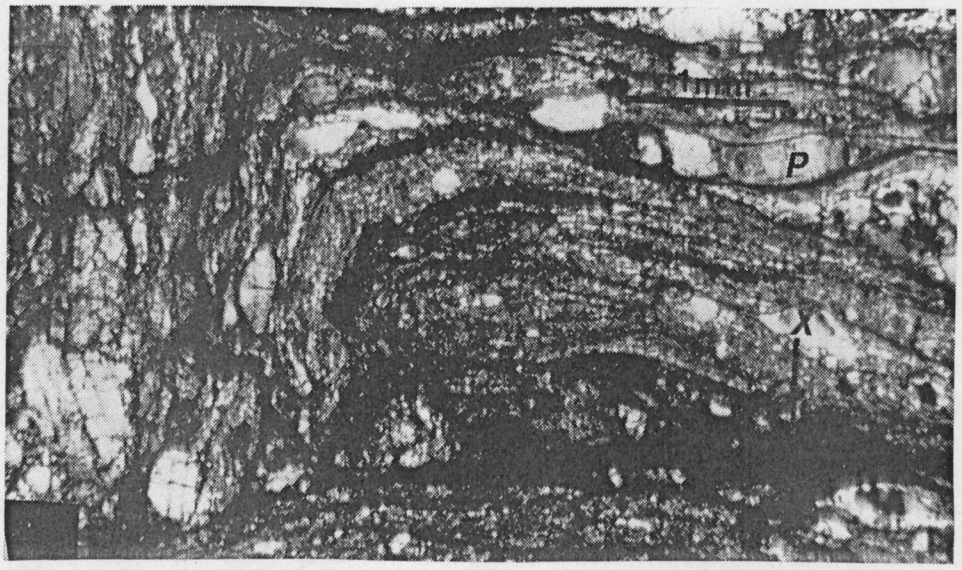


Figure 37. Photomicrograph of Max Patch Metagranite ultramylonite (Sample 1) (see also Figure 22, page 116). Notice that the dominant surviving porphyroclasts are plagioclase (P). Thin, dark strings of material (X) are composed mainly of biotite and Fe-oxides. Ultramylonitic material (UM) is composed of feldspar + quartz + sericite + biotite + epidote ± sphene. Note offset of kink band.

basement terrane in the Blue Ridge of western North Carolina suggests that this granite acted as a preferential weak glide zone during the initial shearing of the basement complex.

The ultramylonitization of Sandsuck sediments beneath the Rector Branch Fault suggests that the deformation at the present level of the fault was at upper greenschist facies conditions in its footwall as well (Sibson, 1977). Assuming minimal heating of the fault zone by frictional processes, the original depth of the present exposure of the fault was probably 10 to 15 km.

Calc-silicate Bodies

As previously described, two large lenses of calc-silicate are exposed in the field area, one within the main mylonite zone just southwest of the community of Barnard and a second within the fault bounded base (Brush Creek Fault) of the large quartz diorite body exposed in the northeast corner of the complex. In both exposures the lenses are internally chaotically disrupted and extensively epidotized. Epidotization is interpretated to be associated with the introduction of water into ductile shear zones. High concentrations of water in general promote diffusion creep and pressure solution processes and enhance strain-softening of the mylonites (Griggs,

1967; Sibson, 1977; Tullis 1979). An early introduction of water into the shear zones may have lead to the dissolution of calcic minerals (plagioclase, etc.) and the syntectonic precipitation of epidote (Simpson, 1983). As shear stresses continued to build, increasing fluid pressures tend to counteract increasing confining pressures and promote cataclastic deformation (Sibson, 1977).

Such a deformational sequence may explain the chaotic nature of the calc-silicate bodies exposed within the study area. This is supported by the spacial association of the lenses within areas interpreted fault zones. The fault zones could have acted as conduits for fluids. The calc-silicate body exposed near Barnard appears to have been incorporated as a rigid body during successive movement within the Rector Branch Ductile Shear Zone.

CHAPTER 6

DISCUSSION AND SUMMARY

Metamorphic History

Metamorphic Events

Deciphering the polymetamorphic history of the Cranberry Basement and Amphibolitic Basement complexes would be very difficult and is beyond the scope of this study. The probable polymetamorphic history of the two complexes and the general scarcity of aluminous metasediments makes Paleozoic chlorite-biotite and biotite-garnet isograds projected through the study area by Carpenter (1970), Hadley and Nelson (1971), and Butler (1972) speculative (Figure 38). No detailed metamorphic studies have been undertaken on the Amphibolitic Basement anywhere in the Blue Ridge.

Widespread hornblende + plagioclase ± epidote ± garnet amphibolites in the Amphibolitic Basement Complex suggest a regional metamorphic event at upper amphibolitic facies conditions (Hyndman, 1972; Myashiro, 1973; Winkler, 1976; Laird, 1982). A single sample containing kyanite + garnet interlayered with amphibolite

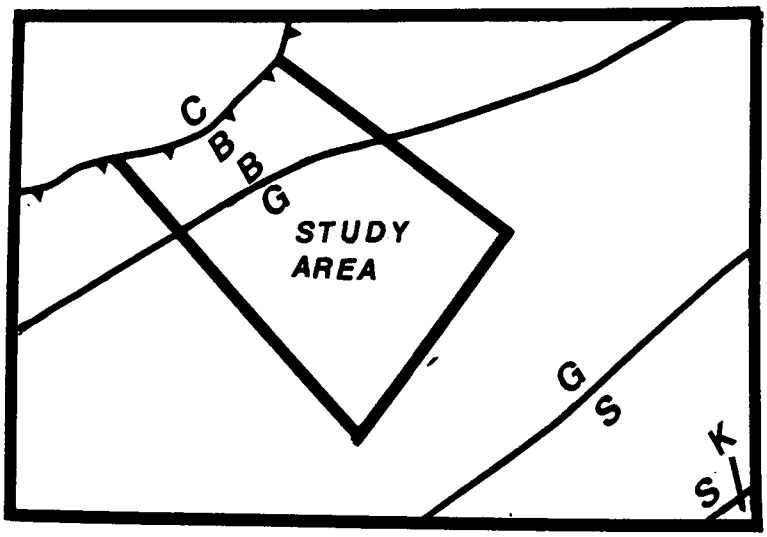


Figure 38. Regional map showing projected Paleozoic isograds in the Blue Ridge (after Hadley and Nelson, 1971; Butler, 1972). Metamorphic isograds interpreted for the study area appear anomonously high with respect to regional projections.

is also compatible with this interpretation. If orthopyroxene was correctly identified in this same sample, metamorphism may have locally reached granulite facies conditions. Scattered charnockitic lithologies in exposures of the complex just east of the study area (Merschat, 1977) similarly suggest local granulite facies conditions.

The talc-rich ultramafic body exposed near the community of Redman (Field Station 650) poses a potentially interesting problem for later detailed metamorphic studies. The assemblage talc + anthophyllite + Fe carbonate (ankerite or siderite ?) + chlorite suggests lower amphibolite facies metamorphic conditions (Evans, 1977). The unusually high concentration of carbonate minerals suggests the addition of CO_2 to the system during metamorphism. A possible source of CO_2 is the series of marble lenses exposed just east of the ultramafic body (see Plate 1).

As discussed earlier, Bakersville Metagabbro and possibly metapyroxenite bodies which appear to crosscut amphibolite bearing rocks are comprised chiefly of actinolite. Geochemically, the rocks are very similar (see Appendix A). This suggests metamorphism at no more than upper greenschist facies conditions (see Spry, 1969; Laird, 1982).

Timing Of Metamorphism

Regional Paleozoic isograds by Carpenter (1970) and Butler (1972) (assuming they are accurate), place the westward extent of amphibolites in the study area well below (to the west of) the biotite-garnet isograd (see Plate 1). The dominance of actinolite in Bakersville metagabbro dikes suggests that the rocks were not subjected to the high grade event which affected the enclosing amphibolitic rocks. The metamorphic conditions reflected in the metagabbro dikes are, however, consistent with regionally projected Paleozoic (Taconic ?) isograds. Because regionally projected Paleozoic isograds are not consistant with metamorphic conditions interpreted for the study area and Bakersville metagabbro bodies appear to record lower metamorphic conditions than the enclosing basement rocks, the amphibolite to higher facies metamorphic event recognized in the Amphibolitic Basement Complex is interpreted to have occured during the Middle to Late Proterozoic. Upper greenschist facies metamorphism of the Bakersville Metagabbro is interpreted to reflect a lower grade (Taconic ?) overprint of the basement complexes. This timing for the major metamorphism of the Bakersville suite is consistant with interpretations by Rankin (1975) and Goldberg and others (1986). The effects of possible lower grade overprints of

the basement complexes needs to be studied over a broader area.

Recognition Of The Amphibolitic Basement Complex

The unit refered to in this study as the Amphibolitic Basement Complex was recognized as a separate, lithologically distinct body of rock by several workers (e.g. Bryant and Reed, 1970; Hadley and Nelson, 1971; and Merschat, 1977). Unlike the structurally underlying granitic basement complexes (e.g. Cranberry Basement), the Amphibolitic Basement Complex contains abundant lenses and pods of amphibolite as well as local occurances of ultramafic bodies and even marble. On the scale of a single outcrop, this distinction is sometimes difficult to make. Unlike the Ocoee Series, the Amphibolitic Basement Complex contains abundant igneous rocks and is not characterized by metasediments.

The field distinction between the Amphibolitic Basement Complex and the structurally overlying terrane consisting of the Ashe, Tallulah Falls, and Coweeta suites can be somewhat difficult because both terranes are characterized by lenses and pods of amphibolite and scattered ultramafic bodies (Bryant and Reed, 1970; Rankin, 1975; Abbott and Raymond, 1984). This contact was not present or studied in this study. The most persistent

distinguishing characteristic appears to be the overall lack of aluminous metasediments in the Amphibolitic Basement Complex. In the area north of Asheville, the Amphibolitic Basement Complex is further distinguishable by the presence bodies of Bakersville Metagabbro and less commonly granites of the Crossnore Plutonic Suite (e.g. the Indian Grave Granite of this study). In this same area, the rocks of the Amphibolitic Basement Complex appear to record anomalously high metamorphic conditions in comparison to regionally projected Paleozoic isograds.

Where a field distinction between the Amphibolitic Basment Complex and the structurally overlying Ashe, Tallulah Falls and Coweeta suites is especially difficult, it may be possible to distinguish between the two terranes by radiometric dating methods and/or comparison of amphibolite geochemistry. As suggested by the radiometric Grenville age on a granitic gneiss from the complex and the apparent intrusion of Bakersville equivalent metagabbro, the Amphibolitic Basement Complex is interpreted to be Middle to Late Proterozoic in age. In contrast, the Ashe, Tallulah Falls and Coweeta suites are interpreted to be Late Proterozoic or younger in age (Rankin, 1975; Hatcher, 1978, Abbott and Raymond 1984). Based on work from this study, hornblende amphibolites in the Amphibolitic Basement Complex appear to largely represent tholeiitic, continental basalts. Amphibolites

of the Ashe Suite, in contrast, appear to largely represent basalts of more oceanic affinity (see Conte, 1986). Geochemical studies of both complexes are at too early a stage to make any conclusive comparisons.

Interpretations

At least five major series of deformational events and possibly a minor late intrusive event led to the present day configuration of the Amphibolitic Basement Complex and the Cranberry Granitic Basement Complex. In the following text, the progressive evolution of the two complexes is subdivided into five time periods: 1) Middle to Late Proterozoic, 2) Late Proterozoic, 3) Ordovician/Devonian, 4) Later Devonian (?), and 5) Permian. These time periods are based on correlations with radiometrically dated regional events, in conjunction with a relative sequencing of crosscutting features observed in the study area.

Middle To Late Proterozoic-Basement Protoliths (D1-D3)

Cranberry Granitic Basement Complex

The Cranberry Basement is interpreted to represent a Middle Proterozoic (Grenville-age) granitic cratonic complex once attached to the eastern edge of the present

day North American Craton (Fullagar and Odom, 1973; Rankin, 1975; Bartholomew and Lewis, 1984). Gneissic rocks in the complex were first foliated and later folded during early D1 and D2 events. Comparatively undeformed bodies of granodiorite to diorite scattered throughout the complex probably intruded the gneissic country rock at some time later during the Middle Proterozoic Grenville event (D3) (Bartholomew and Lewis, 1984). The Max Patch Granite intruded the western part of the complex during the Middle or Late Proterozoic.

Amphibolitic Basement Complex

The protolith of the Amphibolitc Basement Complex is interpreted to have been a plutonic and volcanic (?) complex developed during Middle to Late Proterozoic incipient rifting of Grenville-age granitic crust. During this rifting event, gneissic granitic crust similar to the Cranberry Basement was intruded by continental basaltic magmas now represented by widespread amphibolites. Rifting eventually developed some type of transitional crust. This interpretation of the complex is supported by: 1) the abundance of biotite granitic gneiss, some of which has been dated at 1.2by, and the similarity of this rock with the dominant "country rock" of the Cranberry Basement, 2) the observation that amphibolite dikes crosscut these granitic gneissic rocks,

and 3) geochemical data which suggest that these amphibolites represents "within-plate" basalts.

Middle To Late Proterozoic Closure Of Rift Complex (D4-D8)

Closure of the rift during the middle to Late Proterozoic resulted in the complex disruption/dismemberment of the mafic/granitic complex and the ultimate accretion of the complex to the Cranberry Granitic Basement Terrane to the west. Deformational episodes are represented by structures, etc. associated with the D4-D8 deformational events. Blocks of lower crustal ultramafic rock and dolomitic carbonate were tectonically incorporated into the complex by extraformational mixing during deformation. As discussed earlier, amphibolite to higher facies metamorphism of the complex (D4/M1) occured either during the early stages of or throughout the accretionary event. D4 through D8 most reasonably represent a progressive dismemberment and accretion of the complex to the granitic basement rather than a series of distinct, unrelated events.

During the late stages of this accretionary event, the Amphibolitic Basement and possibly the Cranberry Basement were sporadically migmatized (D6). Migmatization

is tentatively interpreted to be related to either metamorphic differentiation or partial melting of the complexes during peak M1 metamorphism. Charnokitic lithologies just east of the study area (Merschat, 1977) may be indicative of granulite facies metamorphism at the same time, potentially accompanied by partial melting. Quartz veining developed during the late stages or after migmatization of the complex.

The dominant foliation (S3) now expressed in the Amphibolitic Basement Complex and parts of the Cranberry Basement Complex, which is not completely overprinted by S4, is interpreted to have developed during intense shortening or "flattening" of the complexes late during the accretion of the Amphibolitic Basement to the Cranberry Basement along the unnamed fault contact separating the two complexes. The local occurance of quartz veins parallel to and not deformed by S3 suggests a continued intrusion(s) of quartz after the Middle to Late Proterzoic event. Late quartz veins are very common in the Blue Ridge.

Melange-Like Features Of The Amphibolitic Basement Complex

The Amphibolitic Basement Complex displays several features which strongly suggest that it was disrupted

during the Middle to Late Proterozoic to such an extent that it may be more correct to refer to the complex as a melange. These features include:

1) a lack of internal continuity-no mappable stratigraphic order could be developed for the complex, and
2) the presence of randomly distributed, discontinuous lenses and pods of variable lithology, potentially representing "native" and "exotic" blocks tectonically incorporated into the complex during dismemberment of the rifted crust (see Maxwell, 1974; Dickinson and Seely, 1979; Korsch, 1982). These lithologies include:
   a. talc-rich ultramafic bodies and local metapyroxenite, interpreted to represent lower crustal or upper mantle material,
   b. amphobolite (and possibly metabasalt porphyry), interpreted to represent intrusive and possibly extrusive continental basalts, and
   c. diopsidic marble, interpreted to represent siliceous, dolomitic sedimentary carbonates (or possibly carbonatites ?).

Melanges are defined by Raymond (1984) as " a body of rock mappable at a scale of 1:24000 or smaller characterized both by the lack of internal continuity of contacts of contacts or strata and by the inclusion of fragments of blocks of all sizes, both exotic and native, embedded in a fragmented matrix of finer grained material". The term "melange" is purely descriptive and not meant to denote any particular style of deformation to explain its genesis. The apparant dominance of igneous material suggests that the Amphibolitic Basement Complex developed by tectonic processes rather than sedimentary olistostromal processes (see Cowan, 1982). The presence of apparently tectonically incorporated blocks of ultramafic rocks typically mark subduction-related accretionary terranes (see Moores, 1970; Karig and Sharman, 1975; Raymond and Abbott, unpublished manuscript).

Late Proterozoic (D9)

During the Late Proterozoic, both the Cranberry Basement and the structurally overlying Amphibolitic Basement Complex were intruded by gabbroic and granitic magmas of the Bakersville and Crossnore plutonic suites (D9). The intrusion of these magmas is interpreted by Rankin (1975) to reflect early rifting associated the

opening of the Proto-Atlantic Ocean. Continued rifting of the basement led to the deposition of the Late Proterozoic Ocoee Series sedimentary package and the Grandfather Mountain and Mount Rogers sediments and volcanics (Rankin 1975).

Ordovician/Devonian

During the Ordovician (Taconic ?) and/or the Devonian (Acadian ?), the Cranberry and Amphibolitic basement complexes were thrust over the Ocoee deposits to the west along the Rector Branch Fault. This event (D10) led to intense ductile shearing along the Rector Branch Fault and the sporadic mylonitic overprint of both complexes.

The Sweetwater and Brush Creek faults are interpreted to represent minor splays off of the Rector Branch Fault. Horses of Ocoee may have been plucked off of the footwall of the Rector Branch Fault and incorporated into the main mylonite zone along a series of minor imbricates. Waning movement within the Rector Branch Fault Zone is recorded as conjugate sets of kink bands developed only in ultramylonites within a few tens of meters of the fault contact. An alternative interpretation may be that the kinks reflect a later period of deformation and they are only visible in the finely layered ultramylonite.

Other than a distinct, widespread mylonitic overprint, further deformation of the basement complexes during the emplacement of the Rector Branch Fault is very difficult to separate from the Middle to Late Proterozoic deformational fabrics. The locally intense mylonitization of the Indian Grave Metagranite (Crossnore ?) suggests that a great deal of deformation may have occured prior to and/or during the emplacement of the Rector Branch Fault. The intense deformation of the complexes (D8) observed in the study area, however, extends to the eastern margin of the Amphibolitic Basement terrane, well beyond the likely limit of strong deformational effects associated with the emplacement of any single "Rector Branch Fault".

At some time during the Paleozoic (Ordovician and/or Devonian ?) (Taconic ?) the complexes in the study area were overprinted by a metamorphic event at apparently no higher than upper greenschist facies (M2) (Butler, 1972). This may be evident by the alteration of Bakersville gabbros and possibly pyroxenites to rocks composed chiefly of actinolite. Proterozoic-age metamorphic assemblages do not appear to have extensively re-equilibrated to this later metamorphic event.

Later Devonian (D11 ?)

Thin pegmatite dikes crosscutting the S1 and possibly the S3 foliations of the Cranberry and Amphibolitic basement complexes do not appear to have been affected by the late S4 mylonitic overprint associated with the emplacement of the Rector Branch Fault. Exposures of the dikes, however, were too small and too rare to constrain tightly their relative age relationships with other deformational events recognized in the study area. If the dikes post-date S4, they may be associated with the Late Devonian intrusion of pegmatites exposed in the Spruce Pine area northeast of the study area (Butler, 1972). If the dikes predate S4, they may be related to the Late Proterozoic intrusions of the Crossnore and Bakersville suites (Rankin, 1975).

Carboniferous/Permian (D12)

During the Alleghanian (Carboniferous/Permian) development of the Valley and Ridge foreland thrust belt, duplexing beneath the Rector Branch thrust sheet folded the fault and produced a very localized cataclastic foliation within the D10 mylonites (D12, F5, S5) (Oriel 1950, 1951; Rodgers, 1970). In general, this late deformational event appears to have produced little

fabric away from the trace of the fault. An interesting exception may be the Roberts Mountain Fault. The lack of a well-defined mylonite zone and extensive mixing of the Roberts Mountain Basement and Amphibolitic Basement lithologies within the fault zone suggests the fault may have developed under more brittle conditions than faults such as the Sweetwater and the Brush Creek. The localized uplift of the Roberts Mountain Complex may in turn reflect further Alleghanian-age duplexing beneath the basement thrust sheet (see Figure 10-page 86).

Large-Scale Intermixing Of The Basement Complexes

There has been considerable ongoing debate over the relationship of amphibolites in the granitic basement of the Blue Ridge to those in the structurally overlying complexes (e.g. see Vincent, 1983; Abbott and Raymond, 1984). In the field and geochemically, the distinction between the local amphibolitic lenses exposed in the Cranberry Basement and those typical of the Amphibolitic Basement as a whole is imprecise. If the hornblende amphibolite-bearing lenses in the Cranberry Basement are genetically related to the structurally overlying Amphibolitic Basement, they may represent:

1) higher and/or more western intrusive levels of the protolith of the Amphibolitic Basement Complex, or
2) blocks of the Amphibolitic Basement Complex that were tectonically incorporated into the Cranberry Basement either during the Middle to Late Proterozoic accretion event or by later high-angle faulting which cut the contact between the two complexes.

The Brush Creek Fault (described earlier) may be an example of the latter idea. Late, high-angle reverse movement along the fault and subsequent erosion may have isolated a protrusion of the Amphibolitic Basement Complex within the Cranberry Basement Complex (Figure 39, see Plate 1). In a similar fashion, the Roberts Mountain Basement Complex was probably incorporated into the Amphibolitic Basement Complex by localized high-angle reverse movement along the Roberts Mountain Fault (see Figure 10-page 86, Plate 1).

Conclusions

The Amphibolitic Basement Complex exposed in the Blue Ridge of Province of central western North Carolina initially developed during Middle to Late Proterozoic incipient rifting of Grenville-age granitic crust and the

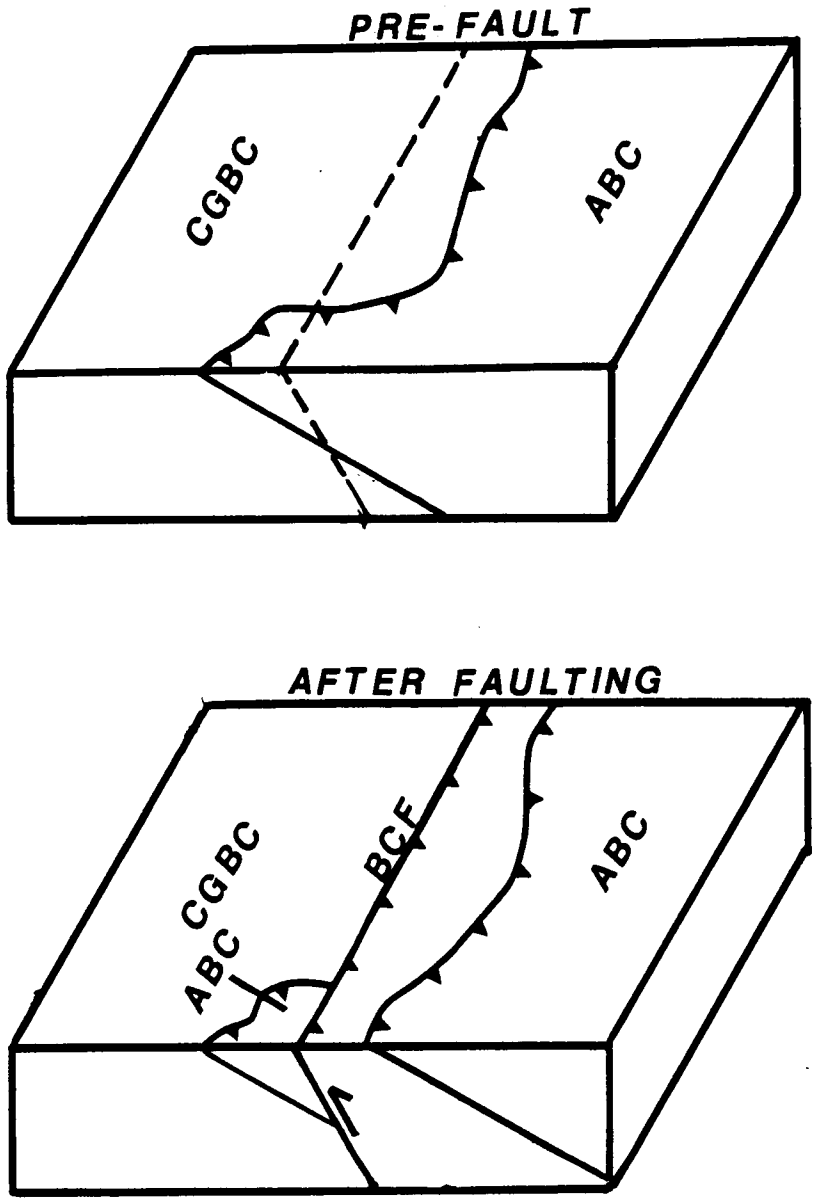


Figure 39. Schematic drawing showing possible explanation for the presence of Amphibolitic Basement Complex-like lithologies (ABC) in the footwall of the Brush Creek Fault (BCF). Uplift along the fault and subsequent erosion may have isolated a protrusion of the Amphibolitic Basement within the Cranberry Granitic Basement Complex (CGBC).

subsequent intrusion of within-plate, probably continental basalts. Possibly subduction-related closure of the rift complex later during the Middle to Late Proterozoic resulted in the intense disruption of the rifted crust and the tectonic incorporation of "native" and "exotic" blocks of Alpine-type ultramafic rocks and pyroxenites, intrusive and extrusive (?) continental basalts, and siliceous, dolomitic carbonates (or possibly carbonatites) into the disrupted transitional crustal material. Major deformation and emplacement of the complex onto the Cranberry Granitic Basement Complex occured no later than the Late Proterozoic (734-700ma), as demonstrated by the crosscutting nature of the Bakersville and Crossnore intrusive suites. The development of the Rector Branch Fault and the coincident emplacement of the basement complexes over the Late Precambrian Ocoee Series clastics produced an extensive but widely spaced mylonitic overprint in both complexes. The Rector Branch Fault was subsequently folded by duplexing associated with the Alleghanian development of the Hot Springs Window Complex (Oriel, 1950, 1951).

Contrary to previous inferences, the fault contact between the Amphibolitic Basement Complex and the Cranberry Granitic Basement Complex is interpreted to be Middle to Late Proterozoic in age and therefore cannot be directly related to the hypothosized Ordovician/Devonian

"Hayesville-Fries Fault". Secondly, the Amphibolitic Basement Complex cannot be genetically or lithologically related to the structurally overlying Ashe, Tallulah Falls and Coweeta suites if these suites are interpreted to have developed after the intrusion of the Bakersville and Crossnore plutonic suites. If a single, continuous Ordovician-Devonian "Hayesville-Fries Fault" can actually be drawn separating a "continental" from an "oceanic" Blue Ridge, this study suggests that the boundary must lie no further west than the upper or eastern contact of the Amphibolitic Basement Complex.

As a closing note which may in the future add some circumstantial support for this interpretation of the Amphibolitic Basement Complex, the clastic sediments of the Late Precambrian Ocoee Series are widely interpreted to have been derived from the erosion of Grenville-age granitic crust, similar to the Cranberry Basement Complex in the study area. The presence during the Late Proterozoic of an additional source terrane similar to the Amphibolitic Basement Complex may aid in explaining the local occurrance of mafic material and more importantly marble lithic fragments in essentially unmetamorphosed conglomerates of the the Ocoee, because these lithologies are not common to the granitic basement complexes exposed in western North Carolina.

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APPENDIXES

APPENDIX A

XRF Methods

Selected samples were manually crushed and then pulverized by use of a ceramic (tungsten carbide) shatter box. Pellets were made using boric acid as a flux. Analyses of the samples was carried out using a computerized EG & ORTEC X-ray fluorescence spectrometer. The program utilized (IGROCK) had been calibrated for igneous rocks using 22 reference materials. The same program was utilized by Conte (1986) in XRF analyses of selected amphibolites from the Ashe Metamorphic Suite northwest of the study area. The standards AGV-1 (andesite), MRG-1 (gabbro), BCR-1 (basalt) were selected for use in this study. Norm-1 (glass) was used to normalize the system. Samples were analyzed for the oxides Na_2O, MgO, Al_2O_3, SiO_2, P_2O_5, K_2O, CaO, MnO, Fe_2O_3, TiO_2 and the elements Cr, Ni, Rb, Sr, V, Zr, and Nb.

Cr values may be anomonously high due to the use of the tungsten carbide shatterbox. For a more complete discussion of the program used to analyze the samples see Conte (1986).

Values for standards

AGV-1

Element	calc. %	measured %	Std Error Calc %	Std Dev
Na_2O	1.42	1.77	0.16	2.19
MgO	12.81	13.66	0.23	3.60
Al_2O_3	8.32	8.68	0.27	1.33
SiO_2	44.24	43.86	0.73	0.79
P_2O_5	0.17	0.09	0.03	2.29
K_2O	0.31	0.31	0.07	0.00
CaO	14.84	14.75	0.09	0.99
MnO	0.18	0.17	0.03	0.37
Fe_2O_3	17.89	17.70	0.20	0.95
TiO_2	3.72	3.70	0.03	0.65
V	538	527	31	0.35
Cr	510	482	59	0.47
Ni	156	138	31	0.58
Rb	5	6	5	0.20
Sr	163	162	36	0.03
Y	9	10	5	0.20
Zr	78	77	21	0.05
Nb	13	13	3	0.00

Values for standards

MRG-1

Element	calc. %	measured %	Std Error Calc %	Std Dev
Na_2O	1.77	1.42	0.16	2.19
MgO	12.81	13.66	0.23	3.60
Al_2O_3	8.32	8.68	0.27	1.33
SiO_2	44.24	43.86	0.73	0.79
P_2O_5	0.17	0.09	0.03	2.29
K_2O	0.31	0.31	0.07	0.00
CaO	14.84	14.75	0.09	0.99
MnO	0.18	0.17	0.03	0.37
Fe_2O_3	17.89	17.70	0.20	0.95
TiO_2	3.72	3.70	0.03	0.65
V	538	527	31	0.35
Cr	510	482	59	0.47
Ni	156	138	31	0.58
Rb	5	6	5	0.20
Sr	163	162	36	0.03
Y	9	10	5	0.20
Zr	78	77	21	0.05
Nb	13	13	3	0.00

Values for standards

BCR-1

Element	calc. %	measured %	Std Error Calc %	Std Dev
Na_2O	3.42	3.32	0.16	0.63
MgO	2.80	3.39	0.23	2.56
Al_2O_3	13.95	13.57	0.27	1.41
SiO_2	56.18	55.06	0.73	1.53
P_2O_5	0.48	0.35	0.03	3.88
K_2O	1.83	1.71	0.07	1.68
CaO	6.77	6.87	0.09	1.10
MnO	0.20	0.19	0.03	0.37
Fe_2O_3	12.95	13.21	0.20	1.30
TiO_2	2.15	2.17	0.03	0.65
V	256	237	31	0.61
Cr	178	187	59	0.15
Ni	48	48	31	0.00
Rb	36	40	5	0.80
Sr	300	280	36	0.56
Y	32	27	5	1.00
Zr	140	138	21	0.10
Nb	13	13	3	0.00

Replicate Analyses of selected samples (oxides in wt%; elements in rounded ppm).

	1st Run	2nd Run	1st Run	2nd Run
Sample #	344	344	14	14
Na_2O	1.77	1.90	3.41	3.38
MgO	8.71	8.54	5.46	5.31
Al_2O_3	9.41	9.34	14.53	14.23
SiO_2	54.60	54.23	49.72	49.37
P_2O_5	0.25	0.22	0.46	0.43
K_2O	0.70	0.70	0.87	0.88
CaO	10.63	10.62	7.91	7.88
MnO	0.20	0.19	0.19	0.17
Fe_2O_3*	11.66	11.55	13.81	13.65
TiO_2	0.50	0.51	2.39	2.37
V	233.00	215.00	215.00	185.00
Cr	331.00	349.00	153.00	150.00
Ni	79.00	73.00	44.00	44.00
Rb	16.00	18.00	25.00	27.00
Sr	163.00	153.00	295.00	294.00
Y	77.00	31.00	31.00	29.00
Zr	79.00	84.00	124.00	125.00
Nb	11.00	13.00	15.00	16.00
Total	98.53	97.91	98.84	97.77

* includes total Fe-oxide.

APPENDIX B

Whole Rock Analysis Of Selected Samples

Whole rock analyses of selected samples (oxides in wt%; elements in rounded ppm). Amphibolite (A); talc-rich ultramafic rock (TUM); actinolite semi-schist (AS); Bakersville metagabbro (BM), metapyroxenite intrusive (PI?).

	A	A	A	A	A
Sample #	344	52b	397	34	52a
Na_2O	1.77	3.82	2.71	2.87	3.11
MgO	8.71	3.99	4.14	5.21	6.67
Al_2O_3	9.41	16.98	12.74	14.87	15.81
SiO_2	54.60	48.83	49.79	47.74	49.03
P_2O_5	0.25	0.82	0.75	0.62	0.30
K_2O	0.70	1.77	1.08	0.60	0.46
CaO	10.63	7.63	7.66	11.10	10.78
MnO	0.20	0.17	0.18	0.15	0.10
Fe_2O_3*	11.66	12.27	17.61	13.86	11.27
TiO_2	0.50	1.96	3.78	2.59	1.26
V	233.00	200.00	183.00	276.00	195.00
Cr	331.00	84.00	204.00	112.00	51.00
Ni	79.00	24.00	80.00	48.00	92.00
Rb	16.00	64.00	18.00	10.00	13.00
Sr	163.00	436.00	250.00	321.00	361.00
Y	77.00	31.00	41.00	18.00	15.00
Zr	79.00	182.00	178.00	96.00	107.00
Nb	11.00	17.00	30.00	12.00	9.00
Total	98.53	98.34	100.51	99.70	99.05

* includes total Fe-oxide.

	A	A	A	A
Sample #	726	702b	22	276
Na_2O	2.18	3.44	3.33	3.09
MgO	5.86	4.93	4.63	3.65
Al_2O_3	13.60	14.41	14.20	14.40
SiO_2	45.88	46.17	48.89	51.03
P_2O_5	0.26	0.81	1.41	0.60
K_2O	0.72	0.63	0.56	0.94
CaO	11.07	9.41	10.34	8.42
MnO	0.13	0.18	0.24	0.15
Fe_2O_3*	18.01	17.56	15.18	14.01
TiO_2	1.04	3.58	2.63	3.23
V	322.00	210.00	214.00	213.00
Cr	145.00	165.00	105.00	148.00
Ni	65.00	47.00	43.00	39.00
Rb	8.00	10.00	8.00	20.00
Sr	126.00	209.00	314.00	414.00
Y	24.00	31.00	47.00	30.00
Zr	65.00	167.00	78.00	167.00
Nb	4.00	28.00	33.00	25.00
Total	98.83	101.21	101.49	99.54

	A	TUM	AS
Sample #	158	650	716
Na_2O	1.60	0.35	1.07
MgO	4.58	28.00	11.76
Al_2O_3	10.69	2.48	6.56
SiO_2	48.60	52.17	50.74
P_2O_5	0.48	0.07	0.22
K_2O	0.88	0.08	0.58
CaO	10.87	0.02	12.20
MnO	0.32	0.13	0.29
Fe_2O_3*	20.18	7.53	14.48
TiO_2	2.73	0.01	0.61
V	347.00	17.00	355.00
Cr	215.00	1954.00	2640.00
Ni	75.00	1568.00	551.00
Rb	31.00	3.00	9.00
Sr	77.00	21.00	48.00
Y	43.00	9.00	138.00
Zr	91.00	23.00	60.00
Nb	16.00	1.00	13.00
Total	101.02	91.19	98.89

	BM	BM?	PI?	PI?
Sample #	14	667	18a	18b
Na_2O	3.41	1.31	1.14	0.95
MgO	5.46	4.44	14.88	19.11
Al_2O_3	14.53	4.31	6.31	3.19
SiO_2	49.73	49.16	50.82	55.38
P_2O_5	0.46	0.33	0.18	0.11
K_2O	0.87	0.66	1.77	0.15
CaO	7.91	10.66	10.95	12.24
MnO	0.91	0.38	0.35	0.29
Fe_2O_3*	13.81	26.76	11.29	6.55
TiO_2	2.39	0.29	0.51	0.08
V	215.00	292.00	274.00	85.00
Cr	153.00	331.00	2876.00	3684.00
Ni	44.00	90.00	221.00	617.00
Rb	25.00	3.00	78.00	6.00
Sr	295.00	24.00	35.00	40.00
Y	31.00	40.00	29.00	19.00
Zr	124.00	41.00	36.00	24.00
Nb	15.00	29.00	8.00	3.00
Total	98.85	98.39	98.57	98.50

APPENDIX C

Road Log And Description Of Stops

ROAD LOG AND DESCRIPTION OF STOPS

Excluding Stop 1, the field stop route is shown on Figure 40.

MILEAGE Cumulative	Interval	Description
0.0	0.0	Depart from Geology and Geography building on UT Campus. Turn left onto Cumberland. Turn right onto 17th Street. Take I-40E/I-81N toward Ashville.
33.2	33.2	I-81N and I-40E divide. Stay on I-40E to Ashville.
93.2	60.0	Take 19/23/70 exit towards Marshall/Weaverville. Proceed north towards Marshall.
111.2	18.0	Marshall/Weaverville exit. Take 25/70 west towards Marshall.
0.0	0.0	Reset mileage to 0.0 after crossing 19/23 overpass (to aid those not traveling from Knoxville).
3.5	3.5	Turn right (south) onto Lower Flat Creek Road.
5.5	2.0	Turn left (east) onto Old State Highway 25/70.
6.1	0.6	Pull off road onto gravel lot beside French Broad River.

Stop 1. Excellent roadcut exposure of the Amphibolitic Basement Complex. Note the general lack of internal continuity of the complex. Migmatitic material crosscuts most deformational fabrics of the complex but is in turn disrupted by later deformation. Xenoliths of hornblende amphibolite/granitic gneiss are locally present in generally nonfoliated intrusions of granodiorite. The relationship between the migmatite and the granodiorite is uncertain. Proceed westward (downriver) along Old 25/70 to town of Marshall. This road parallels the French Broad River.

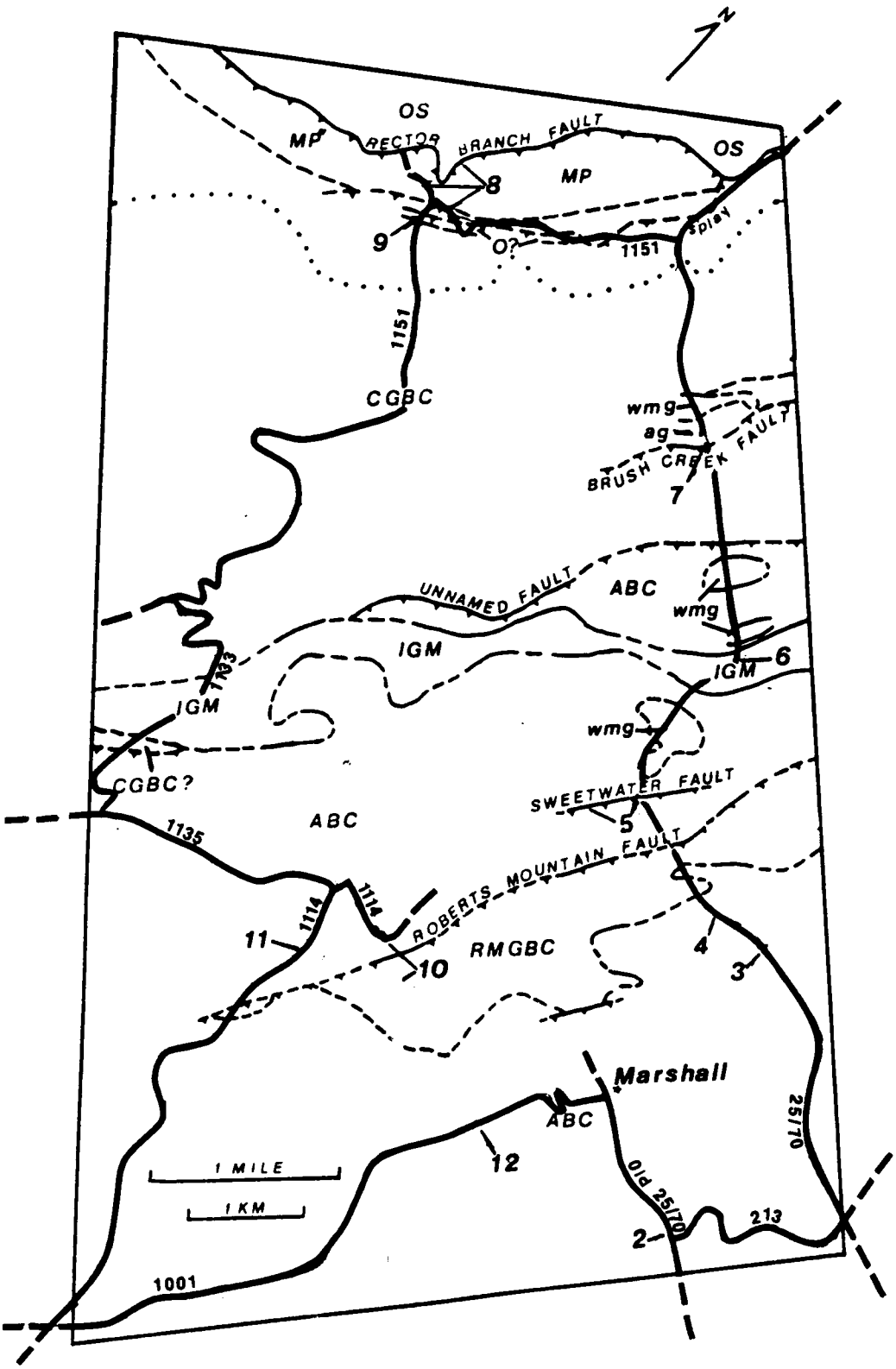


Figure 40. Generalized geologic map of study area showing field trip route. Stops numbered 2-12.

MILEAGE Cumulative	Interval	Description
15.6	1.5	Turn right onto State Road 213 and park beside road.
14.1	8.0	Cross Ivy Creek, turn left onto Old 25/70 Business - Marshall

Stop 2. Field Stations 211-215, 485-489. Extensive roadcut exposure of Amphibolitic Basement Complex. Here the Amphibolitic Basement Complex appears slightly better "layered" than at Stop 1. The rock consists of interlayered/intermixed biotite granitic gneiss/semi-schist and hornblende amphibolite. Note the discontinuous nature of interlayers of hornblende amphibolite within the enclosing rock. Also note the high degree of deformation in the complex. To the west (towards Marshall), the unit grades quickly into a northeast-southwest trending belt of massive to semi-schistose biotite granitic rock with significantly less amphibolitic material. Continue northward on State Road 213.

17.0	1.4	Turn left (northwest) onto State Highway 25/70 (Marshall Bypass) towards Hot Springs.
17.4	0.4	Roadcut exposures of Amphibolitic Basement Complex, similar to previous stop. (Field Stations 191 & 192).
18.5	1.1	Pull off onto shoulder of road.

Stop 3. Field Station 179. Roadcut exposure of Amphibolitic Basement Complex on south side of road. In this outcrop granitic migmatite crosscuts S1 and F1 and is in turn folded about F3 All fabrics in the rock are truncated by the S4 mylonitic overprint (see sample 179*, Figure 20, page 108). Hornblende amphibolitic comprises only a small part of the western end of the outcrop. Proceed northwest on 25/70.

18.9	0.4	Pull off into gravel road on right.

Stop 4. Field Station 183. A narrow lense (dike ?) of metabasalt porphyry exposed in the roadcut on the left (south) side of road. Note the excellently preserved plagioclase phenocrysts within hornblende plagioclase

MILEAGE		
Cumulative	Interval	Description

groundmass (see Figure 29, page 132). Sample sparingly, this is the only exposure of this lithology. Proceed west on 25/70.

19.7	0.8	Turn left (south) onto Sweetwater Road. Park on shoulder of road approximately 50 meters from intersection.

Stop 5. Field Station 340. A 6-7 meter wide dike of Bakersville metagabbro is poorly exposed in small cut just to the left (east) of the gravel road (see Figure 19(a), page 106). The dike is truncated by the hangingwall of the Sweetwater Fault. The fault is marked by the contact between a locally sheared granitic rock in the hangingwall and very amphibolitic gneisses/semi-schists in the footwall. Better exposures of the Sweetwater Fault are present approximately 1-2/10 ths of a mile (include on road log mileage) down the road. At the time of the study ,the fault was not traceable beyond these exposures. Note the local crosscutting nature of hornblende amphibolite "dikes" with granitic gneisses, local migmatite crosscutting hornblende amphibolites and grantitic gneisses, and local pegmatitic dikes crosscutting migmatite and most deformational fabrics. Improvements on Sweetwater Road by the state began during field work. Numerous new roadcuts through the Amphiboitic Basement Complex should be completed during further construction on this road. Return to State Highway 25/70, proceed northwest (left).

21.2	1.5	State Highway 25/70 - Indian Grave Gap Road intersection. Park at intersection.

Stop 6. Field Station 166. Small but fresh exposure of Indian Grave Granite (see Figure 19(b), page 106). This granite is lithologically identical to the Beech Granite of the Crossnore Plutonic Suite. This belt of granite appears to crosscut the contact between the Amphibolitic Basement Complex and the Cranberry Granitic Basement Complex (see Plate 1). Proceed northwest on 25/70.

22.3	1.1	Pull off on shoulder of road.

Stop 7. Field Stations 156-158, 727. Brush Creek Fault Zone exposed in roadcuts on the north side of 25/70, just past intersection with Brush Creek Road (see Figure 12,

MILEAGE		
Cumulative	Interval	Description

page 91). The easternmost exposure is a quartz diorite, interpreted to have intruded the Cranberry Basement Complex. The quartz diorite body is underlain by an amphibolitic gneiss, possibly equivalent to the Amphibolitic Basement Complex (see Figure 38, page 148). The two units are separated by a 40 meter + wide zone of locally intensely sheared, internally chaotic, calc-silicate. This zone is interpreted to represent a tectonized, altered equivalent of the quartz diorite body. Proceed northwest on 25/70.

23.6	0.3	Turn left (southwest) at the community of Walnut onto State Road 1151. Proceed southwest.
26.5	2.9	Community of Barnard, French Broad River. Do not cross river, park in the field below and on the southeast side of the bridge.

Stop 8. Field Stations OS1, OS2, 1-3. Rector Branch Fault Zone. Walk approximately 350 meters northwestward along the railroad tracks to the railroad cuts on the north side of the tracks. Note progressive mylonitization of Max Patch Metagranite as you proceed to the west. The well bedded rocks at the sharp bend in the tracks are Sandsuck (Ocoee Series) metasediments. The actual fault contact between the Max Patch and the underlying Sandsuck metasediments is poorly exposed in the gap between railroad cuts of Sandsuck and Max Patch (see Figure 9, page 83). Both units are intensely ultramylonitized within a few tens of meters of the contact. Ultramylonitized Max Patch Granite is distinguishable from underlying Sandsuck ultramylonites by the presence of pink feldspar. Proceed back to bridge. A good railroad-cut exposure of typical Cranberry biotite granitic gneiss/semi-schist and local amphibolitic rock is present approximately 1.4km down the railroad tracks to the southeast (Field Station 5).

Walk across bridge. A lense of internally chaotic, highly epidotized, calc-silicate is exposed approximately 200 meters to the right (northwest) on State Road 1151 (Field Station 556). The lithology is interpreted to represent epidotized Max Patch mylonite. Epidotization may be due to localized infiltration of fluids into the fault zone. Proceed back across bridge to parking area.

MILAGE		
Cumulative	Interval	Description

Drive across bridge and turn left (southeast) onto State Road 1155.

26.7	0.2	Roadcut exposures on right (southwest) side of road. Park on shoulder of road.

Stop 9. Field Station 593. Possible horse of ultramylonitic Ocoee brought up along local hangingwall splays of the Rector Branch Fault (see Figure 11, page 88). Compare to ultramylonites of Max Patch and Ocoee-Sandsuck exposed in railroad cuts across river. Ultramylonites at the northwest end of the roadcut contain pink feldspar and probably represent Max Patch Metagranite. This same trend of odd, Ocoee-like rocks in the basement mylonite zone was first recognized by Keith (1904). Proceed southeast on State Road 1155. Numerous roadcut exposures of Cranberry granitic gneisses/semischists are present along this road.

28.6	0.9	Pavement ends.
30.8	2.2	Turn left (east) on State Road 1133.
31.6-31.9	1.1	Exposures of sheared Indian Grave Granite in fields to right (west) of road. The contact with between the Cranberry Basement and the structurally overlying Amphibolitic Basement is poorly exposed just to the east of exposures of the Indian Grave Granite.
32.9	1.0	Turn left (southeast) onto State Road 1135. Roadcuts on left (north) expose Amphibolitic Basement Complex hornblende amphibolitic semi-schist and local augen semi-schist.
34.4	1.5	Bridge crossing French Broad River. A small, prospected talc-rich ultramafic body is exposed on the hill directly in front of (south) the bridge (Field Station 650). Permission

MILEAGE Cumualtive	Interval	Description
		to visit this exposure may possibly be obtained from the owner of the small store just passed on the way to the bridge. Proceed across bridge on State Road 1114.
34.8	0.4	Redman Dam. Park in picnic area below dam. Walk up to railroad tracks.

Stop 10. An interlayer of weathered diopsidic marble is exposed in the railroad-cuts on the immediate west side of the 1114 underpass (Field Station 558). The Roberts Mountain Fault Zone is exposed in railroad-cuts on the east side of the underpass (Field Stations 60-64). Rather than a single mylonitized fault contact, the fault is marked by a 50 meter + wide zone of mixed of Amphibolitic Basement and Roberts Mountain Granitic Basement lithologies. Outcrop-scale folds are locally truncated by faulting. A 4-5 meter wide pegmatite dike (?) intrudes the fault zone parallel to dominant foliation. Local epidote-rich granitic rocks of the Roberts Mountain Complex are exposed at Field Station 62. Excellent railroad-cut exposures of the pinkish metagranite that characteristizes the Roberts Mountain Complex are present just to the east of the fault zone. Return to parking area, backtrack across bridge and turn left on State Road 1114.

35.6	0.8	Pull onto shoulder of road.

Stop 11. Field Station 654. Roadcut exposures of diopsidic marbles on left (east) side of road. Contacts of the marble with the enclosing rocks are poorly exposed but appear sharp. Continue south on State Road 1114.

36.2	0.6	Roadcut exposures of migmatitic amphibolitic gneiss/semi-schist (Field Station 667). Metagabbro dike (?) exposed at road level.
36.4	0.2	Roadcut exposures of diopsidic marble and interlayered, coarse-grained calc-silicate (Field Station 669).

MILEAGE		
Cumulative	Interval	Description
38.3	1.9	Turn left (north) onto State Road 1001.
41.65	3.35	Pull onto left shoulder of road into small gravel area.

Stop 12. Field Station 704. Roadcut exposure of the Amphibolitic Basement Complex displaying a garnet-bearing amphibolitic dike truncating the folded (F1) S1 foliation of the enclosing biotite granitic semi-schist (see Figure 15, page 101). The dike is located in the lower meter of the portion of the exposure directly across from the gravel parking space.

42.7	1.05	Town of Marshall. Turn right (east) onto Old 25/70. Proceed 1 mile back to Stop 2. END OF ROAD LOG.

As is probably often the case, the best exposures of the study area are not readily accessible by driving up to the outcrop. The "type" exposures of the Amphibolitic Basement complex are outcrops in the bed of Walnut Creek (see Plate 1). The best method of approach is too proceed approximately 1.5 miles down Sweetwater Road from Stop 6 to just past Field Station 374 and turn right (west) onto a gravel farm road. Proceed just over one mile to a farmhouse at the very end of the road. The farm is presently owned by a Mr. Bingham of Marshall and leased by a Mr. Fisher who lives at the farmhouse. Permission should be definitely obtained before hiking down the ravine to Walnut Creek. Exposures of the Indian Grave Metagranite cross the creek from Field Stations 395-397. The granite is very mylonitic in these exposures. Rare xenoliths of mafic gneisses are locally exposed in the metagranite. By proceeding downstream to the French Broad River one can get an excellent overveiw of the Amphibolitic Basement Complex. The contact between the Amphibolitic Basement Complex and the Cranberry Granitic Basement Complex is placed at the mouth of Walnut Creek (see Plate 1). The contact is marked by the sudden, widespread appearance of lenses and pods of hornblende amphibolite. An alternative approach to the Walnut Creek exposures would be to park at Barnard (Stop 8) and hike in the approximately 2.5 miles along the railroad tracks. Numerous exposures of typical Cranberry granitic gneiss are located along these tracks, as is also a possibly intrusive metapyroxenite at Field Station 18. END OF FIELD GUIDE.

VITA

Roger Clay Brewer was born in Richmond, Virginia, on 11 July 1962. He attended elementary school and high school in Norwood, North Carolina from 1968 to 1980. He graduated with a Bachelor of Science degree in geology from Appalachian State University in May 1984. At Appalachian State he served as president of the Geology Club in 1983-1984 and received the Outstanding Senior Award upon graduation. In September 1984 he was granted a teaching assistantship at the University of Tennessee, Knoxville and graduated with a Master of Science degree in geology in August 1986.