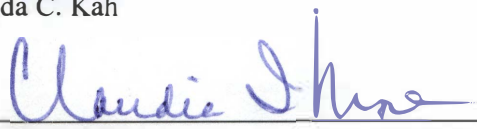


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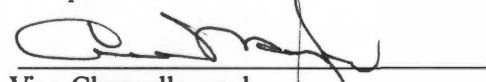
I am submitting herewith a thesis written by James Ryan Thigpen entitled "Stratigraphic and structural relationships of the Ocoee Supergroup, southern Appalachians: Implications for Neoproterozoic rift basin architecture and Paleozoic collisional orogenesis." I have examined the final paper copy of this 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.


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Thesis
2005
, T45

***STRATIGRAPHIC AND STRUCTURAL RELATIONSHIPS OF THE OCOEE
SUPERGROUP, SOUTHERN APPALACHIANS: IMPLICATIONS FOR
NEOPROTEROZOIC RIFT BASIN ARCHITECTURE AND PALEOZOIC
COLLISIONAL OROGENESIS***

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

James Ryan Thigpen
December 2005

DEDICATION

*This thesis is dedicated to my family
for their eternal love and guidance*

*My friends
for their support*

*And Janna
for her amazing patience, understanding, and love*

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ABSTRACT

The late Proterozoic-Early Cambrian Ocoee Supergroup (OSG) is the dominant lithostratigraphic sequence of the western Blue Ridge (WBR) province in southeast Tennessee, southwest North Carolina, and northern Georgia. The OSG is divided into the basal Snowbird Group (SG) that nonconformably overlies Grenvillian basement, the thick Great Smoky Group (GSG) that is usually in fault contact with the Snowbird Group, and the Walden Creek Group (WCG) that directly underlies the Cambrian Chilhowee Group and conformably overlies both the Snowbird and Great Smoky Groups. Traditional interpretations suggest that the OSG was deposited during late Neoproterozoic-Early Cambrian rifting along the southeast Laurentian margin, initially deformed and metamorphosed during the Taconic (Ordovician) orogeny, metamorphosed again (locally) during the Neoacadian (Devonian-Mississippian) orogeny, and then deformed and transported northwestward as part of the Blue Ridge-Piedmont (BRP) megathrust sheet during the Alleghanian (Pennsylvanian-Permian) orogeny. Recently reported paleontological evidence, however, suggests a mid-Paleozoic (Silurian-Mississippian) age for all or part of the OSG. Detailed mapping (1:12,000 and 1:24,000 scale) of a relatively small, previously unmapped area (~160 km²) of major structural/stratigraphic incompatibility and geochemical analyses of Walden Creek Group carbonates southwest of Great Smoky Mountains National Park (GSMNP) provide new data that are critical for delineating regionally significant stratigraphic and structural relationships.

Detailed mapping in the study area reveals that the Anakeesta-Wehutt, Ammons, Dean, and Wilhite formations form a conformable stratigraphic succession separated from the Elkmont and Thunderhead sandstones only by a minimal displacement Alleghanian fault in the Greenbrier thrust sheet. The lithologic and stratigraphic similarities of the Cades Sandstone and Dean Formation suggest that they are correlatives. The Shields Formation shares many lithologic features with the Dean Formation and lies in the same stratigraphic position beneath the Wilhite Formation in the Miller Cove thrust sheet, although the lack of graded beds suggests that the

Shields is time-transgressive with though depositionally distinct from the Cades and Dean in the study area.

Rocks of the study area are deformed by at least three periods of faulting and folding (F_1 - F_2) and one regional metamorphic cleavage-forming event (S_2). The only F_1 fold in the study area is transected by slaty cleavage (S_2 ; pressure solution and recrystallization) that is axial-planar to F_2 folds. S_2 , S_{2a} (pressure-solution), and F_2 folds are related to Taconic (480-430 Ma) Barrovian metamorphism based on $^{40}\text{Ar}/^{39}\text{Ar}$ and $^{40}\text{K}/^{39}\text{Ar}$ metamorphic mineral cooling ages and the axial-planar relationship of S_2 and S_{2a} to F_2 . Crenulation cleavage (S_3) is suborthogonal to and deforms S_2 , suggesting it occurred later. The Greenbrier and Rabbit Creek faults here were initially emplaced prior to Taconic peak metamorphism under dominantly ductile conditions. The Greenbrier fault was folded (F_2) coveval with peak Taconic metamorphism, which prevented late Paleozoic reactivation of that structure. The brittle Hangover Lead fault likely propagated from the hinge or southeast limb of the Ducktown anticlinorium (first-order F_2) during early Alleghanian orogenesis. The brittle Salt Spring Mountain and possibly coeval Oconaluftee fault cut the folded Greenbrier surface to accommodate Alleghanian thrust displacement, while the Rabbit Creek fault was reactivated. During the latest stages of the Alleghanian orogeny, emplacement and bending of the Great Smoky thrust sheet above the Foothills duplex (Valley and Ridge horses) produced second- and higher-order F_3 folds.

Samples from localities 2 and 4 that are interpreted to contain the least altered $\delta^{13}\text{C}$ values examined in this study temporally delimit the depositional age of the Sanduck Formation to Neoproterozoic intervals interpreted as the Varanger and Sturtian glaciations, intervals near the Precambrian-Cambrian boundary (~540 Ma), and to Phanerozoic intervals from the Late Ordovician to the Silurian-Devonian boundary (~400 Ma) and from the Late Devonian (~360 Ma) to the Triassic (~240). While the results of this study seem to conclusively rule out any depositional age for the Sanduck Formation between the early Middle Cambrian and Late Ordovician, isotopic data are inconclusive with respect to differentiating Neoproterozoic

The interpreted stratigraphic position of the Sandsuck Formation beneath the Cambrian fossil-bearing Chilhowee Group and Taconic metamorphic age dates of Walden Creek samples support a Neoproterozoic rather than mid-Paleozoic depositional age. Taken together, the stratigraphic, chronological, and geochemical data are all consistent only with a Neoproterozoic depositional age.

TABLE OF CONTENTS

CHAPTER I

Introduction and Area of Study	1
Introduction.....	1
Study Area.....	8
Objectives	8
Methods.....	9
Geologic Mapping	9
Isotopic Analyses	10

CHAPTER II

Ocoee Supergroup and basal Chilhowee Group lithostratigraphy between Citico Creek and the Little Tennessee River, Tennessee and North Carolina: Revised stratigraphic correlations and implications for Neoproterozoic-Early Cambrian rift basin architecture.....	11
Ocoee Supergroup.....	11
Snowbird Group	11
Great Smoky Group	14
Walden Creek Group.....	15
Chilhowee Group	15
Previous Work.....	16
Lithostratigraphy between Citico Creek and the Little Tennessee River.....	17
Rocks of the Great Smoky thrust sheet.....	18
Sandsuck Formation.....	18
Cochran Formation (Chilhowee Group)	24
Rocks of the Miller Cove thrust sheet.....	24
Shields Formation	24
Wilhite Formation	26
Rocks of the Rabbit Creek thrust sheet.....	26
Cades Sandstone	26
Rocks of the Greenbrier thrust sheet.....	29
Elkmont Sandstone	29
Thunderhead Sandstone	29
Anakeesta Formation	32
Ammons Formation	34
Dean Formation	37
Wilhite Formation	47
New Regional Stratigraphic Correlations	49
Elkmont-Thunderhead-Copperhill-Anakeesta sequence	49
Cades-Dean-Shields sequence	51
Wilhite Formation subdivisions	53
Ocoee Supergroup unit provenance, detrital component analyses, and basin-wide stratigraphic relationships	54

Snowbird Group Depositional Chronology and Provenance.....	55
Discussion: Rift basin architecture of the southeastern Laurentian margin.....	60
Ocoee basin lithotectonic models	62
Conclusions.....	73

CHAPTER III

Structural Geology between Citico Creek and the Little Tennessee River: A key to the structure of the western Blue Ridge in southeastern Tennessee, southwestern North Carolina, and northern Georgia.....	76
Structure and Metamorphism between Citico Creek and Little Tennessee River	76
Major faults.....	76
Great Smoky fault	79
Miller Cove fault.....	81
Rabbit Creek fault.....	82
Salt Spring Mountain and Greenbrier faults	86
Hangover Lead fault	88
Minor map-scale faults	91
Flats Creek fault.....	91
Slickrock Creek and Nichols Cove fault.....	91
Folds.....	92
F ₀ folds	93
F ₁ folds	93
F ₂ folds	96
Planar structures (S-surfaces)	102
Bedding (S ₀).....	102
Slaty cleavage (S ₂)	106
Crenulation cleavage (S ₃).....	106
Western Blue Ridge structural revisions in and south of GSMNP	109
Greenbrier-Oconaluftee-Salt Spring Mountain fault system	109
Dunn Creek-Rabbit Creek-Line Springs fault system	112
Discussion.....	114
Conclusions.....	117

CHAPTER IV

Carbonate Geochemistry of the Sandsuck Formation, Walden Creek Group:	
Constraints on timing of deposition	120
Introduction.....	120
Walden Creek Group.....	123
Middle Paleozoic age of the Walden Creek Group.....	124
Isotope Chemostratigraphy	125
Methods.....	129
Sample selection	129
Petrographic methods.....	132
Analytical Methods.....	140

Analytical Results	140
Evaluation of post-depositional fluid interaction (alteration)	143
Discussion	151
Conclusions	155
 CHAPTER V	
Conclusions	157
 REFERENCES CITED	161
 APPENDIX	174
 VITA	192

LIST OF FIGURES

Figure

1-1	Major tectonic elements of the southern Appalachians showing the location of the western Blue Ridge (Laurentian margin).....	2
1-2	Regional geologic map of the southern Appalachian western Blue Ridge, portions of the Valley and Ridge and eastern Blue Ridge provinces.	3
1-3	Regional index map of the western Blue Ridge showing areas of previous studies.	5
1-4	Regional geologic map of detailed field area and adjacent areas prior to this recent work, illustrating stratigraphic and structural incompatibilities between detailed mapping in Great Smoky Mountains National Park and the region to the southwest where geology has been mapped in detail.	6
1-5	Location map showing the study area, streams, and features discussed in the study, and major areas such as Cherokee National Forest, Nantahala National Forest, and Great Smoky Mountains National Park.	7
2-1	Regional stratigraphic relations of the Ocoee Supergroup, Chilhowee Group, and Valley and Ridge rocks in eastern Tennessee and western North Carolina.	12
2-2	Regional lithostratigraphy of the Ocoee Supergroup from southeast Tennessee to Hot Springs, North Carolina.	13
2-3	Thinly laminated to medium-bedded micritic limestone and calcareous siltstone/shale in outcrop at Citico Quarry, Tallassee 7.5 minute quadrangle.	19
2-4	Photomicrographs of selected Sandsuck Formation lithologies.	20
2-5	Polymictic conglomerate of the Sandsuck Formation at Chilhowee Dam, Tallassee 7.5 minute quadrangle.	22
2-6	Olistolith blocks of micritic and pisolitic limestone and minor calcareous siltstone and shale at Citico Quarry, Tallassee 7.5 minute quadrangle.	23
2-7	Outcrop photo of vein quartz rich, dominantly clast-supported Shields Formation conglomerate along Abrams Creek in Great Smoky Mountains National Park.	25
2-8	Exposure of green to light-gray banded siltstone of the Wilhite Formation, Tallassee 7.5 minute quadrangle.	27
2-9	Interbedded coarse-grained sandstone and fine-grained slate and siltstone of the Cades Sandstone (a) along US 129 north of Calderwood Dam, Calderwood 7.5 minute quadrangle.	28
2-10	Matrix supported intra-(?) and extraformational conglomerate of Cades Sandstone (a) with preferentially oriented graphitic slate lithic fragments up to ~8 cm in length in a coarse-grained feldspathic sandstone-graywacke matrix.	30
2-11	Thin to thick-bedded sandstone, graywacke, and conglomerate along the shores of the Little Tennessee River, ~2km northeast of Calderwood Dam, Calderwood 7.5 minute quadrangle.	31
2-12	Thick to massive sandstone and conglomerate beds of Thunderhead Sandstone (a) at Clingmans Dome in GSMNP.	33
2-13	Stratigraphic columns of selected units in the Whiteoak Flats and Tapoco 7.5 minute quadrangles.	35
2-14	Very sulfidic and graphitic slate and siltstone of the Ammons Formation.	36

2-15	Exposed contact between the sulfidic and graphitic slate of the Ammons Formation and overlying feldspathic sandstone and conglomerate of the lower Dean Formation on the southeast limb of the Rafter anticline along Citico Creek, Whiteoak Flats 7.5 minute quadrangle.	38
2-16	Conglomerate of the lower Dean Formation.	39
2-17	Graded bedding in float of the lower Dean Formation conglomerate along Citico Creek near Barkcamp Branch, Whiteoak Flats 7.5 minute quadrangle.	40
2-18	Exposure in road of contact between banded siltstone and slate of the middle Dean Formation and the gradationally and conformably underlying conglomerate of the lower Dean Formation on Salt Spring Mountain near Farr Gap, Whiteoak Flats 7.5 minute quadrangle.	42
2-19	Banded siltstone of the middle Dean Formation (a) near Jakes Best Creek, Whiteoak Flats 7.5 minute quadrangle.	43
2-20	Dark-gray to black graphitic, mildly sulfidic slate of the middle Dean Formation above Doublecamp Creek headwaters near Farr Gap on Salt Spring Mountain, Whiteoak Flats quadrangle.	44
2-21	Folded conformable contact between upper Dean Formation sandstone and lower Wilhite Formation slate and siltstone in Doublecamp Creek near confluence with Citico Creek, Whiteoak Flats 7.5 minute quadrangle.	45
2-22	Upper Dean Formation graywacke and conglomerate with thin partings and clasts of light-gray graphitic slate that appear to form soft-sediment folds (F_0) in Doublecamp Creek, Whiteoak Flats 7.5 minute quadrangle.	46
2-23	Wilhite Siltstone (a) outcrop in Doublecamp Creek in Whiteoak Flats 7.5 minute quadrangle.	48
2-24	The Wading Branch Formation and Longarm Quartzite are the basal components of the Snowbird Group.	56
2-25	Reconstruction of the stratigraphic relationships among Snowbird Group units based on thickness of exposed units recognized in the Dellwood, North Carolina region.	58
2-26	Models for development of GSG-type turbidite flows and their subsequent deposits.	61
2-27	Schematic model of the Ocoee basin prior to drift transition and deposition of the Chilhowee Group along the southeastern Laurentian margin.	63
2-28	Late Neoproterozoic-Early Cambrian Laurentian margin sedimentation on and near the basin margin.	64
2-29	Schematic model of the Ocoee basin during the Taconic (Ordovician) orogeny.	65
2-30	Schematic model of depositional environments of the Thunderhead, Elkmont, Copperhill, and Anakeesta-Wehutt Formation turbidites along the northeastern basin margin.	66
3-1	Location map showing the study area, streams, and geographic features discussed in the text.	77
3-2	Reduced-size geologic map of the study area showing faults and major lithostratigraphic units.	78
3-3	Structure contour map (in km) of the base of the Great Smoky thrust sheet (Blue Ridge-Piedmont megathrust sheet).	80

3-4	Digital elevation model (30 m resolution) of a portion of the study area showing the pronounced topographic lineaments produced by geologic features such as the Rabbit Creek fault (RCF), Salt Spring Mountain fault (SSMF), Greenbrier fault (GBF), and the Great Smoky fault (GSF) framing the Calderwood Window.	83
3-5	Road exposure of the Rabbit Creek fault in the northern extent of the Whiteoak Flats 7.5 minute quadrangle at the base of Salt Spring Mountain, showing sandstone and conglomerate of the Cades Sandstone in the hanging wall thrust over slate and siltstone of the Wilhite Formation (not visible) in the footwall.....	85
3-6	Exposure of the Salt Spring Mountain fault along Forest Service Road 2115 in the Whiteoak Flats 7.5 minute quadrangle, (a) showing Horse Branch slate (Ammons Formation) thrust over conglomerate of the Cades Sandstone (Rabbit Creek thrust sheet).....	87
3-7	Schematic diagram of the interpreted structural evolution of part of the WBR which resulted in complex relationships observed in the northeastern portion of the study area.	89
3-8	Soft-sediment isoclinal (sheath?) (F_0) folds in coarse graywacke of the Dean Formation (a) exposed in Doublecamp Creek, Whiteoak Flats 7.5 minute quadrangle.....	94
3-9	Photo and geometric illustration of the F_1 fold in the study area.....	95
3-10	Stereoplot of 28 fold (F_1 and F_2) axes, with corresponding girdles (dashed black lines; N47E/54SE).....	97
3-11	Stereoplots of 776 poles to foliation (S_2) surface, with corresponding mean great circles (solid red lines; N47E/42SE), calculated girdles (dashed black lines; N44W/89NE), and calculated beta axis (red squares; 226, 1°).	98
3-12	Stereoplot of poles to the axial surface of F_2 folds in the study area, with corresponding mean great circles (solid red lines; N73E/76SE).....	99
3-13	Slightly divergently fanned slaty cleavage (S_0 ; black lines) in a northwest vergent F_2 fold in highly sulfidic (note yellowish-orange weathering) and graphitic Ammons Formation slate (thinner beds) and siltstone (thicker beds) along Citico Creek, Whiteoak Flats 7.5 minute quadrangle.	100
3-14	Slickenlines formed an extremely thin graphitic bedding surface of a sample of sulfidic Dean Formation conglomerate taken from the limb of an open fold near Doublecamp Creek, Whiteoak Flats 7.5 minute quadrangle.	101
3-15	Northwest vergent, open F_2 buckle fold with a moderately southeast dipping axial surface and transecting to slightly divergent axial planar slaty cleavage (S_2 ; black lines) in interbedded slate and sandstone of the Wilhite Formation along Doublecamp Creek, Whiteoak Flats 7.5 minute quadrangle.....	103
3-16	Stereoplots of 552 poles to bedding (S_0) surfaces, with corresponding mean great circles (solid red lines; N60E/14SE), calculated girdles (dashed black lines; N50W/85NE), and calculated beta axis (red squares; 220, 5°).	104
3-17	Stereoplots of 91 cleavage (S_2)-bedding (S_1) intersection lineations (L_{2x0}).	105
3-18	Pressure solution cleavage (S_{1a}) in Wilhite Formation siltstone collected in the Greenbrier thrust sheet, Whiteoak Flats 7.5 minute quadrangle.	107
3-19	Zonal crenulation cleavage (S_3) deforming slaty cleavage (S_2) in Wilhite Formation siltstone from an exposure near Doublecamp Creek in the Greenbrier thrust sheet, Whiteoak Flats 7.5 minute quadrangle.	108
3-20	Cross section interpretation of Hatcher and Carter (1995) based on remapping in the Jones Cove and Richardson Cove quadrangles north of GSMNP that were originally mapped by Hamilton (1961).	115

4-1	Major tectonic elements of the southern Appalachians showing the location of the western Blue Ridge (Laurentian margin).....	121
4-2	Regional geologic map of the southern Appalachian western Blue Ridge, portions of the Valley and Ridge and eastern Blue Ridge provinces.	122
4-3	Temporal variation of $\delta^{13}\text{C}$ from early Neoproterozoic-Recent.....	126
4-4	Temporal variation of $^{87}\text{Sr}/^{86}\text{Sr}$ from early Neoproterozoic-Recent.....	127
4-5	Polymictic conglomerate of the Sandsuck Formation from Locality 1 at Chilhowee Dam..	130
4-6	Carbonate lithologies of Locality 2 (Citico Quarry).....	131
4-7	Sawed slab of Sandsuck Formation carbonate breccia at Locality 3 (Springtown).	133
4-8	Measured stratigraphic carbonate section of Locality 2 (Citico Quarry), with corresponding C, O, and Sr isotope curves.....	134
4-9	Photomicrographs of carbonate and siliciclastic lithologies of Sandsuck Formation samples.	136
4-10	Cathodoluminescence petrography of samples is utilized to evaluate the extent of carbonate recrystallization and to identify areas of significant alteration prior to microdrilling.	138
4-11	Mn/Sr values of samples from Chilhowee Dam (Locality 1), Citico Quarry (Locality 2), and Ocoee Gorge (Locality 4).	145
4-12	$^{87}\text{Sr}/^{86}\text{Sr}$ vs. Mn/Sr covariation diagram.....	146
4-13	$\delta^{13}\text{C}$ vs. Mn/Sr and $\delta^{13}\text{C}$ vs. Mn (ppm) covariation diagrams.	147
4-14	$^{87}\text{Sr}/^{86}\text{Sr}$ vs. $\delta^{18}\text{O}$ covariation diagrams.	148
4-15	$\delta^{13}\text{C}$ vs. $\delta^{18}\text{O}$ covariation diagram.....	150
4-16	Temporal variation of $\delta^{13}\text{C}$ from early Neoproterozoic-Recent.....	152
4-17	Temporal variation of $^{87}\text{Sr}/^{86}\text{Sr}$ from early Neoproterozoic-Recent.....	153

LIST OF PLATES

- Plate 1** Geologic map of portions of the Tallassee, Whiteoak Flats, and Tapoco 7.5
minute quadrangles, Tennessee and North Carolina..... In Pocket
- Plate 2** Station map In Pocket
- Plate 3** Cross sections through portions of Tallassee, Whiteoak Flats, and Tapoco 7.5
minute quadrangles..... In Pocket
- Plate 4** Geologic map of the western Blue Ridge province southwest of Great Smoky
Mountains National Park, southeast Tennessee and southwest North Carolina. .
..... In Pocket
- Plate 5** Geologic map of the western Blue Ridge and portions of the eastern Blue
Ridge and Valley and Ridge provinces in southeast Tennessee, southwest North
Carolina, and northern Georgia. In Pocket

CHAPTER 1

INTRODUCTION AND AREA OF STUDY

INTRODUCTION

The stratigraphy of the Ocoee Supergroup (OSG) was first synthesized by King et al. (1958). These rocks had been known since the mid-1800s when Safford (1869) first described them. It was not until the 1940s and 1950s, however, that a major effort by the U.S. Geological Survey (King et al., 1958; Hamilton, 1961; Hadley and Goldsmith, 1963; Neuman and Nelson, 1965) resulted in a modern subdivision and basic understanding of the complex stratigraphic and structural relationships between the different components of the OSG. This study presents a number of refinements to regional stratigraphic and structural interpretations of the OSG, and explores the implications of these revisions on rift basin architecture along the southeastern Laurentian margin during the latest Neoproterozoic-Early Cambrian breakup of Rodinia.

The western Blue Ridge (WBR) in eastern Tennessee, western North Carolina, and northern Georgia, is bounded to the northwest by the Holston Mountain, Miller-Cove, and Great Smoky-Cartersville faults, and to the southeast by the Allatoona-Hayesville-Holland Mountain-Gossan Lead fault (Figs. 1-1 and 1-2). It preserves Neoproterozoic to Ordovician units (Ocoee Supergroup, Chilhowee Group, Murphy belt rocks) deposited as synrift to platform sedimentary rocks along the southeastern Laurentian margin following the ~565 Ma breakup of Rodinia (Stose and Stose, 1949; King et al., 1958; DeWindt, 1975; Rankin, 1975; Hatcher, 1972, 1978; Rast and Kohles, 1986; Aleinikoff et al., 1995). Traditional interpretations suggest that this sequence was initially deformed and metamorphosed during the Taconic (Ordovician) orogeny, metamorphosed again during the Neoacadian (Devonian-Mississippian) orogeny, and then transported westward as part of the Blue Ridge-Piedmont (BRP) megathrust sheet during the Alleghanian (Pennsylvanian-Permian) orogeny (Butler, 1972; Rankin, 1975; Hatcher, 1972, 1978; Hatcher et al., 1989; Kish, 1989; Connelly and Dallmeyer, 1990; Kish, 1991; Woodward et al., 1991; Connelly and Woodward, 1992).

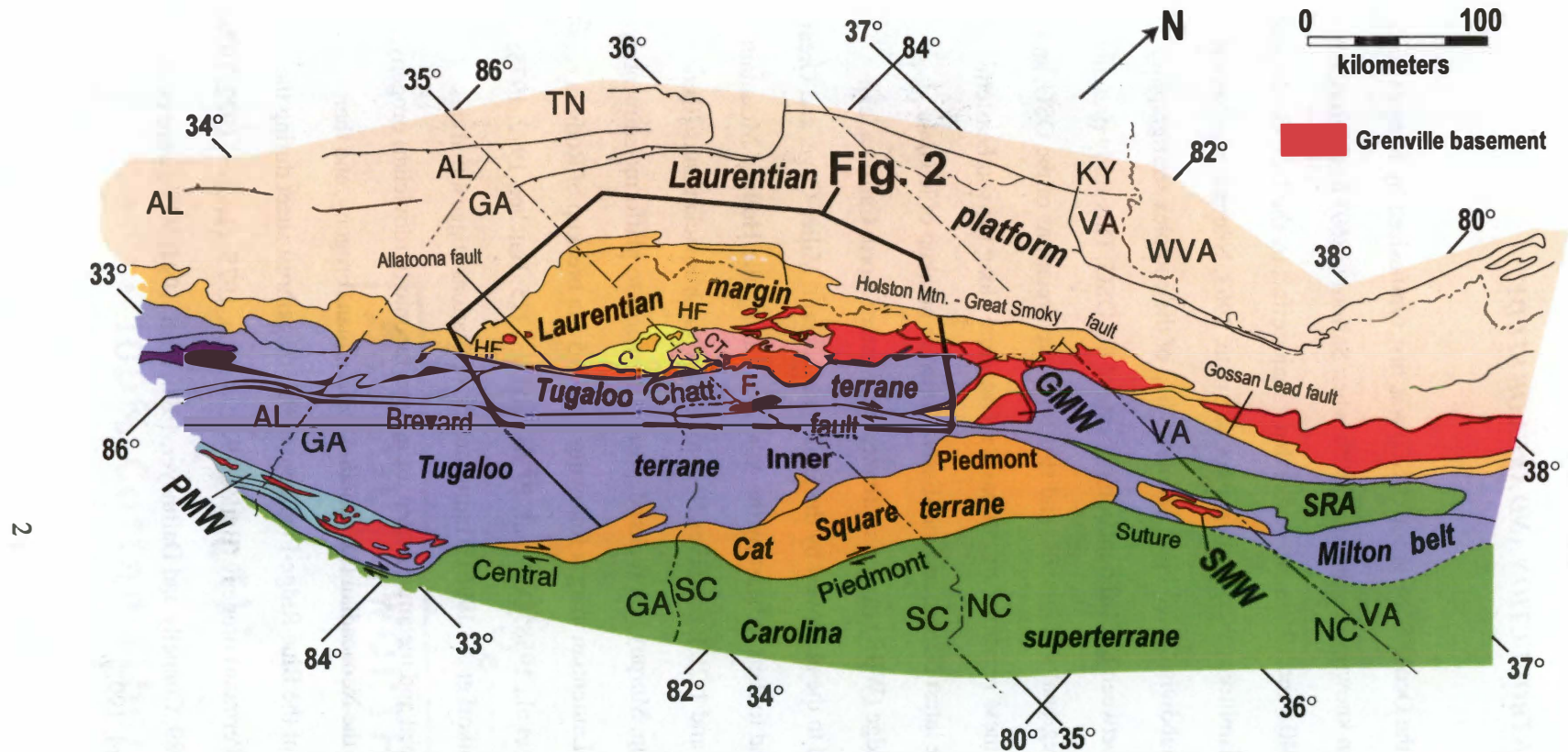


Figure 1-1. Major tectonic elements of the southern Appalachians showing the location of the western Blue Ridge (Laurentian margin). GMW—Grandfather Mountain window. SRA—Smith River Allochthon. SMW—Sauratown Mountains window. PMW—Pine Mountain window. Chatt F.—Chattahoochee fault. HF—Hayesville fault. C—Cowrock terrane. CT—Cartoogechaye terrane. DGB—Dahlonega gold belt (Modified from Hatcher, 2002).

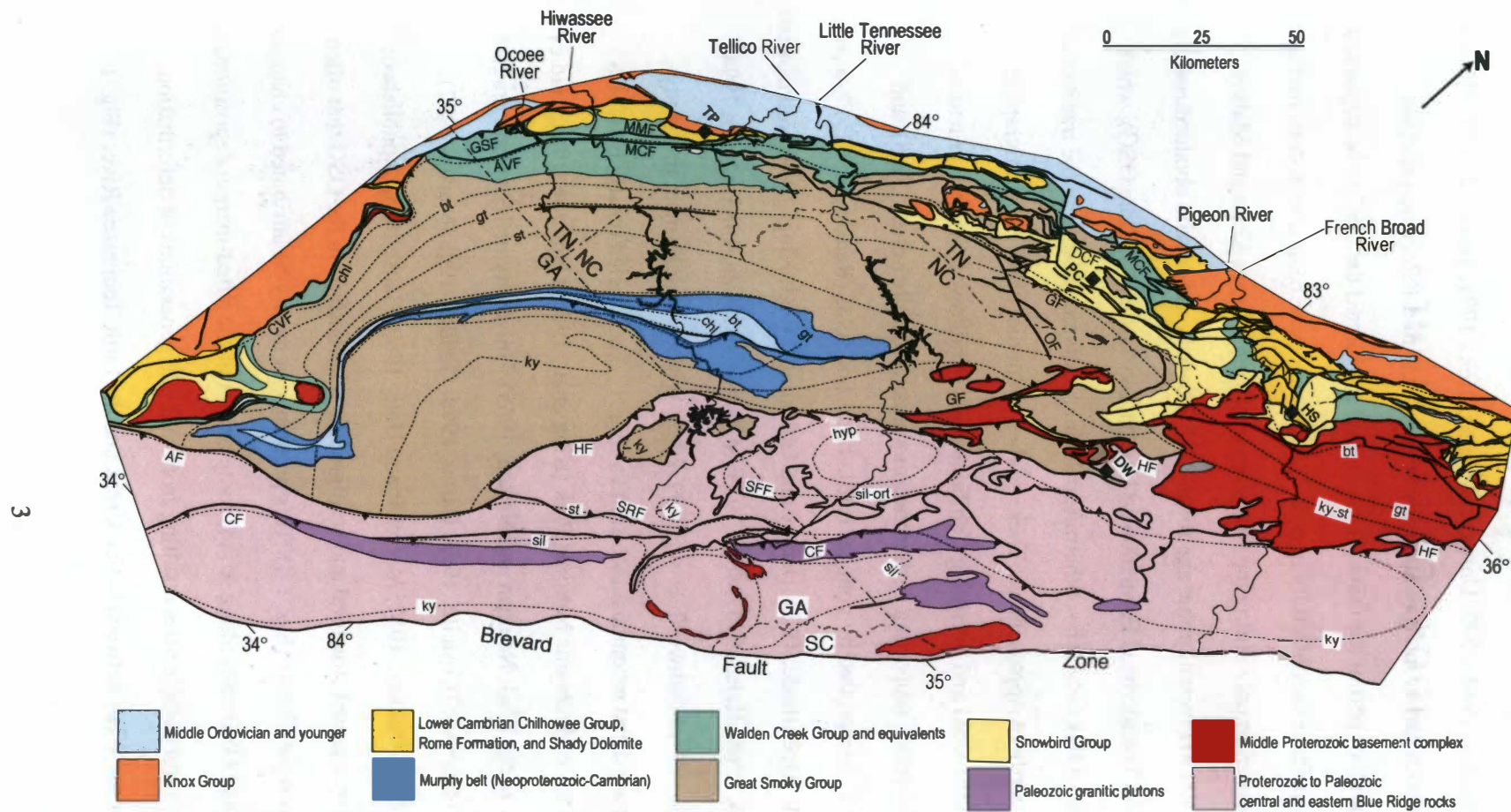


Figure 1-2. Regional geologic map of the southern Appalachian western Blue Ridge, portions of the Valley and Ridge and eastern Blue Ridge provinces. AF—Allatoona fault. CVP—Cartersville fault. CF—Chattahoochee fault. GSF—Great Smoky fault. AVF—Alaculsa Valley fault. MMF—Maggies Mill fault. MCF—Miller Cove fault. DCF—Dunn Creek fault. GF—Greenbrier fault. OF—Oconaluftee fault. HF—Hayesville fault. SFF—Shope Fork fault. SRF—Soque River fault. TP—Tellico Plains. DW—Dellwood. PC—Pittman Center. HS—Hot Springs. chl—chlorite isograd. bt—biotite isograd. gt—garnet isograd. st—staurolite isograd. ky—kyanite isograd. hyp—hypersthene isograd. sil—sillimanite isograd. sil-ort—sillimanite to K-feldspar isograd.

Recently, several studies have contradicted this traditional view. Paleontological evidence (Tull and Grosz, 1988, 1990; Unrug and Unrug, 1990, 1991; Tull et al., 1993; Unrug et al., 2000) contrasts with earlier interpretations by suggesting a mid-Paleozoic (Silurian-Mississippian) age for all or part of the OSG. These studies interpreted the OSG to be deposited above the Middle Ordovician unconformity in post-Taconic successor basins, with deformation and metamorphism occurring only during the Alleghanian orogeny. Later, Kohn and Malloy (2004) suggested a ~400 Ma metamorphic age for the WBR based on monazite obtained mainly from the Anakeesta and Thunderhead Formations (Great Smoky Group – middle OSG), which they utilized to propose a link between southern Appalachian metamorphism and the traditional Acadian event in the northern Appalachians. These studies contradict observed stratigraphic relationships between the OSG and overlying Cambrian units (Chilhowee Group), structural and geochronologic evidence supporting earlier metamorphism (Moecher et al., 2005), and penetrative deformation overprinted by younger brittle faults and folds (Rackley, 1951; Phillips, 1952; Hamilton, 1961; Espenshade, 1963; Hadley and Goldsmith, 1963; King, 1964; Neuman and Nelson, 1965; Hernon, 1968; Hale, 1974; Mohr, 1975; Merschat and Hale, 1983; Carter, 1994; Geddes, 1995; Martin, 1997; Southworth et al., 1999, 2005; Wiener, unpublished; this study).

Numerous detailed and reconnaissance studies (Fig. 1-3) conducted mostly by USGS geologists in Great Smoky Mountains National Park (King et al., 1958; Hamilton, 1961; Hadley and Goldsmith, 1963; King, 1964; Neuman and Nelson, 1965), University of Tennessee graduate students in southeast Tennessee (Costello, 1993; Carter, 1994; Geddes, 1995; Martin, 1997), and others (Rackley, 1951; Phillips, 1952; Merschat and Hale, 1983; Hanselman, unpublished; Wiener, unpublished) interpreted structural and stratigraphic relationships in the OSG that often contained inherent incompatibilities (Fig. 1-4). This problem can mostly be attributed to changes in facies and thickness of OSG units along strike, complexities of the rifted-margin depositional setting, as well as structural complexities resulting from multiple generations of deformation.

The portion of the WBR between Citico Creek and the Little Tennessee River (Fig. 1-

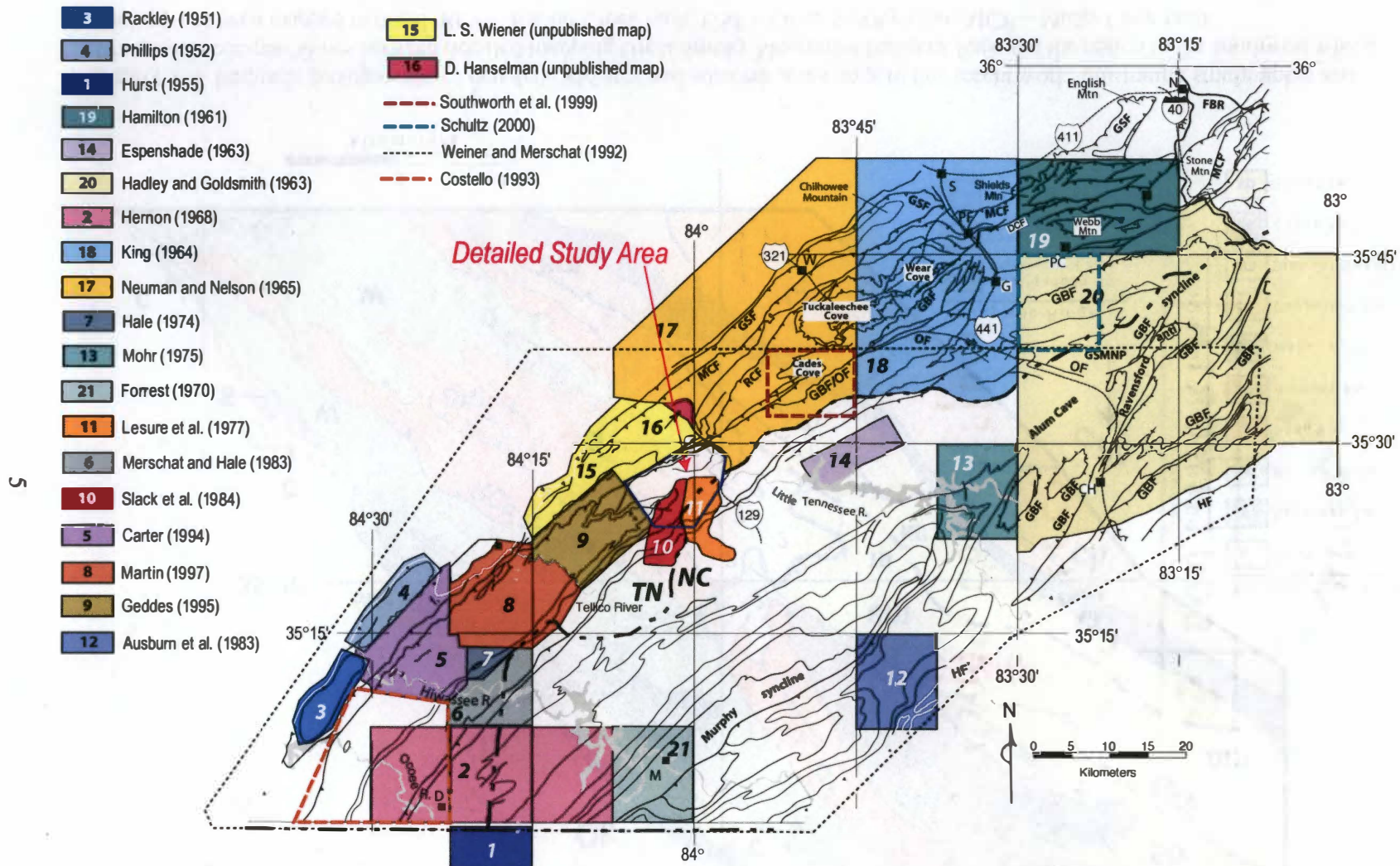


Figure 1-3. Regional index map of the western Blue Ridge showing areas of previous studies. HF—Hayesville fault. GBF—Greenbrier fault. GSF—Great Smoky fault. MCF—Miller Cove fault. RCF—Rabbit Creek fault. OF—Oconaluftee fault. PF—Pigeon Forge. S—Sevierville fault. G—Gatlinburg. PC—Pittman Center. N—Newport. CH—Cherokee. FBR—French Broad River.

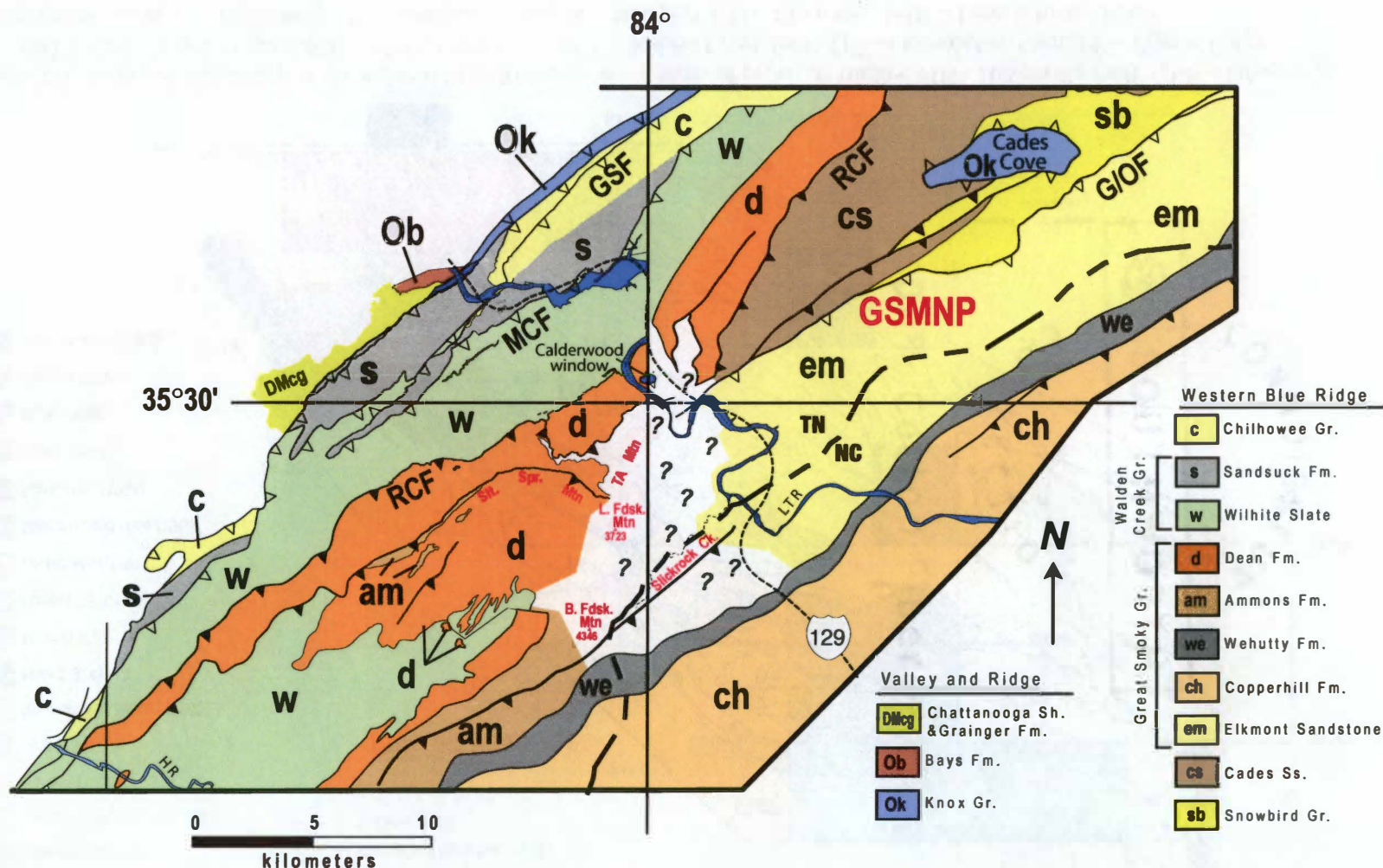


Figure 1-4. Regional geologic map of detailed field area and adjacent areas prior to this recent work, illustrating stratigraphic and structural incompatibilities between detailed mapping Great Smoky Mountains National Park and the region to the southwest where geology has been mapped in detail. RCF—Rabbit Creek fault. GSF—Great Smoky fault. MCF—Miller Cove fault.

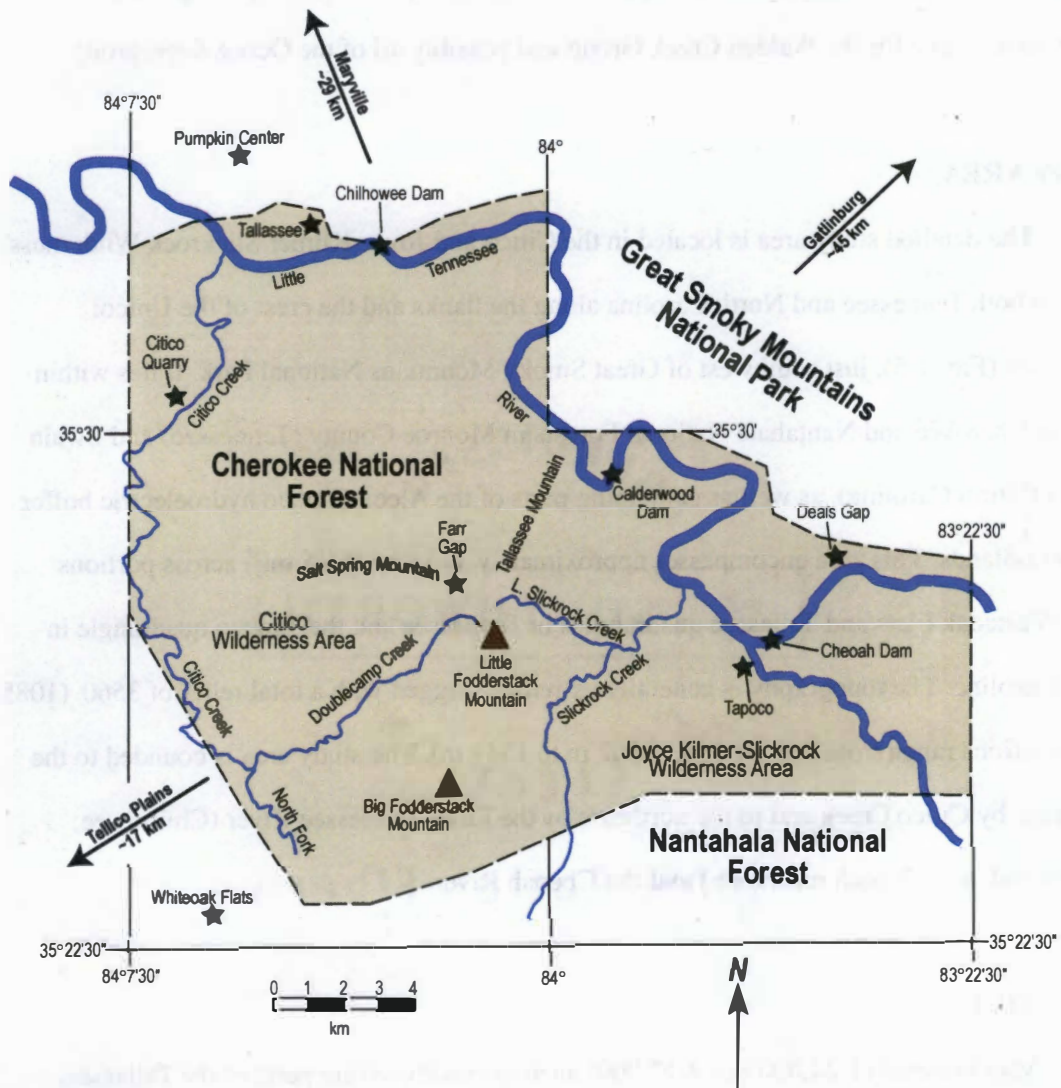


Figure 1-5. Location map showing the study area (light brown), streams and features discussed in the study, and major areas such as Cherokee National Forest, Nantahala National Forest, and Great Smoky Mountains National Park.

5) is critical for delineating stratigraphic and structural relationships that have been otherwise extrapolated by studies from the southwest and northeast of this region (Figs. 1-3 and 1-4; Plate 1). This study area is also important because it contains or is close to several of the “fossil localities” cited by Unrug and Unrug (1990, 1991) and Unrug et al. (2000). They suggested a mid-Paleozoic age for the Walden Creek Group and possibly all of the Ocoee Supergroup.

STUDY AREA

The detailed study area is located in the Citico and Joyce Kilmer Slickrock Wilderness Areas in both Tennessee and North Carolina along the flanks and the crest of the Unicoi Mountains (Fig. 1-5), just southwest of Great Smoky Mountains National Park. It lies within both the Cherokee and Nantahala National Forests in Monroe County (Tennessee) and Swain County (North Carolina), as well as containing parts of the Alcoa-Tapoco hydroelectric buffer zone woodlands. This area encompasses approximately 173 km² (66.5 mi²) across portions of the Whiteoak Flats and Tallassee quadrangles in Tennessee and the Tapoco quadrangle in North Carolina. The topography is generally extremely rugged with a total relief of 3560 (1085 m) (elevations range from 860 to 4400 ; 262 m to 1341 m). The study area is bounded to the southwest by Citico Creek and to the northeast by the Little Tennessee River (Chilhowee, Calderwood, and Cheoah reservoirs) and the Cheoah River.

OBJECTIVES

- 1) Map in detail (1:24,000 and 1:12,000) an area encompassing parts of the Tallassee, Whiteoak Flats, and Tapoco quadrangles (Plates 1 and 2), containing both the Citico Creek and Joyce Kilmer-Slickrock Wilderness Areas, to:
 - a. Delineate the stratigraphic and structural relationships of the Great Smoky and Walden Creek Group rocks.
 - b. Determine the nature and extent of the Greenbrier and Rabbit Creek-Dunn Creek

fault systems southwest of Great Smoky Mountains National Park (Plates 1, 3, and 4) and the regional structural-stratigraphic implications these early faults may have had on OSG lithostratigraphy.

- c. Tie the geology of Great Smoky Mountains National Park to that established to the southwest (Plate 4) by Carter (1994), Geddes (1995), and Martin (1997).
- 2) To construct a new digital regional geologic map (Plate 5) of the western Blue Ridge incorporating all data from this and previous detailed studies to the southwest (Carter, 1994; Geddes, 1995; Martin, 1997; Weiner, unpublished)
- 3) Chronostratigraphically constrain the age of Sandsuck Formation carbonate rocks (Walden Creek Group) at four selected localities using geochemical and isotopic evidence.
- 4) Use data and interpretations derived from previous objectives to confirm traditional interpretations and/or suggest revisions to the depositional architecture of the southeastern Laurentian margin during late Neoproterozoic-Early Cambrian rifting and orogenic evolution during the Paleozoic.

METHODS

Geologic Mapping

The foundation of this research involved detailed (1:24,000 and 1:12,000 scale) geologic mapping (Plates 1 and 2) by collecting stratigraphic and structural data along foot and road traverses both across and along strike to delineate stratigraphic and structural relationships in the field and allow construction of a 1:24,000 scale geologic map of the study area. Field work was conducted from January 2003 to August 2003 and January 2004 to April 2004. Structural data were collected at more than 1,500 stations throughout the study area using a Brunton™ compass. Measurements were taken on bedding, cleavages, folds, faults, lineations, joints, and veins.

Isotopic Analyses

Samples for isotopic analyses will be collected from sections that have been measured and described on a high resolution scale. After collection, each sample was cut, polished, examined petrographically and under cathodoluminescence (CL) to determine alteration and diagenetic effects, and then analyzed using a Finnigan Mat Dual Inlet Mass Spectrometer at the University of Tennessee. Methods and details of the geochemical analyses are discussed in Chapter 4.

CHAPTER II

OCOEE SUPERGROUP AND BASAL CHILHOWEE GROUP LITHOSTRATIGRAPHY BETWEEN CITICO CREEK AND THE LITTLE TENNESSEE RIVER, TENNESSEE AND NORTH CAROLINA: REVISED STRATIGRAPHIC CORRELATIONS AND IMPLICATIONS FOR NEOPROTEROZOIC-EARLY CAMBRIAN RIFT BASIN ARCHITECTURE

OCOEE SUPERGROUP

The Late Neoproterozoic-Early Cambrian OSG is the dominant lithostratigraphic sequence of the WBR, southern Appalachians (King et al., 1958). This succession of clastic sedimentary and subordinate carbonate rocks, extends along strike from northern Georgia to northeast Tennessee (Plate 5) and is estimated to have a maximum thickness of ~15 km in Great Smoky Mountains National Park (GSMNP). Subdivision of the OSG into three distinct groups (Snowbird, Great Smoky, Walden Creek) is based on observed lithologic relationships and interpreted depositional relationships peculiar to units within each respective group.

Difficulties of stratigraphic correlation within the OSG (Fig. 2-1) are related to complexity of the original rifted-margin depositional setting (Fig. 2-2), structural complexities resulting from multiple Paleozoic orogenies, and a lack of detailed geologic mapping in many regions of the WBR. Detailed work in a crucial area of regional structural and stratigraphic incompatibility (Fig. 1-4) “bridges” earlier detailed interpretations of OSG units and major Paleozoic structural boundaries identified to the northeast (King et al., 1958; Hamilton, 1961; Hadley and Goldsmith, 1963; King, 1964; Neuman and Nelson, 1965) and to the southwest (Costello, 1993; Carter, 1994; Geddes, 1995; Martin, 1997; Weiner, unpublished).

Snowbird Group

The Snowbird Group (SG), is the basal unit of the OSG and lies nonconformably on Middle Proterozoic (Grenvillian) basement granitoids and paragneisses (Keith, 1904, 1907;

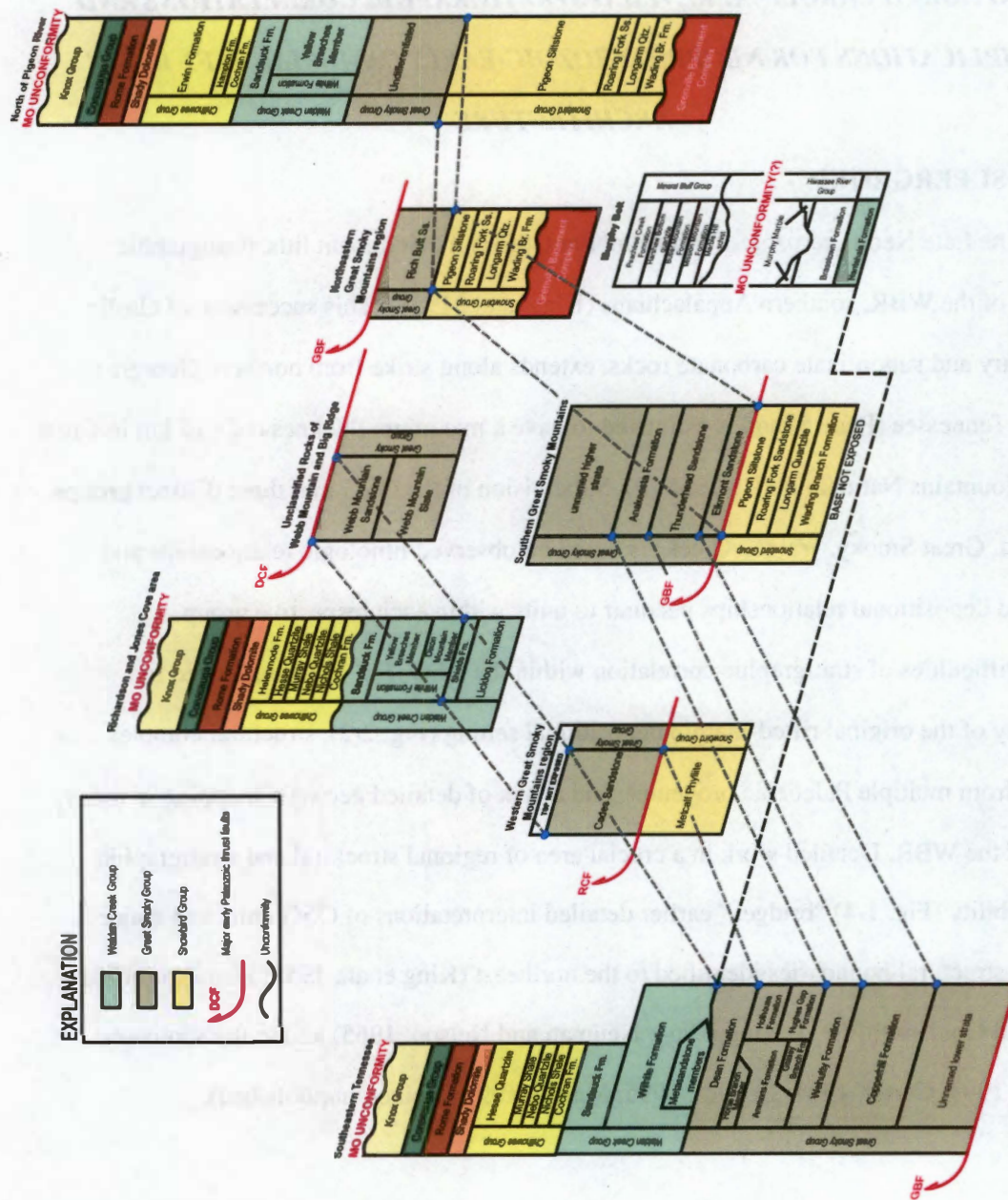


Figure 2-1. Regional stratigraphic relations of the Ocoee Supergroup, Chilhowee Group, and Valley and Ridge rocks in eastern Tennessee and Western North Carolina. Thickness of units are relative and approximate. DCF—Dunn Creek fault. GBF—Greenbrier fault. RCF—Rabbit Creek fault.

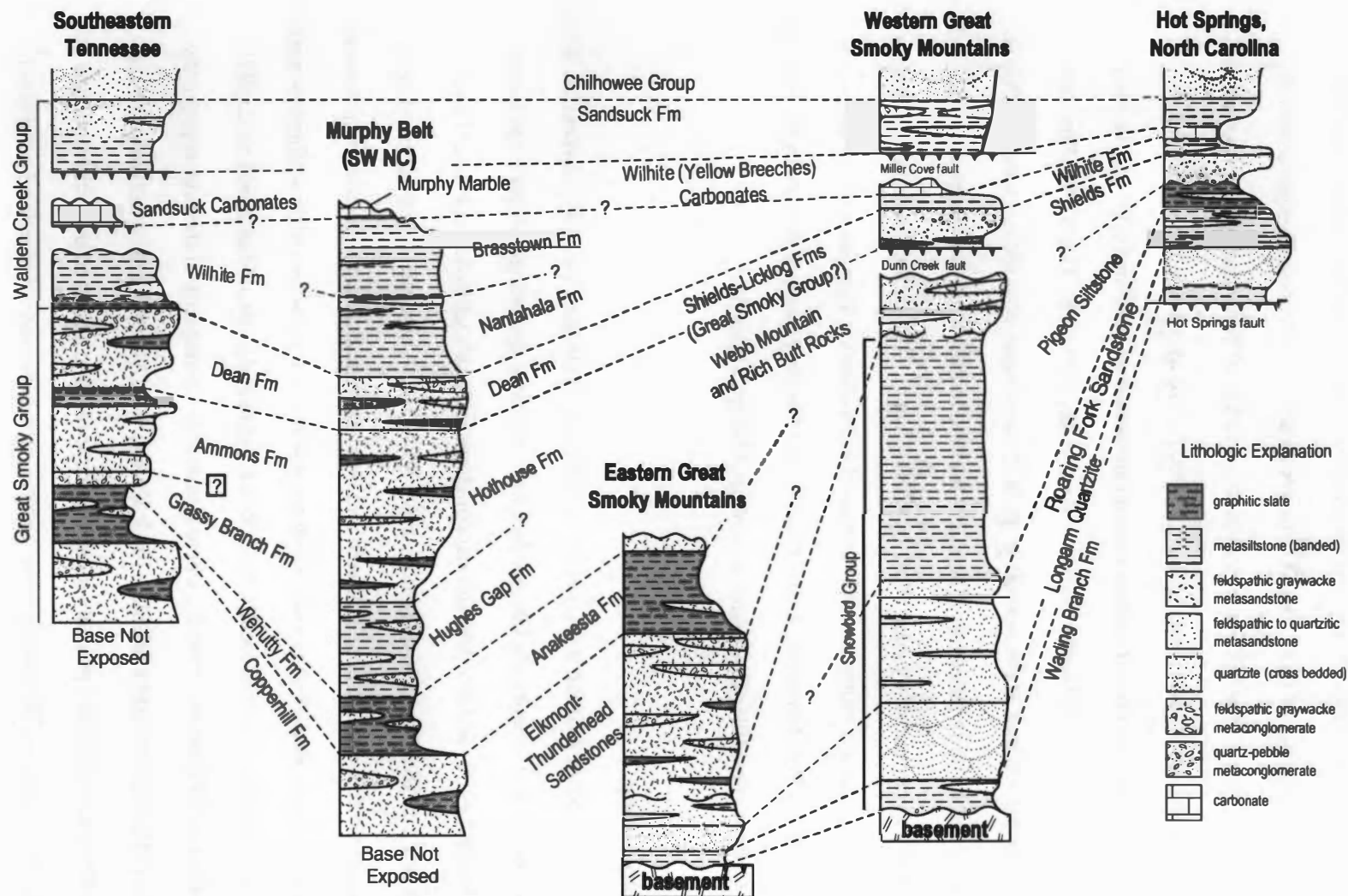


Figure 2-2. Regional lithostratigraphy of the Ocoee Supergroup from southeast Tennessee to Hot Springs, North Carolina. Murphy belt, Eastern Great Smoky Mountains, and western Great Smoky Mountains represent the thickest sections and are interpreted as the deepest extent of the Ocoee basin. Modified from unpublished drafting by Mark Carter.

Stose and Stose, 1949; King et al., 1958). It consists of a conformable, intertonguing sequence of feldspathic sandstone, siltstone, and argillaceous rocks that reveal pronounced lateral facies variation and intertonguing of units. The SG also records major thickness changes across the region. The type section of the SG in the Pigeon River Gorge of Tennessee and North Carolina preserves a minimum thickness of ~4,000 m (~13,000 ft.). To the east, in the vicinity of Waynesville, NC (Plate 5), the SG pinches out and strata of the Great Smoky(?) and Walden Creek Groups directly overlie basement rocks. (King et al., 1958). The Metcalf Phyllite, the stratigraphically highest unit in the SG that is laterally transitional with the more eastern Pigeon Siltstone, is cut out by early Paleozoic (Taconic?) faulting in the vicinity of Cades Cove, TN, ~20 km northeast of the current study area. Work by Costello et al. (1982), McConnell and Costello (1984), and Tull (in review) suggests the presence of units (Pinelog Formation) correlated with the SG overlying the Fort Mountain, Salem Church, and Corbin basement massifs in the hanging wall of the Cartersville-Miller Cove fault in northern Georgia (Plate 5).

Great Smoky Group

The Great Smoky Group (GSG) is the thickest and likely most extensive succession in the OSG. It is composed of repetitively interbedded, fine- to coarse-grained graywacke, sandstone, granule to boulder extra- and intraformational conglomerate, dark siltstone, and slate (Hurst, 1955; King et al., 1958; King, 1964; Hernon, 1968; Mohr, 1973, others). Coarser-grained units are often poorly sorted, contain abundant vein and blue quartz and angular to subangular feldspar clasts, and minor black to dark-gray slate, siltstone, and micritic carbonate lithic fragments. Rare granitoid clasts are also observed locally. The GSG is estimated to be at least 8,000 m (25,000 ft) thick in the GSMNP region (Plate 5), where it underlies the majority of the high topography (King et al., 1958; Hadley and Goldsmith, 1963; King, 1964). That thickness decreases to zero only 35-40 km to the northeast, possibly indicating deposition in a fault (transform)-bounded basin. Lack of a complete, GSG stratigraphic section, mostly because of structural complexities

(faulted contacts, SW plunging folds expose only lower GSG rocks) in GSMNP (Plate 5), created numerous correlation difficulties for early investigations (King et al., 1958; Hamilton, 1961; Hadley and Goldsmith, 1963; King, 1964; Neuman and Nelson, 1965).

Walden Creek Group

The Walden Creek Group (WCG) is the youngest succession in the OSG, and consists of interbedded shale, siltstone, sandstone, conglomerate, with minor quartz arenite, limestone, and dolomite (King et al., 1958; Hamilton, 1961; King, 1964). Thickness estimates of 2,500 m (8,000 ft) are derived from the most complete sequence observed south of English Mountain (Hamilton, 1961), in the eastern part of the Tennessee Foothills (Plate 5). This succession lies conformably beneath the Cochran Formation of the Early Cambrian Chilhowee Group (King et al., 1958; Neuman and Nelson, 1965; Carter, 1994; Weiner, unpublished; this study) and conformably above the Great Smoky Group southwest of GSMNP (Hale, 1974; Poppelreiter, 1980; Costello and Hatcher, 1986, 1991; Costello, 1993; Carter, 1994; Geddes, 1995; Martin, 1997; this study).

CHILHOWEE GROUP

The Chilhowee Group, originally defined by Safford (1856) as the Chilhowee Sandstone, is a sequence of quartz arenite, conglomerate, and interbedded sandstone and shale. Keith (1895) subdivided the Chilhowee Group into five formations, although he did not employ the Chilhowee Group designation. Fossils collected in the upper formations of the Chilhowee Group (Murray Shale and Helenmode Formations) indicate an Early Cambrian age (Walcott, 1891; Keith, 1895). Walcott (1891) identified *Olenellus* and *Isoxys chilhoweana*, and Resser (1938) identified *Indiana tennesseensis* and *Hyolithes*. Consequently, the Precambrian-Cambrian boundary in the WBR must be below the uppermost Chilhowee Group stratigraphic horizon.

PREVIOUS WORK

Safford (1856, 1869) defined the Ocoee Series from exposures in the Ocoee River Gorge in southeastern Tennessee. He also concluded that the Ocoee was conformably overlain by the rocks on Chilhowee Mountain, so both the Ocoee and Chilhowee were correlated with the Cambrian and Lower Ordovician Potsdam Group. This work was modified by Hayes (1891, 1895) and Keith (1895, 1896, 1903, 1904, 1907a, 1907b), who separated mappable units in each group; some divisions, however, were ultimately incorrect. Hayes (1891) and Keith (1895) originally correlated Ocoee rocks with Silurian rocks of the Valley and Ridge, but later Hayes (1895) reassigned these units to the “Algonkian” (later Precambrian).

Rodgers (1953), Hurst (1955), and later Mohr (1973, 1975) revised Hayes (1891, 1895) work in southeastern Tennessee and northwestern Georgia and Keith's (1895, 1896, 1903, 1904, 1907a, 1907b) work in eastern Tennessee and western North Carolina into a constituent stratigraphy. Stose and Stose (1944, 1949) reassigned the Ocoee rocks of Safford (1856, 1869) to the Ocoee series in GSMNP and redivided Keith's stratigraphic succession. Although they assigned the Ocoee to the Precambrian, they correlated the interbedded shales and siltstones of the Nantahala Slate with the Ordovician Tellico Formation. King (1949) and King et al. (1958) later assigned the entire Ocoee series, including interbedded shales and carbonates, to the Precambrian. They also concluded that the lowermost Chilhowee Group represented the base of the Cambrian, because these units contained Early Cambrian fossils. King et al. (1958) also revised the stratigraphic succession of the Ocoee north of the Little Tennessee River, defining the Snowbird Group from Keith's (1904) Snowbird Formation. Hurst (1955) elevated the Great Smoky conglomerate of Keith (1904) to group status, and other units such as the Wilhite Slate, Citico Conglomerate, and Sandsuck Shale were incorporated into the WCG (King et al., 1958). Questions arose about the stratigraphic placement of several unclassified formations defined by King et al. (1958), including the Rich Butt Sandstone, Cades Sandstone, and the Webb Mountain and Big Ridge rocks, which were placed in the GSG based on later palinspastic reconstructions

(Lewis, 1988; Walters, 1988; Woodward et al., 1991), and detailed mapping (Hatcher and Carter, 1992).

Hurst (1955) introduced a revised Murphy belt stratigraphy and reconfirmed Keith's (1907a) conclusion that Murphy belt rocks lie stratigraphically above the GSG. He suggested that the lithologic break between these two groups may represent the base of the Cambrian. Hernon (1968) revised Hurst's GSG stratigraphy near Ducktown, Tennessee. Mohr (1973, 1975) was able to correlate Hurst's (1955) stratigraphy with that of King et al. (1958) along part of Fontana Lake in North Carolina (Plate 5).

Some studies (Merschat and Wiener, 1973; Wiener and Merschat, 1978, 1981; Merschat and Hale, 1983; Wiener and Merschat, 1992) interpreted the contact between the GSG and WCG to be the southern continuation of the Greenbrier fault, although work by Hale (1974), Costello and Hatcher (1991), Carter (1994), Geddes (1995), and Martin (1997) revealed a mappable conformable contact between the Dean Formation (uppermost GSG) and the Wilhite Formation (lowermost WCG). The conformable nature of the GSG-WCG contact was also suggested by Poppelreiter (1980) by making regional correlations between major structures south of the Little Tennessee River. Geddes (1995) and Martin (1997) proposed an ability to delineate the southern continuation and eventual termination of the Greenbrier-Oconaluftee fault just south of Tellico Plains, TN.

LITHOSTRATIGRAPHY BETWEEN CITICO CREEK AND THE LITTLE TENNESSEE RIVER

Rocks recognized in the study area have been subdivided based on observed lithologic characteristics and organized with respect to their position within a number of major early and/or late Paleozoic northwest-directed thrust sheets (Plates 1 and 5). Whereas many units can be correlated across these structural boundaries, others are confined to single thrust sheets.

Moreover, notable changes in lithology and/or thickness are sometimes recognized in units interpreted to occupy the same stratigraphic position within different thrust sheets.

Rocks of the Great Smoky thrust sheet

Sandsuck Formation

A unit composed of thin-bedded to thinly-laminated, light to medium-gray siltstone, dark-gray, fine- to medium-grained sandstone and interbedded dark-gray shale, with minor feldspathic sandstone, conglomerate, and carbonate represents the uppermost recognized OSG unit and is here correlated with the Sandsuck Formation of King et al. (1958) in GSMNP. The carbonate facies, sampled for geochemical analysis at Citico Quarry, Springtown, and US 64 in Ocoee Gorge (Plate 5), is generally a fine-grained micritic limestone (Figs. 2-3, 2-4a) with minor sparry calcite-dominated limestone (Fig. 2-4f), polymictic (polycarbonate nodes) conglomerate (Fig. 2-5) and breccia, and less common pisolitic limestone present mostly as olistoliths (Figs. 2-3c-d, 2-6). Clasts (single and composite) of the conglomerate and breccia are often composed of pisolitic limestone, micritic limestone partially replaced by sparry calcite (Fig. 2-4f), and mono- or polycrystalline quartz (Fig. 2-4e) in a micritic or sandy matrix. As the uppermost unit in the OSG, the Sandsuck Formation lies conformably (locally unconformably) beneath the Cochran Formation of the Chilhowee Group. Keith (1895) originally placed the Sandsuck-Chilhowee contact at the base of prominent sandstone and conglomerate layers overlying a dominantly shaly succession, yet because of the intertonguing nature of the shale, sandstone, and conglomerate, King et al. (1958) revised this interpretation, placing the contact higher in the stratigraphic section at the base of persistent beds of arkose and quartz-rich sandstone. The Sandsuck Formation is present only in the northwesternmost portion of the field area in the footwall of the Miller Cove fault (Plate 1). A maximum of 700 m (2300 ft) of Sandsuck Formation rocks are exposed in the study area.



Figure 2-3. Thinly laminated to medium-bedded micritic limestone and calcareous siltstone/shale in outcrop at Citico Quarry, Tallassee 7.5 minute quadrangle. Thicker beds dominantly composed of micritic limestone sometimes replaced by diagenetic sparry calcite and cut by calcite veins. Thinner beds are mostly calcareous siltstone and shale. Fresh color is dark-gray to black, though this photo show typical yellowish-gray weathered colors.

Figure 2-4. Photomicrographs of selected Sandsuck Formation lithologies. (a) Micritic limestone and minor sparry limestone cut by at least two generations of calcite veins, Citico Quarry. (b) Sparry limestone with very thin laminations of finer-grained micritic limestone. Some neomorphic spar has been replaced by quartz during diagenesis, Citico Quarry. (c) Concentrically laminated pisolites and ooids nucleated around siliciclastic and sparry limestone cores. Some cores show neomorphic replacement of quartz with calcite or vice-versa, Citico Quarry. (d) Deformed, concentrically laminated pisolite with nucleus of undulatory monocrystalline quartz being replaced by neomorphic calcite that is usually twinned. Matrix is microspar and minor micrite, Citico Quarry. (e) Mono- and polycrystalline undulatory quartz clasts in fine-grained micritic matrix. Quartz clasts show incomplete recrystallization following deformation. Replacement of micrite by larger quartz grains is pervasive. Stylolites present tend to be subparallel throughout the sample, suggesting that they are coeval. Quartz clasts are fringed by epitaxial calcite cement growth, Springtown. (f) Micritic limestone clast of carbonate breccia. Micrite shows very thin depositional laminations and pervasive replacement by sparry calcite. Dissolution of micrite concentrated along stylolite surfaces, Springtown. Citico Quarry and Springtown sample localities may be seen on Plate 5.

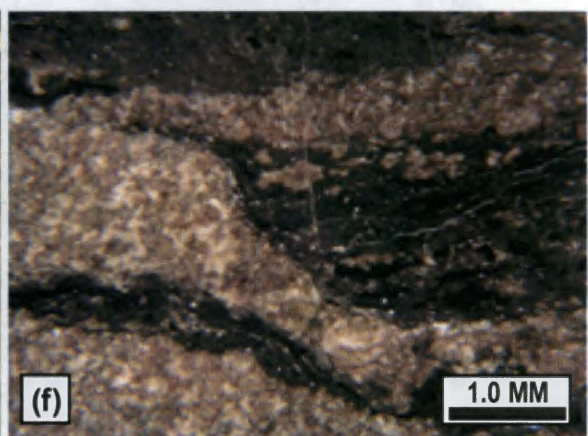
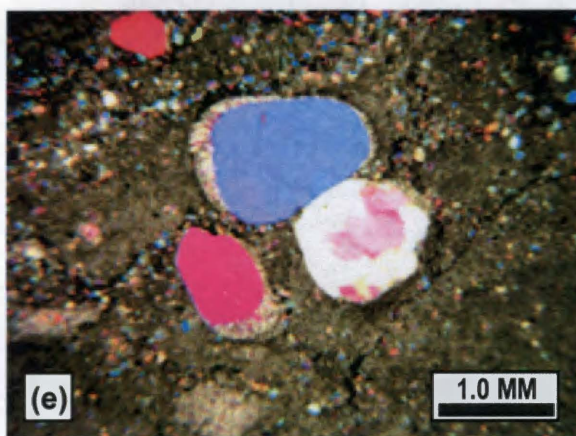
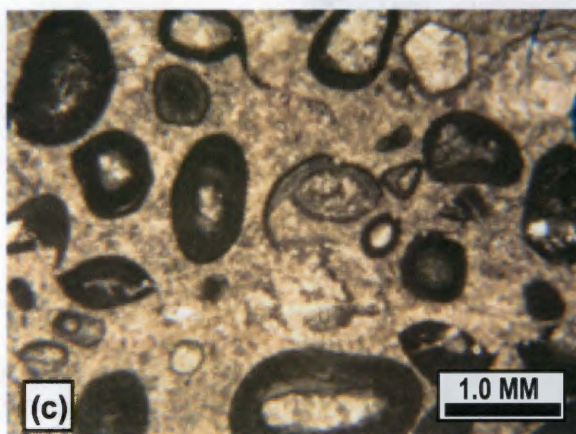
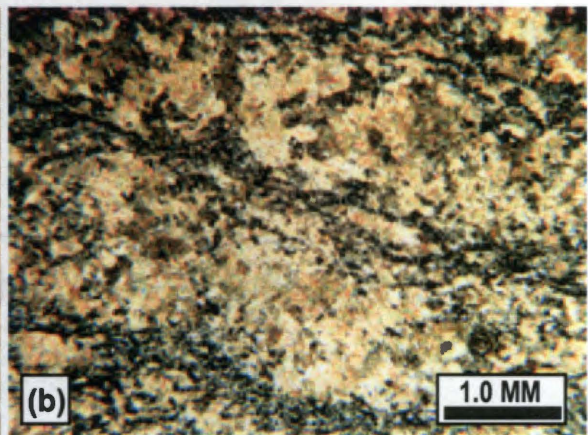
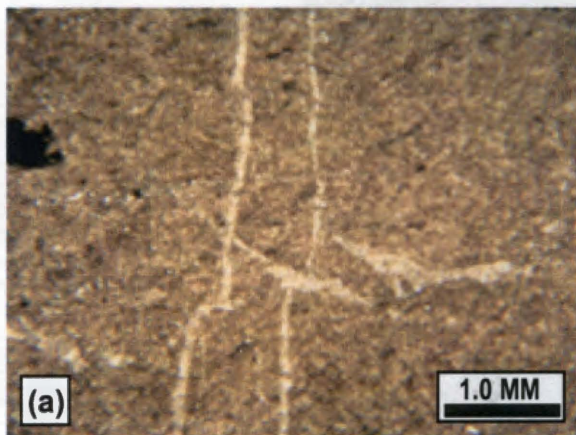




Figure 2-5. Polymictic conglomerate of the Sandsuck Formation at Chilhowee Dam, Tallassee 7.5 minute quadrangle. (a) Conglomerate is interbedded with minor amounts of medium- to coarse-grained arkosic sandstone and dark-gray shale. (b) Close up of conglomerate showing dominant clasts of rounded vein quartz, with minor amounts of feldspar, blue quartz, and carbonate (dark-reddish to orange weathered spots).



Figure 2-6. Olistolith blocks of micritic and pisolitic limestone and minor calcareous siltstone and shale at Citico Quarry, Tallassee 7.5 Minute quadrangle. Within the olistolith block, sizes of boulders and cobbles of limestone and calcareous siltstone/shale range from a few inches to more than 3 ft. in diameter.

Cochran Formation (Chilhowee Group)

Rocks overlying the Sandsuck Formation in the Great Smoky thrust sheet are assigned to the Cochran Formation, the lowermost formation of the Chilhowee Group. This unit is generally composed of coarse-grained feldspathic sandstone that is often conglomeratic in nature. The sandstone at the top of the formation is mostly cross-bedded, medium to coarse-grained, and light gray in color. Gray hematite concretions in quartzite beds distinguish them from beds of the Nebo or Hesse Quartzites higher in the Chilhowee section (Neuman and Nelson, 1965). The base of the formation is located at the transition between thick conglomeratic and feldspathic sandstone overlying thin, fissile siltstone and intertonguing sandstone and conglomerate of the Sandsuck Formation (Neuman and Nelson, 1965). The approximate thickness of this unit in the study area, 400-425 m (1300-1400 ft.), may be overestimated because of faulting. Exposures in the study area are best viewed north of Little Tennessee River along Highway 129, approximately 2 km (1.2 mi) west of Chilhowee Dam, Tallassee 7.5 minute quadrangle (Plate 1).

Rocks of the Miller Cove thrust sheet

Shields Formation

The stratigraphically lowest unit recognized in the Miller Cove thrust sheet (Plate 1) was originally correlated with the Shields Formation of the WCG (Weiner, unpublished). The Shields Formation is composed primarily of interbedded feldspathic conglomerate, graywacke, and sandstone, and may lithologically resemble rocks of the underlying GSG, although it commonly lacks the characteristic graded beds observed in those units. Sandstones and conglomerates are interbedded with argillaceous units that are often lensatic and sometimes mappable. Clasts of the coarser units are dominated by vein quartz pebbles (Fig. 2-7), commonly up to 3 cm in diameter, with minor smoky quartz, carbonate, slate, and siltstone in a feldspathic sandstone matrix. Blue quartz clasts, though present, are rare. Truncation of the Shields Formation by the



Figure 2-7. Outcrop photo of vein quartz-rich, dominantly clast-supported Shields Formation conglomerate along Abrams Creek in Great Smoky Mountains National Park. Altimeter is ~2 inches wide. (Photo by Scott Southworth)

Rabbit Creek fault on the north slope of Salt Spring Mountain (Plate 1) precludes a total thickness approximation of this unit, although up to ~600 m is exposed in the study area.

Wilhite Formation

Wilhite Formation rocks in the hanging wall of the Miller Cove thrust intertongue with and gradationally overlie strata of the Shields Formation (Plate 1). In the study area, rocks correlated with the Wilhite Formation in the footwall of the Rabbit Creek thrust sheet are generally gray to grayish-green banded siltstones, with interbedded light-gray to dark-gray banded and unbanded slates (Fig. 2-8), and lesser amounts of dark-gray calcareous slate, carbonate, sandstone, and conglomerate lenses of minimal extent. The dominant lithologies are similar to the Wilhite Formation rocks in the Greenbrier thrust sheet, although a well-defined ankerite-bearing unit recognized between upper and lower Wilhite siltstones and slates in the Greenbrier thrust sheet (Geddes, 1995; Wiener, unpublished) could not be identified in the Miller Cove thrust sheet. Based on Hamilton's (1961) descriptions, the lithologies of this unit appear most similar to the Dixon Mountain Member of the Wilhite Formation, although some differences exist. The top of the Wilhite section is truncated by the Miller Cove fault and consequently, the contact with the overlying Sandsuck Formation is not exposed in the study area (Plate 1). South of English Mountain (Plate 5) however, ~1200 m (~4000 ft.) of Sandsuck Formation is observed conformably overlying the Wilhite Formation (Hamilton, 1961).

Rocks of the Rabbit Creek thrust sheet

Cades Sandstone

Strata of the Rabbit Creek thrust sheet, much like lithologies of the GSG (Dean Formation, Elkmont Sandstone, Thunderhead Sandstone, etc.) consist primarily of fine-grained to conglomeratic sandstone with interbedded black to dark-gray slate and siltstone (Fig. 2-9a). Finer-grained lithologies are much less prevalent in this unit and blue rutiled quartz clasts,



Figure 2-8. Exposure of green to light gray banded siltstone of the Wilhite Formation, Tallassee 7.5 minute quadrangle. Light-gray to tan layers are coarser-grained than green layers and preserve symmetric ripple marks, though Paleozoic deformation and cleavage formation makes ripples appear asymmetric.

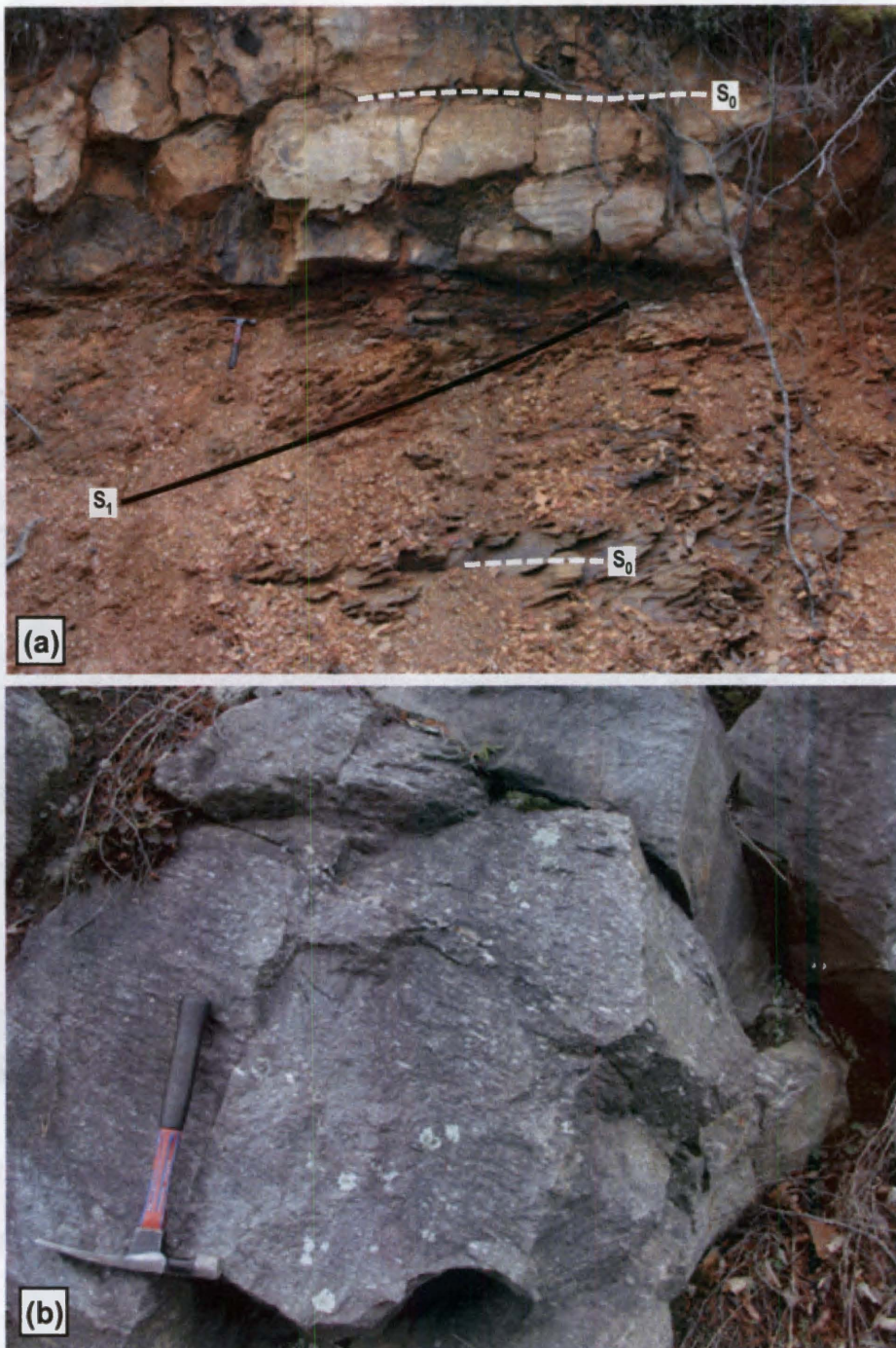


Figure 2-9. Interbedded coarse-grained sandstone and fine-grained slate and siltstone of the Cades Sandstone (a) along US 129 north of Calderwood Dam, Calderwood 7.5 minute quadrangle. Note the lack of pervasive cleavage (S_1) in overlying sandstone compared to the slate-siltstone below. S_0 —bedding. S_1 —slaty cleavage. (b) Graded beds in Cades Sandstone near Calderwood Dam. Note that this bed becomes coarser-grained towards the top of the page, indicating that it is overturned.

abundant in the Elkmont and Thunderhead sequences, are rare. Feldspar content is notably higher than that in the Elkmont. Graded beds are common in the coarser lithologies, generally fining upward from granule conglomerate to argillite (Fig. 2-9b), although some large pebble and even boulder conglomerate has been observed at the base of the graded beds (Geddes, 1995; this study). Like the Elkmont, coarser facies (sandstone-conglomerate) contain abundant vein quartz, dark-gray quartz, weathered feldspar, and black to dark-gray metasiltstone and slate (Fig. 2-10). Sandstones and conglomerates are generally thick to massively bedded, although thin beds are present in some exposures. The lithologic and stratigraphic similarities of these units to the Dean Formation in the Greenbrier thrust sheet (Plate 4) led Geddes (1995) to suggest a possible correlation between the two formations.

Rocks of the Greenbrier thrust sheet

Elkmont Sandstone

The stratigraphically lowest unit recognized in the study area consists of fine- to coarse-grained sandstone, granule to boulder conglomerate, and coarse graywacke interbedded with finely laminated black to dark-gray slate and siltstone in layers up to 30 m (100 ft) thick (Fig. 2-11). Coarser facies (sandstone-conglomerate) contain vein quartz, dark gray quartz, feldspar, and distinctive rutilated blue quartz clasts, which are abundant in small to medium-grained pebble conglomerate (Fig. 2-11) and coarse graywacke. Based on bedding thickness, lithologies, and clast composition, as well as the interpreted stratigraphic position, this unit has been correlated with the Elkmont Sandstone (King et al., 1958) in the hanging wall of the Greenbrier fault (Plate 1) in GSMNP (Neuman and Nelson, 1965).

Thunderhead Sandstone

Conformably overlying the Elkmont Sandstone is a relatively thick (≥ 1500 m; 5000 ft) sequence dominantly composed of graded beds 1.5 - 7.5 m (5-25 ft) thick with small-pebble

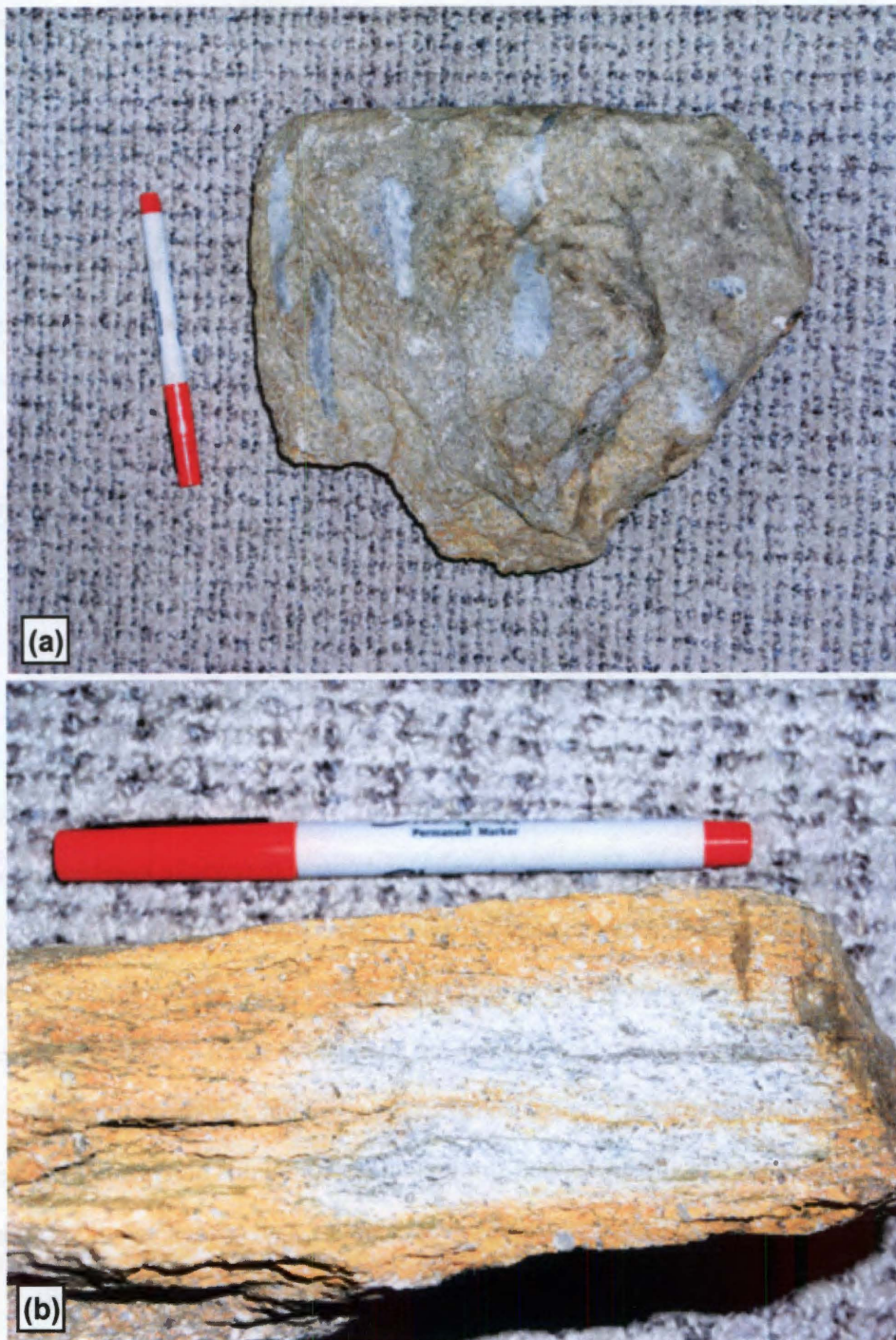


Figure 2-10. Matrix supported intra-(?) or extraformational conglomerate of Cades Sandstone (a) with preferentially oriented graphitic slate lithic fragments up to ~8 cm in length in a coarse-grained feldspathic sandstone-graywacke matrix. (b) Cross section view through same conglomerate, showing abundance of vein quartz and feldspar clast constituents. Very few blue quartz clasts may be recognized in this specimen. White to light-gray fresh surface surrounded orangish-yellow weathering rind. Pen for scale ~17 cm long.



Figure 2-11. Thin- to thick-bedded sandstone, graywacke, and conglomerate (a) along the shores of Little Tennessee River, ~2km northeast of Calderwood Dam, Calderwood 7.5 minute quadrangle. (b) Graded bedding in Elkmont Sandstone float near Tapoco Dam, Tapoco 7.5 minute quadrangle. Knife for scale is ~10 cm in length.

conglomerate or coarse sandstone at the base, grading upward through medium and fine-grained sandstone, to silty or argillaceous rocks at the top. This unit is correlated with the Thunderhead Sandstone in GSMNP, which Keith (1895) originally identified as the Thunderhead Conglomerate on Thunderhead Mountain in the western part of GSMNP. Later, King et al. (1958) elevated this unit to formation status. In GSMNP, relatively thicker beds (Fig. 2-12a) and coarser-grained average clast sizes with respect to other GSG formations often distinguish this unit. The conglomerates and sandstones are generally light to medium-gray, with abundant quartz and feldspar clasts and lesser amounts of plagioclase, leucogranite, and quartzite. Most notable are the abundant rutilated blue quartz clasts observed in coarse-grained graywackes and fine- to medium-grained pebble conglomerates. Spherical to sub-spherical concretions, sometimes with carbonate rims (Fig. 2-12b), are randomly observed throughout the formation.

Anakeesta Formation

The Anakeesta Formation (King et al., 1958) is composed predominantly of graphitic, sometimes sulfidic dark-gray to black slate and metasiltstone with relatively few interbeds of fine-grained sandstone. It conformably underlies the Ammons Formation in the Greenbrier thrust sheet and conformably overlies the Thunderhead Sandstone in the Hangover Lead thrust sheet. The slates and siltstones are often thinly-laminated to thinly-bedded, contain little or no banding like that observed in many argillaceous GSG rocks, and often contain abundant organic carbon, suggesting deposition in a low energy, possibly reducing environment. In the Greenbrier thrust sheet, a late (?) Paleozoic brittle fault truncates the base of the Anakeesta Formation and separates it from the underlying Elkmont and Thunderhead Sandstones (Plate 1), so the maximum exposed thickness of ~900 m (2950 ft) probably represents a minimum thickness. In the Hangover Lead thrust sheet, only ~700 m (2300 ft) is preserved between the Thunderhead-Anakeesta contact and the study area boundary, though reconnaissance work (Wiener and Mersch, 1992; Southworth et al., 2005; this study) indicates an approximate thickness of 1200



Figure 2-12. Thick to massive sandstone and conglomerate beds of Thunderhead Sandstone (a) at Clingmans Dome in GSMNP. (b) Spheroidal carbonate concretions in massive graded bed of the Thunderhead Sandstone. These features are extremely similar to concretions recognized in the Thunderhead Sandstone in the Tapoco 7.5 minute quadrangle, though no photographs were taken. Both photos by Robert D. Hatcher, Jr.

m (3900 ft). In the Murphy syncline, the Anakeesta Formation lies conformably above the Thunderhead-Copperhill sequence and is in turn conformably overlain by the Ammons Formation (Mohr, 1973; 1975; Ausburn et al., 1983; 1998). The increasing prevalence of coarser-grained lithologies (feldspathic graywacke, minor conglomerate) within the dominantly finer-grained succession (Fig. 2-13) marks the contact between the Anakeesta Formation and the conformably overlying Ammons Formation.

Ammons Formation

Fine-grained dark-gray to black graphitic and sulfidic slate (Fig. 2-14) interbedded with medium- to dark-gray graywacke and coarse-grained sandstone overlie the relatively finer-grained rocks of the Anakeesta Formation comprise the Ammons Formation. The upper part of this sequence contains increasingly abundant interbedded graywacke and feldspathic sandstones (Fig. 2-13), and is recognized to conformably underlie the Dean Formation (Plate 1). In southwestern Tennessee and in the Murphy Syncline, the Ammons Formation (1975) conformably underlies the Dean Formation. The Ammons Formation of Mohr (1975), first described in the Noland Creek 7.5 quadrangle to the east of the study area, consists of fine- to medium-grained feldspathic metagraywacke, dark metasiltstone, quartz-mica schist, and rare metaconglomerate that is often capped by sulfidic and graphitic slates and minor metagraywacke of the Horse Branch member (Mohr, 1973; Ausburn). The Ammons Formation is stratigraphically equivalent to the Hothouse Formation of Hurst (1955) and Hernon (1968), and to the upper section of the Boyd Gap Formation of Mersch and Wiener (1973) and Wiener and Mersch (1978, 1981, 1992). Near Fontana Lake, on the northern tip of the Murphy syncline, Mohr (1973) estimated that the Ammons Formation was 1200-1500 m (4000-5000 ft) thick, while Hurst (1955) suggested a 2400-3300 m (7900-10800 ft) thickness for the Ammons equivalent Hothouse Formation near Ducktown, TN (Plate 5). In the study area, in the hinge and along the southeast

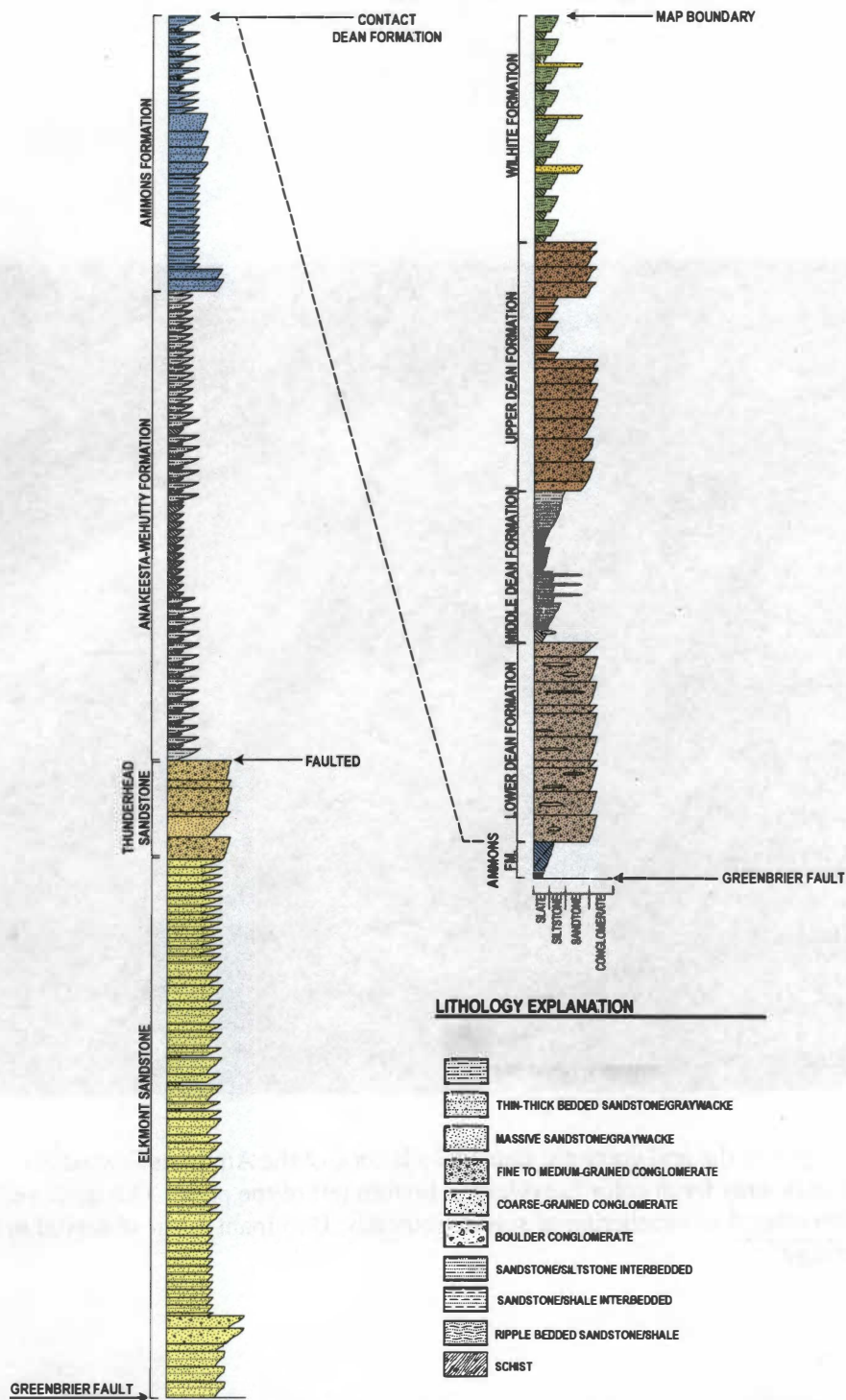


Figure 2-13. Stratigraphic columns of selected units in the Whiteoak Flats and Tapoco 7.5 minute quadrangles. Note the obvious change in bedding thickness and the appearance of relatively minor graywacke, sandstone, and conglomerate that allow subdivision of the lithologically similar Ammons and Anakeesta-Wehuty Formations. Thicknesses estimated from structural sections. Location of sections indicated on Plate 1.



Figure 2-14. Very sulfidic and graphitic slate and siltstone of the Ammons Formation. Weathering of dark-gray fresh color is evident in bottom left of the photo. Orangish-yellow and white coloration related to weathering of sulfide minerals. Dominant fabric observed in this photo is S_1 slaty cleavage.

limb of the Epperson synclinorium, the estimated thickness of this unit is 600-700 m (1900-2300 ft), revealing thinning of Ammons deposits to the northwest.

Dean Formation

Medium to massively bedded, feldspathic, coarse-grained sandstone, graywacke, and conglomerate, with interbedded siltstone and slate conformably overlying finer-grained sulfidic and graphitic slate, siltstone, and graywacke of the Ammons Formation (Fig. 2-15) are correlated with the Dean Formation (Geddes, 1995; Martin, 1997; this study). The Ammons Formation, originally defined by Hurst (1955) and later recognized by Hernon (1968) in southeast Tennessee and Mohr (1975) on the northernmost limbs of the Murphy syncline, is dominantly composed of staurolite-mica schist and cross-biotite schist, with equal or sometimes greater amounts of metaconglomerate, feldspathic sandstone, and quartzite. Most notably, the Dean Formation represents the uppermost Great Smoky Group and is conformably overlain by the Nantahala Slate in the Murphy syncline and the Wilhite Formation in the study area (Plate 1). In this study area, the Dean is subdivided into three major units with numerous interbedded and laterally variable members.

The lower Dean Formation is dominantly medium-gray, thin to massive-bedded, feldspathic and quartz-granule to pebble intra- and extraformational conglomerates (Fig. 2-16a), and fine to very coarse-grained graywacke with lesser amounts of fine to coarse-grained feldspathic sandstone (Fig. 2-16b). Milky vein quartz is the dominant clast type in the coarser units, with lesser amounts of smoky quartz, dark-gray quartz, potassium feldspar, plagioclase, dark slate siltstone, and rare blue quartz (rutilated). Graded beds are ubiquitous (Fig. 2-17), sometimes grading from pebble conglomerate to fine-grained slate in beds only 1 m (3-4 ft.) thick. Interbeds of dark slate and siltstone, sometimes banded, occur frequently at the top of graded successions and in individual beds, although many times they are lensatic in nature and are rarely thick enough to form mappable units at a 1:24,000 scale.

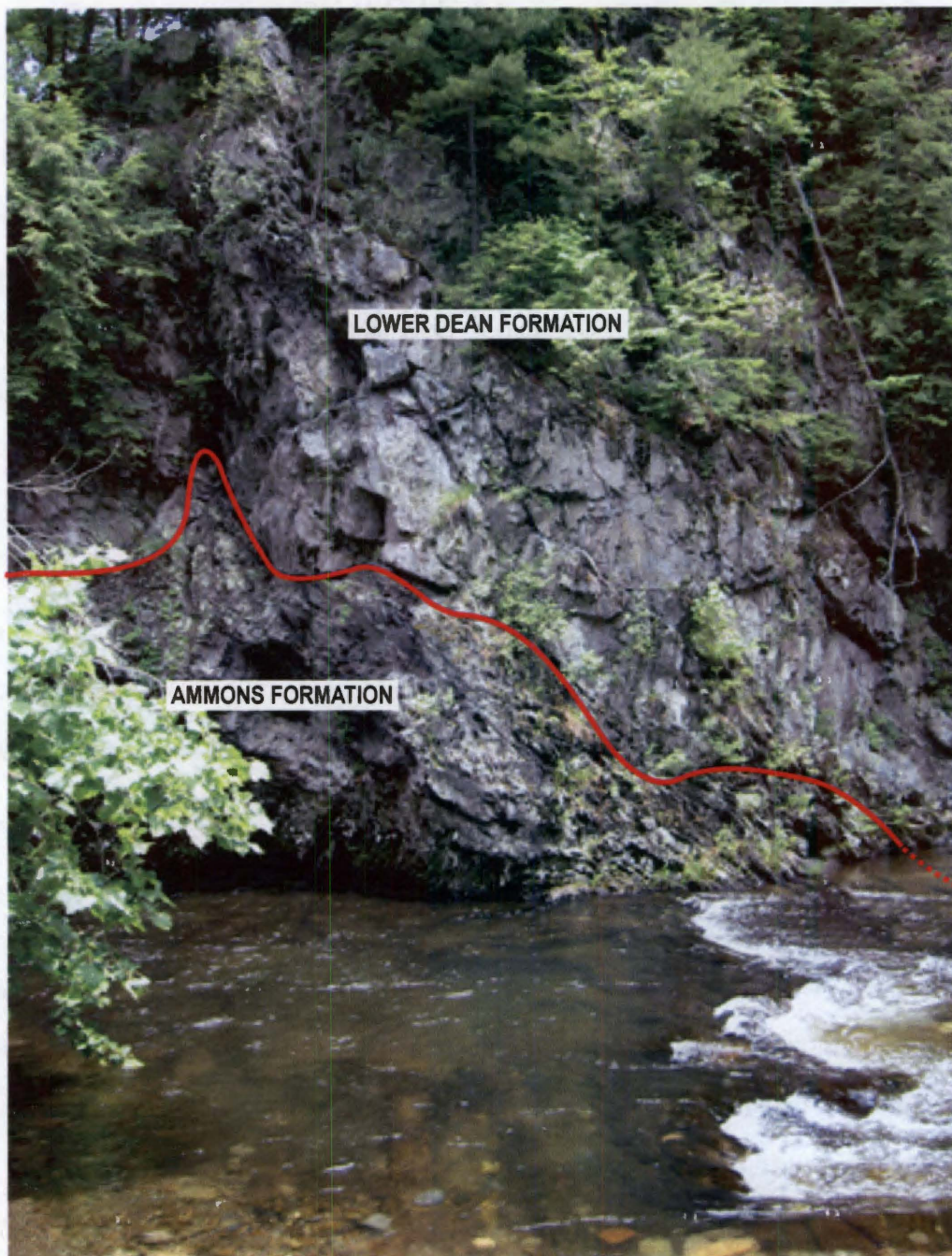


Figure 2-15. Exposed contact between the sulfidic and graphitic slate of the Ammons Formation and overlying feldspathic sandstone and conglomerate of the lower Dean Formation on the southeast limb of the Rafter anticline along Citico Creek, Whiteoak Flats 7.5 minute quadrangle.

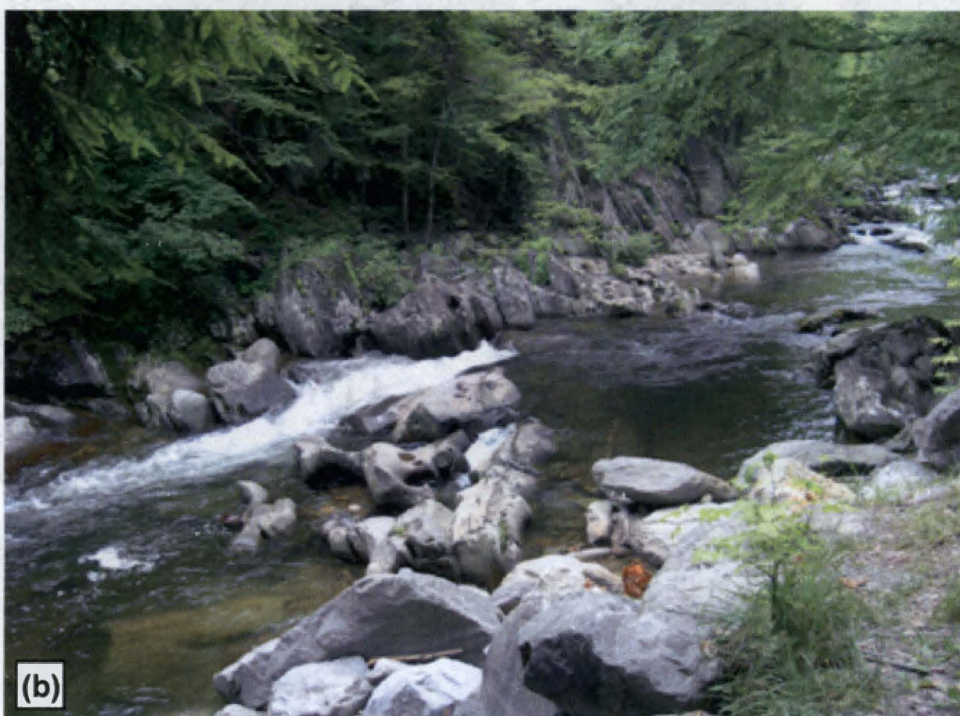


Figure 2-16. Conglomerate of the lower Dean Formation. (a) Clasts up to 2mm in diameter composed mostly of vein quartz and feldspar, minor carbonate, and rare blue quartz. (b) Medium to thin beds of lower Dean Formation sandstone forming ledges in Citico Creek, Whiteoak Flats 7.5 minute quadrangle.



Figure 2-17. Graded bedding in float of the lower Dean Formation conglomerate along Citico Creek near Barkcamp Branch, Whiteoak Flats 7.5 minute quadrangle. Lighter for scale is ~7 cm long.

The middle unit of the Dean Formation lies conformably above the lower unit of the Dean Formation (Fig. 2-18) and consists primarily of light to dark-gray banded, sulfidic siltstone (Fig. 2-19) and dark-gray to black sulfidic and variably graphitic slate (Fig. 2-20). Occasional exposures of fine to coarse-grained feldspathic sandstone and graywacke do occur within this unit, although thicknesses do not permit these coarser lithologies to be mapped at a 1:24,000 scale. To the southwest, Geddes (1995) noted one relatively thick (200 m; 660 ft) tongue of quartz-granule to pebble conglomerate and fine- to coarse-grained, graded feldspathic graywacke, which is compositionally and lithologically very similar to the lower unit of the Dean Formation. No member of this thickness was recognized between Citico Creek and the Little Tennessee River. The gradational nature of the upper contact of the middle slate and siltstone with the overlying upper conglomerate, graywacke, and sandstone requires that the contact be placed where continuously mappable slate and siltstone units no longer exist (Geddes, 1995; this study). The middle unit of the Dean Formation is approximately 100-200 m (320-640 ft) thick in the northwest limb, 500-600 m (1650-2000 ft) thick in the hinge, and 350-450 m (1150-1500 ft) thick in the southeast limb of the Whiteoak Flats syncline (Plate 1).

Rocks representing the upper unit of the Dean Formation conformably and gradationally overlie the middle slate and siltstone of the Dean, and in turn are conformably overlain by siltstone and slate of the Wilhite Formation (WCG; Fig. 2-21) in the Whiteoak Flats syncline (Plate 1). The upper unit of the Dean Formation is dominated by feldspathic granule to boulder intra- and extraformational conglomerates and graywackes (Fig. 2-22), with fine to coarse-grained feldspathic graywacke being predominant to the north and west. Clasts in the extraformational conglomerates and graywackes are generally composed of milky vein-quartz, gray quartz, plagioclase, potassium feldspar, and minor amounts of rutiled blue quartz and carbonate in a fine- to medium-grained feldspathic sandstone matrix. Less commonly, intraformational conglomerates contain clasts of black slate and banded metasiltstone up to 10 cm in length (Fig. 2-22), which appear to result from cannibalization of underlying finer-grained units. Upper Dean

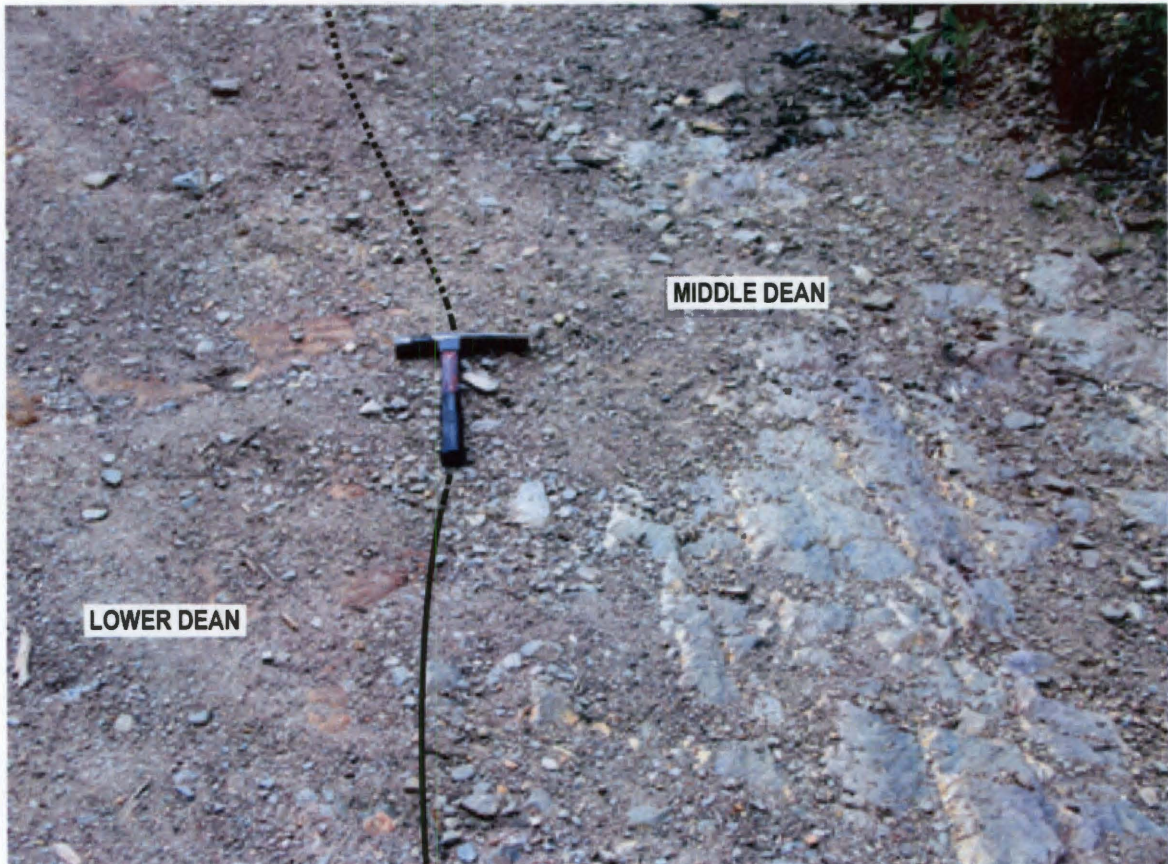


Figure 2-18. Exposure in road of contact between banded siltstone and slate of the middle Dean Formation and the gradationally and conformably underlying conglomerate of the lower Dean Formation on Salt Spring Mountain near Farr Gap, Whiteoak Flats 7.5 minute quadrangle. Multi-colored banding observed in most highly weathered exposures of the Middle Dean. Hammer handle is ~22 cm long. Photo by Robert D. Hatcher, Jr.



Figure 2-19. Banded siltstone of the middle Dean Formation near (a) Jakes Best Creek, Whiteoak Flats 7.5 minute quadrangle. Dark-gray layers composed of fine-grained siltstone and light-gray to white layers composed of fine- to medium-grained sandstone. Orangish-yellow color results from weathering of sulfides. Cubic voids left after weathering of pyrite in sulfide rich layers. (b) Prominently banded middle Dean siltstone near crest of Salt Spring Mountain, Whiteoak Flats 7.5 minute quadrangle. White bands predominantly composed of fine sandstone.

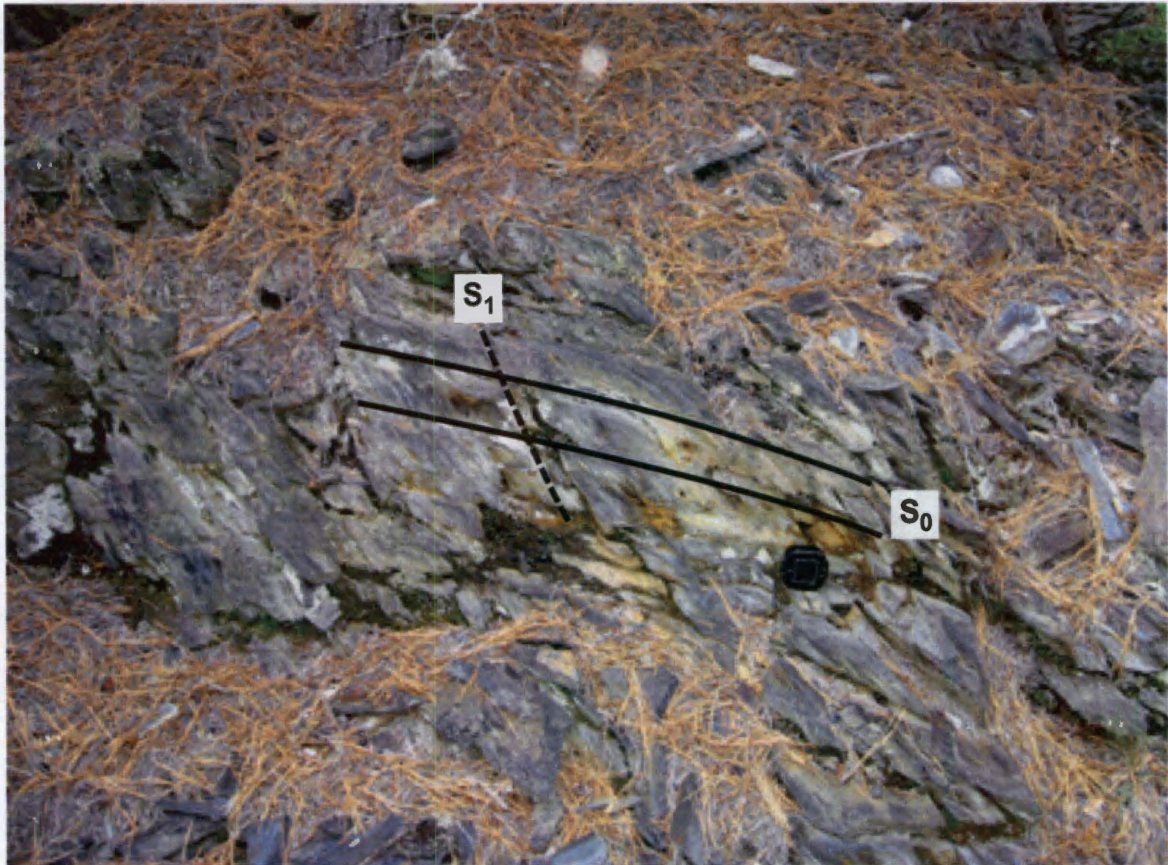


Figure 2-20. Dark-gray to black graphitic, mildly sulfidic slate of the middle Dean Formation above Doublecamp Creek headwaters near Farr Gap on Salt Spring Mountain, Whiteoak Flats 7.5 minute quadrangle. Higher angle of pervasive cleavage (S_1) with respect to bedding (S_0) possibly indicates that this exposure is upright.

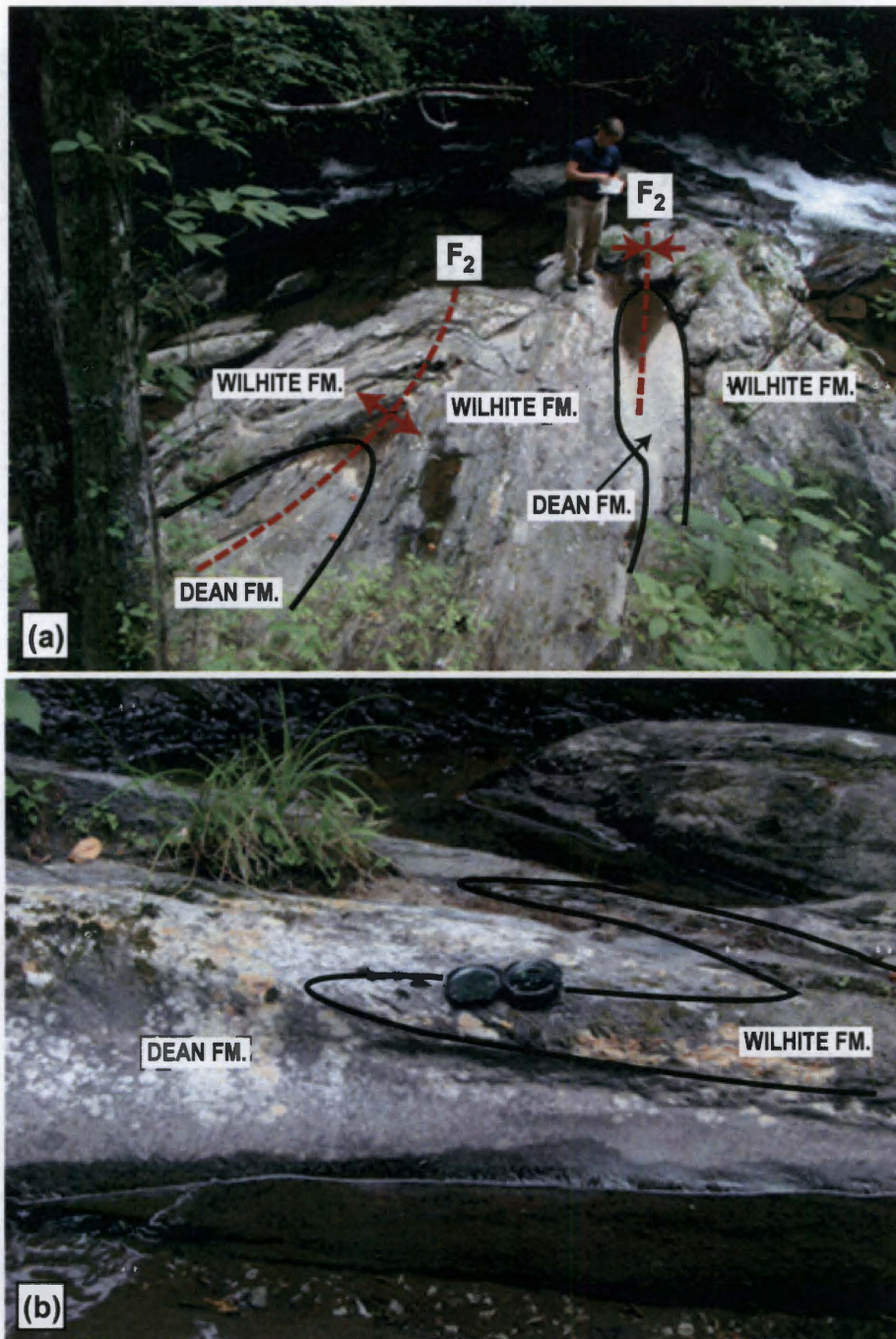


Figure 2-21. Folded conformable contact between upper Dean Formation sandstone and lower Wilhite Formation slate and siltstone in Doublecamp Creek near confluence with Citico Creek, Whiteoak Flats 7.5 minute quadrangle. (a) F_2 fold axes are axial planar to regional slaty cleavage development (S_2). (b) Folded contact ~200 m upstream of (a). Wilhite Formation slate and siltstone near contact with upper Dean Formation tends to become darker-gray-green due to gradational nature of contact. Photos by Robert D. Hatcher, Jr.



Figure 2-22. Upper Dean Formation graywacke and conglomerate with thin partings and clasts of light-gray graphitic slate that appear to form soft-sediment folds (F_0) in Doublecamp Creek, Whiteoak Flats 7.5 minute quadrangle. These clasts may be rip-up clasts removed from the basin surface by turbidite flows that deposited the coarser-grained lithologies in this unit. These F_0 folds are folded again by later Paleozoic deformation. The light-gray, fine-grained lithology of the slate is similar to lithologies observed in the Wilhite Formation, further suggesting that the Dean-Wilhite contact is gradationally conformable.

Formation conglomerate, graywacke, and sandstone has a variable thickness of 200-500 m (650-1650 ft) in the Whiteoak Flats syncline (Plate 1).

Wilhite Formation

Rocks correlated with the Wilhite Formation lie conformably above the Dean Formation in the core of the Whiteoak Flats syncline (Plate 1), and the gradational contact (Fig. 2-21) between these two units is interpreted as the boundary between the GSG (Dean) and the WCG (Wilhite). Like those in the Miller Cove thrust sheet, Wilhite Formation rocks in the Greenbrier thrust sheet consists predominantly of light gray to green banded siltstone, phyllite, and slate (Fig. 2-23), with minor amounts of quartz-rich conglomerate and fine to coarse-grained feldspathic sandstone.

Geddes (1995) subdivided the Wilhite Formation in the Greenbrier thrust sheet into three distinct units, with characteristic banded green to grayish-green slate and siltstone units on the top and bottom, separated by an ankerite-bearing slate and siltstone unit in the middle of the formation (Plate 1). In this study area, only the lower slate and siltstone unit of the Wilhite Formation is present due the southwest plunge of the Whiteoak Flats syncline bringing up older units than those recognized to the southwest (Plate 1). Wilhite Formation rocks in the study area are generally darker gray-green than those observed higher in the section to the southwest, which Geddes (1995) related to the gradational contact of the Dean and Wilhite Formations. The top of the lower Wilhite is not exposed in the study area, but Geddes (1995) indicated an approximate thickness of 300-400 m (1,000-1,300 ft), although an accurate thickness could not be made due to structural complexities.



Figure 2-23. Wilhite Siltstone (a) outcrop in Doublecamp Creek in Whiteoak Flats 7.5 minute quadrangle. (b) Interbedded light gray-green siltstone and dark-gray sulfidic slate of the Wilhite Formation in float near Doublecamp Creek. Note slaty cleavage (S_1) is more prominent in slate layers (S_0). Knife for scale is ~8 cm long. Photo in (b) by Robert D. Hatcher, Jr.

NEW REGIONAL STRATIGRAPHIC CORRELATIONS

Elkmont – Thunderhead – Copperhill – Anakeesta sequence

In GSMNP, the Elkmont and Thunderhead Sandstones represent the basal succession of the GSG in the Greenbrier thrust sheet (King et al., 1958; Plate 5). Hadley and Goldsmith (1963) and King (1964) suggested that these southward thickening, coarse-grained, graded sandstones and conglomerates are likely turbidites deposited in a deep marine trough, possibly with a northeastern or northwestern source area of rapidly eroded granitic basement terranes. The Copperhill Formation (Hurst, 1955) in southeastern Tennessee (Plate 5) consists dominantly of graded graywacke, arkose, and conglomerate, with a noted absence of very coarse-grained sediments recognized in the Elkmont-Thunderhead sequence.

Southworth et al. (2005), while remapping the southern GSMNP, recognized a three-fold division of the Thunderhead Sandstone (Plate 5). The lower sequence, dominated by relatively thicker-bedded, coarse-grained feldspathic sandstone and conglomerate is separated from the middle Thunderhead succession by the lower tongue of the Anakeesta Formation. Lithologically, the middle Thunderhead succession is nearly identical to the lower succession, and represents a coarse-grained horizon within the Anakeesta Formation. The upper Thunderhead sequence, equivalent to the unnamed sandstone of King et al. (1958) in GSMNP, lies conformably above the Anakeesta Formation. Although the upper succession is compositionally similar to the lower and middle Thunderhead successions, the average grain size is notably finer. The upper Thunderhead sequence is dominated by graded beds of medium to coarse-grained graywacke with only occasional conglomeratic lithologies. It is here correlated with the Copperhill Formation of Hurst (1955) in the core of the Ducktown anticlinorium. Whereas the Copperhill Formation in southeast Tennessee may reveal a finer-grained character than the upper Thunderhead in GSMNP, this correlation is based on similarity of stratigraphic positions and suggests basin-scale fining to the southwest at this depositional horizon.

Exposures of dark-gray to black dominantly fine-grained rocks underlying the Ammons

Formation in the Greenbrier thrust sheet and overlying the Thunderhead Sandstone in the Hangover Lead thrust sheet (Plate 1) are both correlated with the Anakeesta Formation, yet they are interpreted to lie at significantly different stratigraphic horizons. In GSMNP, the Anakeesta Formation is recognized to both overlie and intertongue with the Thunderhead Sandstone – Copperhill Formation (King et al., 1958; King, 1964; Southworth et al., 2005). Thus two distinctive Anakeesta horizons were suggested, with the lower tongue separating the lower Thunderhead Sandstone from the upper Thunderhead Sandstone-Copperhill Formation. The upper tongue of the Anakeesta lies above the upper Thunderhead-Copperhill Formation (Plate 5), and separates the sandstone and minor conglomerate of the Copperhill from the graphitic and sulfidic slate and graywacke of the Ammons Formation. Thus, the exposures of Anakeesta Formation beneath the Ammons Formation in the Greenbrier thrust sheet represent the upper tongue of the Anakeesta Formation and are believed to be stratigraphically equivalent to the Wehuty Formation, which Hernon (1968) originally defined in the Ducktown, Tennessee region. Near Ducktown, the Wehuty is dominantly composed of sulfidic and graphitic schist with alternating amounts of feldspathic metagraywacke, quartzite, and metaconglomerate (Hernon, 1968). Some (Wiener and Mercshat, 1992) have even suggested that the upper portion of the Copperhill Formation (Hurst, 1955) may be equivalent to the lower sections of the Wehuty, revealing the same gradational, intertonguing of these units similar to Thunderhead-Anakeesta relations in GSMNP (King et al., 1958).

The unit correlated with the Anakeesta Formation overlying the Thunderhead Sandstone in the Hangover Lead thrust sheet represents the lower tongue of the Anakeesta. Regional mapping of GSMNP by Southworth et al. (2005) reveals that exposures of the Thunderhead in this thrust sheet represent the lower portion of the Thunderhead, which is separated from the lower Thunderhead-Elkmont sequence by a moderate (>5 km) displacement thrust fault just west of Fontana Lake (Plates 1 and 5).

Cades-Shields-Dean sequence

Previous studies (Neuman and Nelson, 1965; Southworth, 2001) found difficulty assigning the Cades Sandstone a proper stratigraphic position because of interpretations of a faulted(?) contact between the Cades and all surrounding units in the western GSMNP region, although they recognized that the lithologic character of the Cades is very similar to units of the GSG, most notably the Elkmont Sandstone and Dean Formation. Studies by Carrol et al. (1957) suggested that approximately identical overall mineralogy and heavy mineral suites of the Elkmont Formation and Cades Sandstone was evidence that they are stratigraphic equivalents. Workers in GSMNP (King et al., 1958; King, 1964; Neuman and Nelson, 1965) noticed that, while the Elkmont and Cades are lithologically very similar, the Cades Sandstone again lacks the characteristic blue rutilated quartz clasts found in the coarser lithologies of the Elkmont Sandstone. Map patterns in the Cades Cove region of GSMNP (Plate 5) appear to suggest that the Cades Sandstone either stratigraphically underlies or overlies the Metcalf Phyllite of the Snowbird Group (Neuman and Nelson, 1965). Later work by Walters (1988) suggested that this contact is tectonic based on the presence of shear-band cleavage and mylonitic fabrics on the surface of the Parsons Branch and Coalen Ground faults (Metcalf thrust over Cades) in the vicinity of Cades Cove, as well as similar fabrics along the Metcalf-Cades contact northeast of Cades Cove.

DeWindt (1975) interpreted the unclassified formations (Cades, Rich Butt, and Webb Mountain Sandstones) of King et al. (1958) to be deep-water turbidite fans, and suggested a possible correlation between these units and the Elkmont-Thunderhead-Copperhill sequence. Woodward et al. (1991) used this correlation to suggest that the Cades Sandstone in the Rabbit Creek thrust sheet and the rocks of Webb Mountain and Big Ridge are klippe of the Greenbrier thrust sheet (Plate 5). Whereas no other rocks recognized in the GSMNP region are very similar to the rocks of Webb Mountain and Big Ridge, the thick graded beds (1.5-3 m) of coarse-grained feldspathic sandstone, dark-gray sandy metasilstone and slate, and minor conglomerate are

most similar to the Cades Sandstone. Furthermore, both the Cades and Webb Mountain/Big Ridge rocks have an extremely limited blue quartz content. Carroll et al. (1957) compared heavy mineral suites from the Cades and Elkmont, but were unable to note significant compositional differences. Ilmenite and zircon were present in all samples examined, with ilmenite composing up to 90 percent of the heavy minerals in some suites. Zircon and tourmaline were both observed, mostly in relatively small amounts. Petrographic examination of Webb Mountain/Big Ridge rocks commonly revealed abundant zircon, tourmaline, and ilmenite, although no heavy mineral separation has been attempted. The aforementioned observations were the primary evidence for early correlations between the Cades, Webb Mountain, and lower GSG formations. However, the obvious contrast in blue quartz content between these formations still requires a local(?) depositional separation between them, even if they have many similar component types/amounts from broadly similar source areas. Structural evidence, discussed later, seems to further refute these correlations.

Geddes (1995) originally suggested that the Cades Sandstone in the Rabbit Creek thrust sheet southwest of Little Tennessee River may be correlative with the Dean Formation because of lithologic similarities and its position in the Rabbit Creek thrust sheet in GSMNP. Continued mapping to the northeast between Citico Creek and the Little Tennessee River further indicates that the Dean and the rocks of the Rabbit Creek thrust sheet (Cades Sandstone) are correlative, as no fault was recognized (Plate 1). Furthermore, interbedded and mappable fine-grained slate and siltstone of the Dean Formation southwest of GSMNP (Plate 4) appear to be correlative with mappable slate and siltstone units of the Cades Sandstone recognized in the Kinzel Springs 7.5 minute quadrangle (Neuman and Nelson, 1965) (Plate 5). While the thicknesses of the finer-grained Cades units in GSMNP are not as great as those recognized southwest of the Little Tennessee River, thickness changes are observed throughout Ocoee Supergroup units, so the observation of a relatively large thickness change does not adequately refute a correlation between the Dean Formation and the Cades Sandstone.

The position of the Shields Formation beneath the Wilhite Formation in the Miller Cove thrust sheet suggests a stratigraphic correlation between this unit and the Dean Formation, which rests beneath the Wilhite Formation in the Greenbrier thrust sheet. Clasts from both the Dean and Shields are very similar, although a lack of graded beds in the Shields Formation makes these units fundamentally different. Clasts of the Shields conglomerate are generally more rounded and the overall composition is more vein quartz-rich and seemingly less feldspathic. Correlation of these units, however is based on similar stratigraphic position and detrital sediment source.

Wilhite Formation subdivisions

Weiner (unpublished) previously subdivided the Wilhite Formation into two units, the Yellow Breeches and Dixon Mountain Members, in the northwestern part of the study area. Based on mapping in the Jones Cove and Richardson Cove quadrangles northeast of GSMNP, Hamilton (1961) assigned sequences consisting mostly of carbonate rocks to the Yellow Breeches Member of the Wilhite Formation. This unit is generally defined by thick limestone beds forming sections ≤ 30 m (≤ 100 ft) thick, commonly sandy or conglomeratic, often interbedded with micaceous, silty, and sandy rocks, and generally colored medium- to dark-gray. Exposures range from nearly pure carbonate to as much as 50% well-rounded quartz sand. Many limestone beds contain cherty or fine-grained shale/slate layers and, less commonly, limestone may appear nodular in appearance. An overall thickness of ~600 m (~2000 ft) may be observed near Yellow Breeches creek east of Jones Cove, TN.

Hamilton (1961) originally assigned the thick (~450 m; 1500 ft) sequence of siliciclastic dominated, carbonate-bearing rocks lying conformably beneath the Yellow Breeches Member to the Dixon Mountain Member of the Wilhite Formation. This unit is composed primarily of micaceous and fine-grained sandstone or coarse-grained siltstone, with alternating light and dark laminations. Less commonly, thin interbeds of medium to coarse-grained feldspathic sandstone are also present. Rare exposures of massive-bedded sandstone and thin beds of detrital or

clastic limestone, and light-gray dolomite, have also been observed. The contact between the Dixon Mountain and Yellow Breeches Members near Jones Cove and Richardson Cove is a conformable, yet often sharp break between fine-grained sandstone or coarse-grained siltstone (Dixon Mountain) and the overlying limestone-dominated rocks of the Yellow Breeches Member (Hamilton, 1961). While Hamilton's (1961) subdivision is applicable in the Jones and Richardson Coves region, no contrast such as those previously mentioned were recognized southwest of GSMNP by this study, and therefore the subdivision of Wiener (unpublished) has been abandoned and all Wilhite Formation slate, siltstone, and limestone are grouped as one unit in the Miller Cove thrust sheet.

OCOEE SUPERGROUP PROVENANCE, DETRITAL COMPONENT ANALYSES, AND BASIN-WIDE STRATIGRAPHIC RELATIONSHIPS

Many interpretations have been suggested to explain the complexity of Ocoee Supergroup (OSG) lithostratigraphy (King et al., 1958; Hamilton, 1961; Hadley and Goldsmith, 1963; King, 1964; Neuman and Nelson, 1965; DeWindt, 1975; Keller, 1980; Rast and Kohles, 1986). The compositional similarity of rift basin rocks, the heterogeneous nature of rift basin architecture and the large aerial extent of these basins often precludes an ability to decipher precise paleotectonic and paleogeographic environments based on interpretations from any area. In this study, we utilize characteristics such as detrital heavy minerals, lithic fragment composition (intra- and extraformational), paleocurrent indicators, and sedimentary structures to evaluate sediment provenance and examine lateral changes in lithology, thickness, and compositional maturity to delineate depositional relationships. Ultimately, this analysis will aid interpreting the complex architecture of the Ocoee basin.

Discussions in Chapter 1 provide information on the lithologic and depositional characteristics of most Great Smoky Group (GSG) and Walden Creek Group (WCG) units, as well as their regional stratigraphic relationships. The following detailed discussion of Snowbrid

Group (SG) lithologic/depositional characteristics, and interpreted stratigraphic relationships are presented in order to provide the reader with necessary information prior to discussion of the basin models constructed during this study. Extensive discussion of all OSG units may be found in King et al. (1958), DeWindt (1975), Keller, (1980), Rast and Kohles (1986), and Carter (1994).

Snowbird Group Depositional Chronology and Provenance

The Wading Branch Formation is the stratigraphically lowest unit in the OSG (King et al., 1958) and consists primarily of dark-gray to black sandy argillite, siltstone, and pebbly feldspathic sandstone (Fig. 2-24a). According to King et al. (1958) and DeWindt (1975), the presence of residual clays and discontinuous nature of the Wading Branch Formation suggest a source of deeply weathered granitic or high grade metamorphic rocks deposited directly (unconformably) on Laurentian (Grenvillian) basement in isolated, relatively low-elevation pockets and depressions (Fig. 2-24c). Consequently, the Wading Branch Formation is interpreted as the only OSG unit not directly related to rifted-margin development.

A sharp contact between the Wading Branch Formation and the overlying Longarm Quartzite (Fig. 2-24b; Hadley and Goldsmith, 1963; Montes, 1997) marks an abrupt change in depositional conditions. Current bedding, sole marks, penecontemporaneous slump structures (DeWindt, 1975) and coarser-grained compositions indicate deposition above wave base in dominantly intertidal, braided fluvial, and/or fluvio-deltaic environments. Compared to the Wading Branch Formation, this unit is much more homogenous and laterally continuous. The high feldspar content in the Longarm is a strong indication of rapid mechanical disintegration at the source with virtually no chemical decomposition (Hadley and Goldsmith, 1963; Hadley, 1970). Montes (1997) observed fine-grained orthoquartzite to be dominant to the southeast, while less mature, coarser-grained arkosic to sub-arkosic facies are dominant to the northwest, which suggests a northwestern source for the Longarm. Interpretations by King et al. (1958) alternately suggested a southeastern source for the Longarm based on paleocurrent indicators

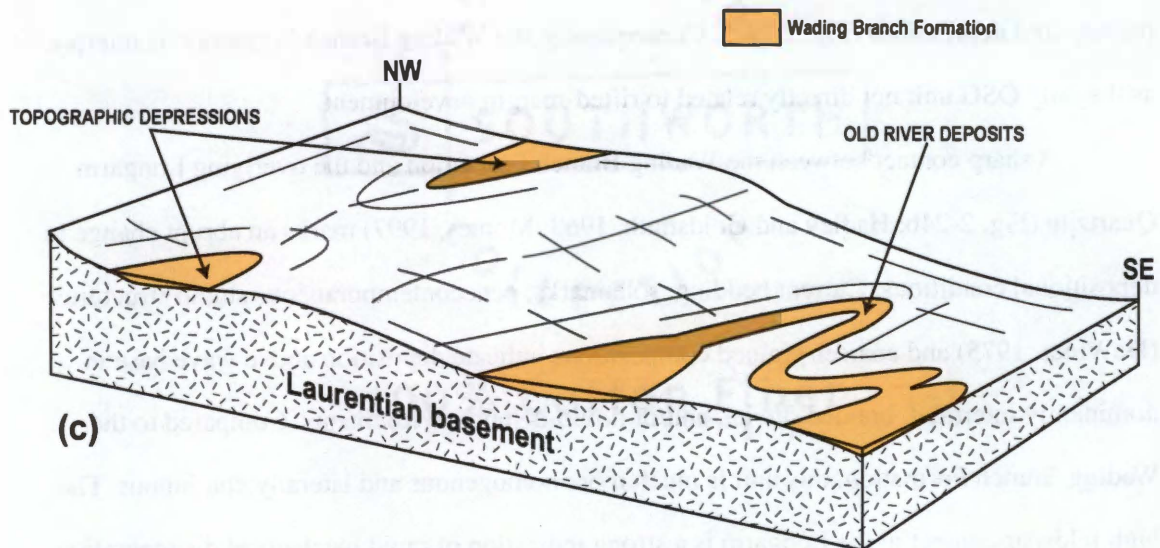
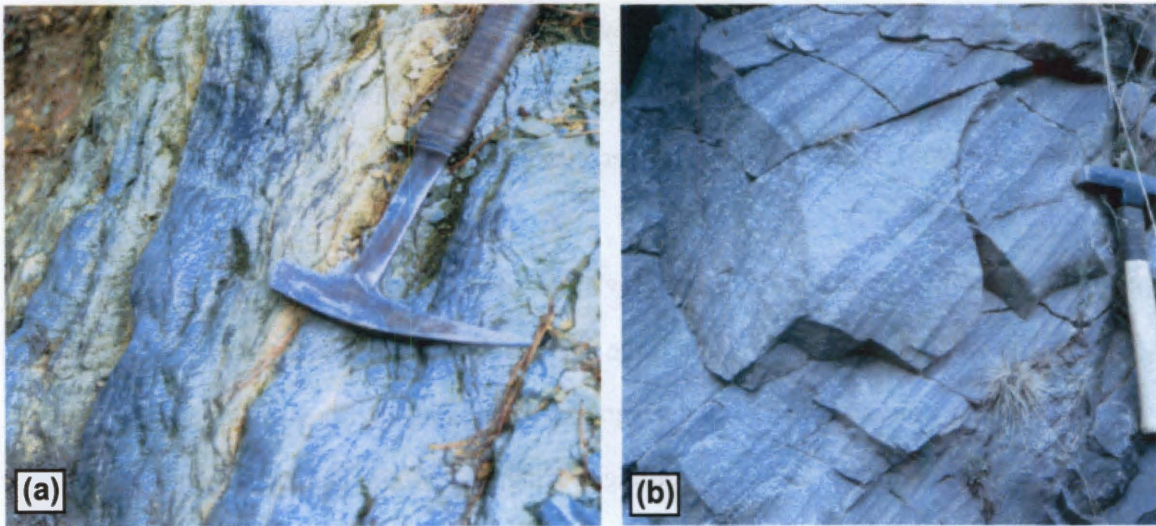


Figure 2-24. The Wading Branch Formation and Longarm Quartzite are the basal components of the Snowbird Group. (a) Phyllite and schist of the Wading Branch Formation in the Smokemont, NC 7.5 minute quadrangle. (b) Cross-bedded, feldspathic sandstone of the Longarm Quartzite in the Bunches Bald, NC 7.5 minute quadrangle. Photos by Scott Southworth. (c) Schematic model of the the Wading Branch Formation depositional environment. This unit was most likely derived from deeply weathered granitic basement and deposited in isolated, discontinuous topographic depressions and river channels on a subdued basement surface prior to the onset of the initial rifting phase, marked by deposition of the Longarm Quartzite.

and a recognized prevalence of coarser-grained sediments to the southeast. In the Dellwood, North Carolina region (eastern GSMNP and vicinity; Plate 5), thickness changes of ≥ 500 m occur in the Longarm over lateral distances of 2-3 km near the Cataloochee Divide (Montes, 1997). Without evidence of compressional/deformational features these thickness changes are best explained by the presence of syndepositional normal faulting (Fig. 2-25; Montes, 1997). Contrary to interpretations by Hadley and Goldsmith (1963), Montes (1997) proposed that the SG was deposited as a northwest sourced distal downlap on the basement surface. Regionally, the Longarm becomes coarser-grained and more feldspathic to the southeast. The locally higher feldspar content to the northwest observed by Montes (1997), however, may have resulted from the locally rapid subsidence of the hanging-wall trough and high relief source area (footwall scarp) to the southeast. Longarm sediments atop the footwall block, however, should not have exhibited an increase in either feldspar content or grain size. Thus, a southeastern source for the Longarm Quartzite appears to be the most valid interpretation when considering regional scale relationships, which is the primary focus of the study.

The Roaring Fork Sandstone conformably overlies and intertongues with the Longarm Quartzite and is dominated by massive-bedded medium- to fine-grained feldspathic quartzite with ripple marks and horizons of phyllitic slate (Hadley and Goldsmith, 1963). DeWindt (1975) interpreted the Roaring Fork to represent a delta-front or interdeltaic laterally transitional facies between the Longarm and deeper-water Pigeon and Metcalf facies. Sandstone beds in the Roaring Fork are compositionally similar to the underlying Longarm Quartzite (King et al., 1958; Hadley and Goldsmith, 1963; King, 1964) and Montes (1997) recognized that the Roaring Fork-Longarm contact is transitional over stratigraphic intervals of 20-40 m. An increasing prevalence of fine-grained sediments up section and to the northwest (Hadley and Goldsmith, 1963; Montes, 1997; Montes and Hatcher, 1999) indicates that the Roaring Fork was sourced from the southeast and deposited above and basinward of the Longarm. The abundance and composition of detrital heavy minerals in the Roaring Fork Sandstone are similar to those of the Longarm Quartzite and Wading

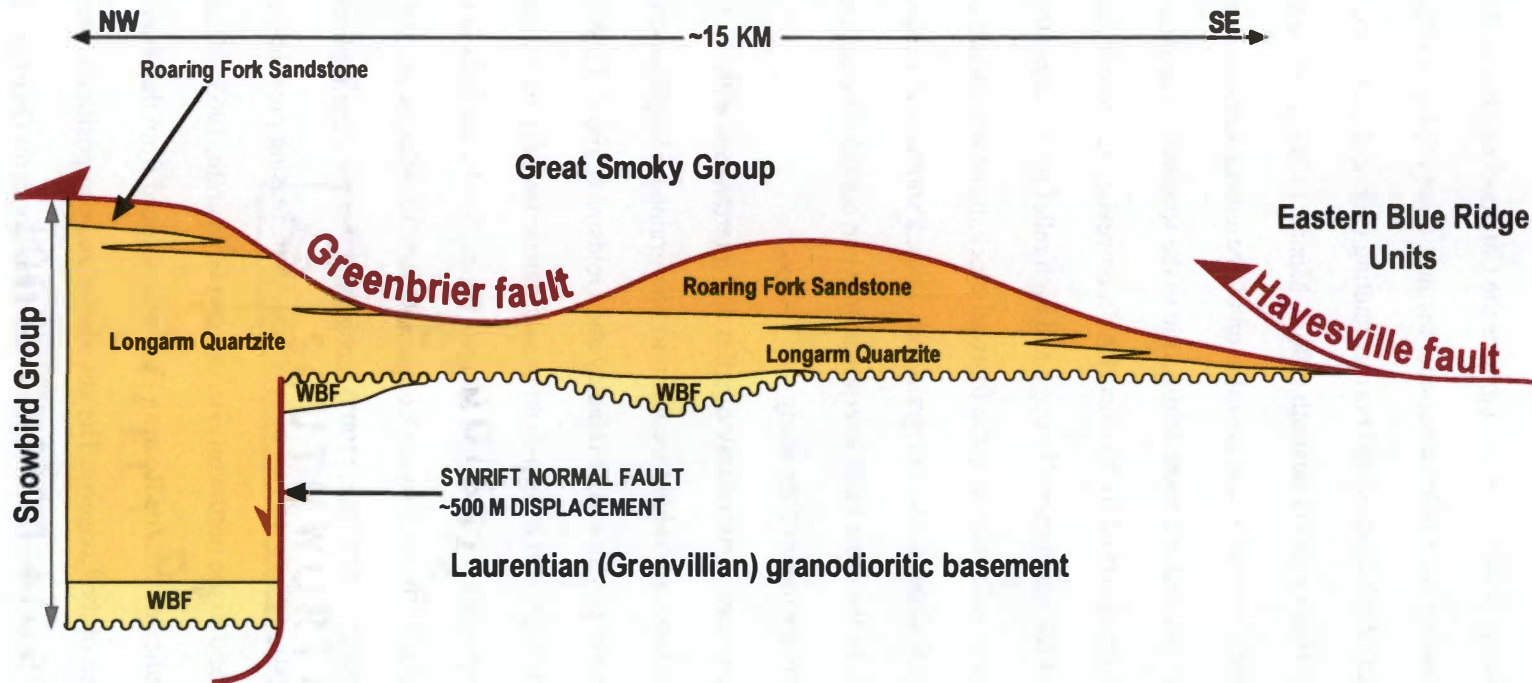


Figure 2-25. Reconstruction of the stratigraphic relationships among the Snowbird Group units based on extensiveness of thickness of exposures recognized in the Dellwood, North Carolina region. Synrift normal fault is inferred from significant thickness changes (~500 m) across the trace of the Alleghanian Caldwell Creek fault, which has minimal displacement. The Caldwell Creek fault may have been a normal fault prior to thrust reactivation during later Alleghanian orogenesis, or it may truncate and conceal the earlier synrift fault. Modified from Montes (1997) and Montes and Hatcher (1999). WBF - Wading Branch Formation.

Branch Formation (Hadley and Goldsmith, 1963), supporting interpretations that these units had a similar source area.

The Pigeon Siltstone conformably overlies and intertongues with the Roaring Fork Sandstone, and was considered by Hadley and Goldsmith (1963) to represent the uppermost unit in the SG. Tremendous thicknesses ($\geq 3,000$ m in the eastern GSMNP region; Hadley and Goldsmith, 1963; $\geq 5,000$ m near Gatlinburg; Hamilton, 1961) of medium- to dark-gray, fine-grained sandstone and siltstone with abundant olive-gray slate are interpreted as laterally transitional interdeltic and prodeltic sediments deposited into a basin becoming progressively deeper to the northwest (Rast and Kohles, 1986). DeWindt (1975) recognized that the sandier components of the Roaring Fork and Pigeon are Na-feldspathic and their subtly expressed current-ripple bedding structure suggests westward to southwestward transport by subaqueous traction currents.

The Metcalf Phyllite represents the uppermost SG unit, although this sequence of pale-green to gray-green phyllite, interbedded slate and phyllite, and minor amounts of fine-grained sandstone (King, 1964) is lithologically similar to and interpreted to be laterally transitional with the Pigeon – Roaring Fork sequence farther east (DeWindt, 1975). The pervasive foliation of its finer-grained components (phyllite and metasiltstone) sets the Metcalf apart as an independent unit. DeWindt (1975) interpreted the Metcalf as being deposited by turbidity currents in a deep water, rapidly subsiding basin with a sediment transport direction predominantly to the southwest, parallel to the long axis of the basin trough. Later investigation by Rast and Kohles (1986) revealed few indications of turbidite activity such as well-developed grading, unsorted sediments, or flute casts. This suggests that the Metcalf as an offshore basinal deposit related to a prodelta.

The SG displays a notable absence of both zircon and tourmaline, with the exception of the Pigeon Siltstone and Metcalf Phyllite, which both contain less than 1% of these detrital components (King, 1964; Neuman and Nelson, 1965). Inversely, detrital epidote and sphene are virtually restricted to the SG, which may indicate an amphibolite source for these units Rast and

Kohles (1986). Virtually all SG units, as well as those of the GSG, contain abundant feldspar clasts, a first-order inference of a nearby, rapidly eroded source area.

DISCUSSION – RIFT-TO-DRIFT BASIN ARCHITECTURE OF THE SOUTHEASTERN LAURENTIAN MARGIN

Rodgers (1991) concluded that the great thickness of the OSG, and the generally poorly sorted and compositionally immature nature of its sediments, indicates contemporaneous deposition within a tectonically active basin(s). Early interpretations (King et al., 1958; Hadley and Goldsmith, 1963; Hadley, 1970) suggested that basal OSG units (SG), with deeply weathered residual clay and compositionally mature siltstone, sandstone, and conglomerate at its base (Wading Branch Formation), cross-bedded quartzite higher in the section (Longarm Quartzite), and plane- to flaser-bedded, ripple cross-stratified finer-grained rocks (Roaring Fork Sandstone – Pigeon Siltstone) near the sequence top, resulted from deposition during a transgression from continental or littoral facies deposited directly upon deeply weathered crystalline basement to deposition in deeper-water marine environments. Southeastward thinning of the SG is interpreted by this study as a lower boundary proximal onlap of a sequence transgressive toward the southeast margin of the basin, with sediment sourced from the southeast.

The tremendously thick GSG (up to 15 km), which rests above and/or laterally basinward of the SG, is characterized throughout by graded-bedded conglomerate, graywacke, sandstone, and minor argillaceous units that generally fine to the south, southeast, and east. Graded bedding and lateral variation in average grain size indicate that GSG units likely resulted from deep-water turbidite deposition (Fig. 2-26). The high feldspar content of most GSG units is attributed to a relatively proximal northwestern or northeastern cratonic highland source area with considerable relief (Hadley and Goldsmith, 1963; King, 1964; Rodgers, 1972; DeWindt, 1975; Rast and Kohles, 1986). The WCG, overlying both SG (Keller, 1980) and GSG rocks (Geddes, 1995; Martin, 1997; this study), is also characterized by graded bedding, but of rhythmically and thinly

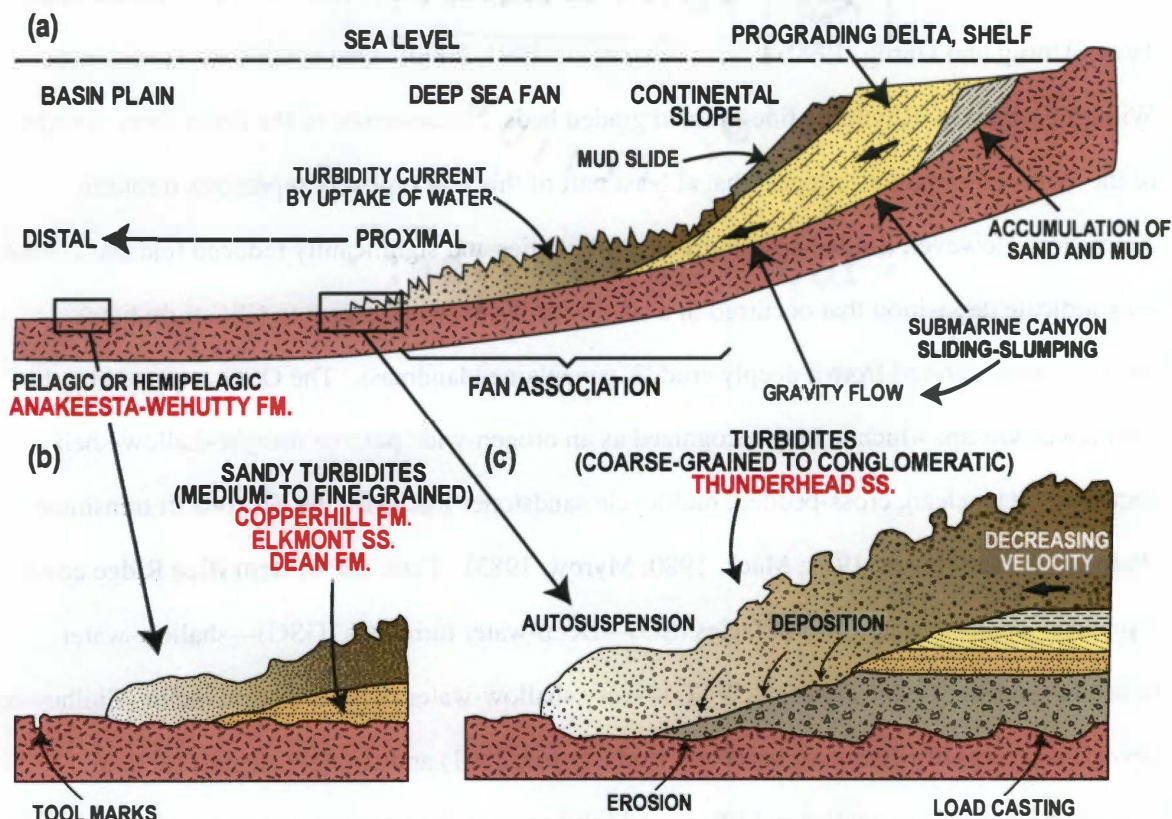


Figure 2-26. Models for development of GSG-type turbidite flows and their subsequent deposits. (a) Transition from slope failures (slumps, debris flows, grain flows, etc.) on the basin margin to turbidity flows that may often be catastrophic in scale. (b) Components of proximal turbidites, including laminated mudstone (gray), ripple cross-bedded sand (light yellow), plane laminated sand (light brown), and graded gravels and conglomerates (dark brown). (c) Components of distal turbidites, including laminated sands and mud turbidites. (Modified from Einsele, 2000).

(≤ 5 cm) banded rippled siltstone, with subordinate channel fills of coarse-grained clastic and carbonate lithologies. Paleocurrent indicators (crossbedding, pebble imbrication, asymmetrical load casting) and an increase in compositional maturity to the southeast suggest a northwestern source area (Hamilton, 1961; Neuman and Nelson, 1965; DeWindt, 1975; Keller, 1980) and most WCG sediments are interpreted to be unstable shelf deposits (DeWindt, 1975; Hanselman et al., 1974; Unrug and Unrug, 1990, 1991; Unrug et al., 1991, 2000). One notable exception is the Wilhite Formation. Rhythmic fine-grained graded beds, characteristic of the lower three-fourths of the Wilhite Formation, suggest that at least part of this unit probably represents turbidite deposition. However, limited coarse-grained lithologies and significantly reduced feldspar content may indicate deposition that occurred in a shallower basin (with respect to GSG turbidites) with sediment derived from a deeply eroded, peneplained landmass. The OSG is capped by the Chilhowee Group, which is long recognized as an orogen-wide passive-margin shallow-shelf sequence by its clean, cross-bedded, multicycle sandstones that mark the rift-to-drift transition (Palmer, 1971; Schwab, 1971; Mack, 1980; Myrow, 1983). Thus, the western Blue Ridge cover sequence: shallow-water littoral facies (SG)—Deep-water turbidites (GSG)—shallow-water turbidites and shelf-edge deposits (WCG)—very shallow-water passive-margin facies (Chilhowee Group) is typical of rifted margins (Fedo, and Cooper, 2001) and strongly suggests active tectonism attributed to continental rifting and infilling of a deep depositional basin along the Late Proterozoic to earliest Cambrian Laurentian margin.

Ocoee basin lithotectonic models

Utilizing all currently available data, new lithotectonic models of the OSG basin were constructed to illustrate the evolution of the southeastern Laurentian margin throughout most of the paleogeographic vicinity of the present-day western Blue Ridge (Figs. 2-27, 2-28, 2-29, 2-30). The most comprehensive OSG basin studies to date by DeWindt (1975) and Rast and Kohles (1986) derived a number of conclusions and provided strong, yet subtly contrasting framework

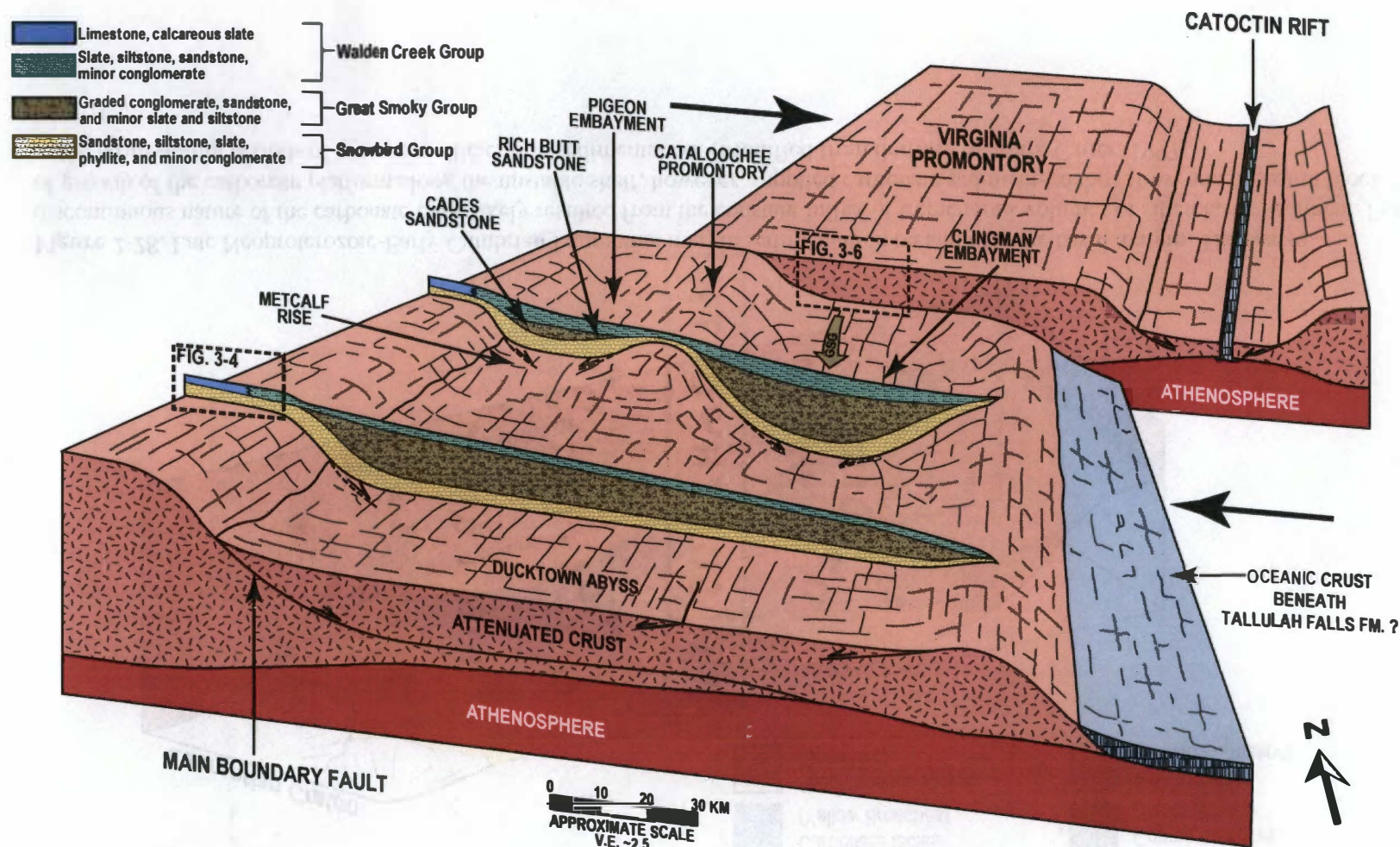


Figure 2-27. Schematic model of the Ocoee basin prior to drift transition and deposition of Chilhowee Group along the southeastern Laurentian margin. Basement surface geometry and basin depths were interpreted from estimated thicknesses of Ocoee Supergroup units, displacement direction and magnitude of major Paleozoic faults, and exposed basement-cover contacts. Appropriate references utilized in model construction are cited in the text. Location of Figures 3-4 and 3-6 are shown in dashed boxes. (Partially derived from unpublished drafting of Mark Carter, 1997).

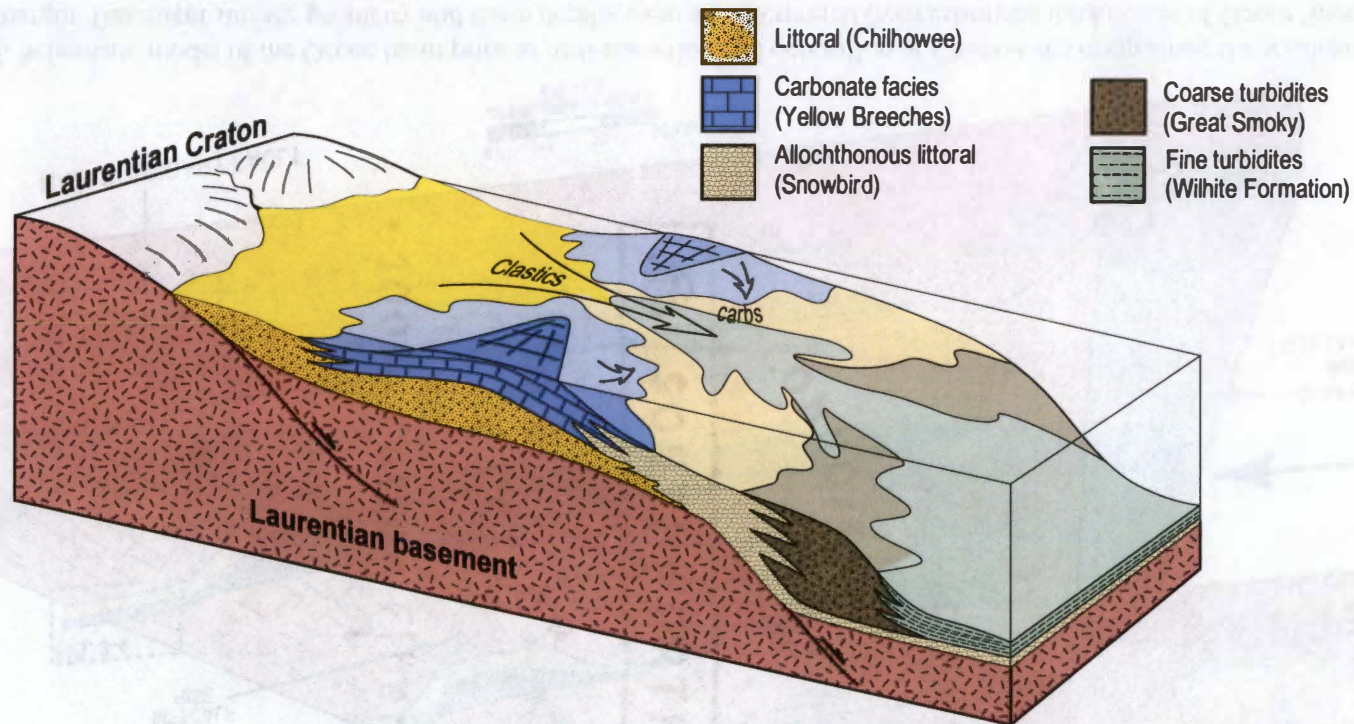


Figure 2-28. Late Neoproterozoic-Early Cambrian Laurentian margin sedimentation on and near the basin margin. The sparse, discontinuous nature of the carbonate bank likely resulted from the constant influx of tremendous volumes of siliciclastic sediment. Pulses of growth of the carbonate platform along the unstable shelf, however, supplied carbonate sediments, debris flow, and olistolith blocks(?) to the basin during periods of quiescent siliciclastic sedimentation. (Modified from drafting by Mark Carter, 1997).

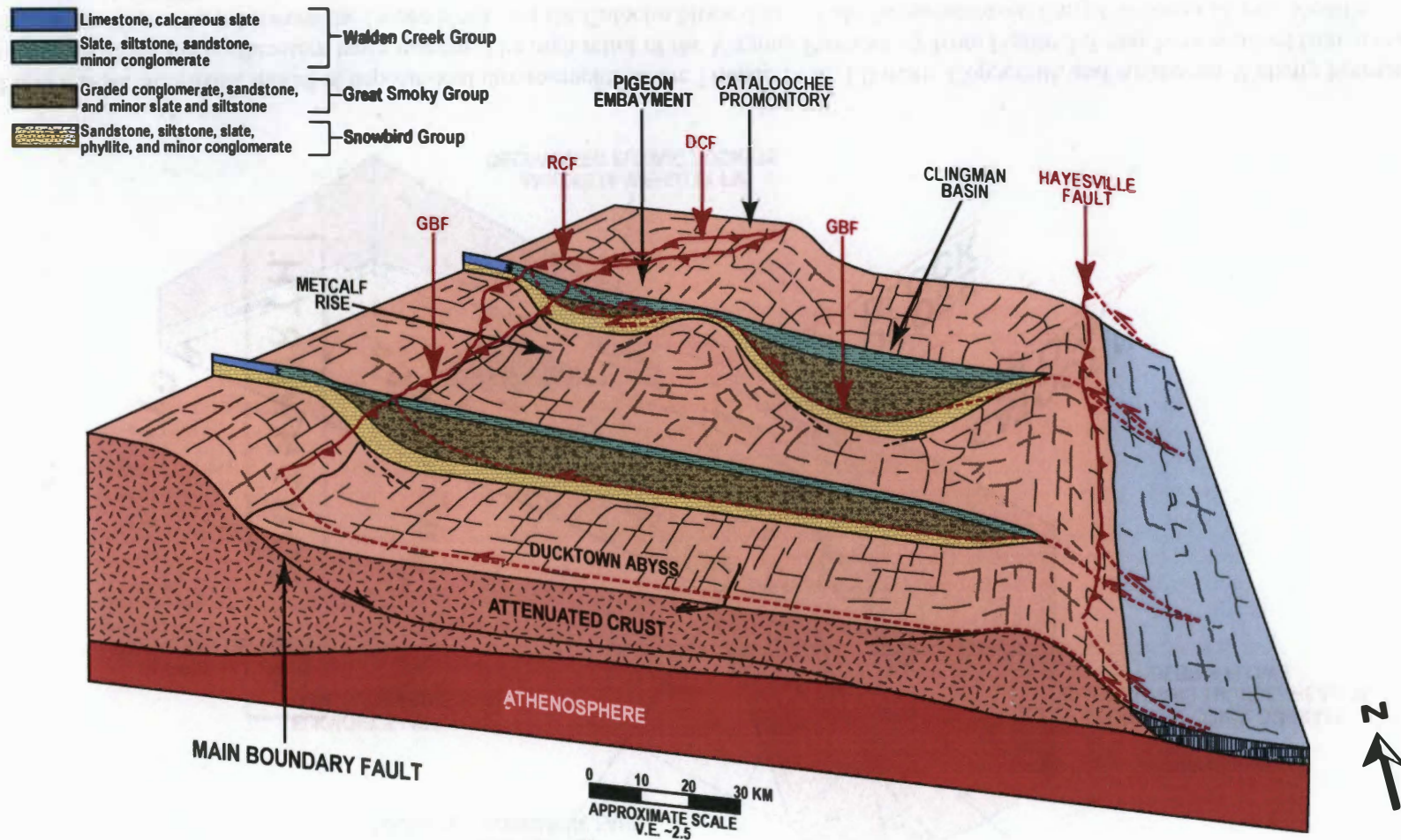


Figure 2-29. Schematic model of the Ocoee basin during the Taconic (Ordovician) orogeny. Red solid lines indicate approximate surface locations of pre-Alleghanian faults. Red dashed lines represent interpreted subsurface trajectories of those same faults. GBF - Greenbrier fault. RCF - Rabbit Creek fault. DCF - Dunn Creek fault.

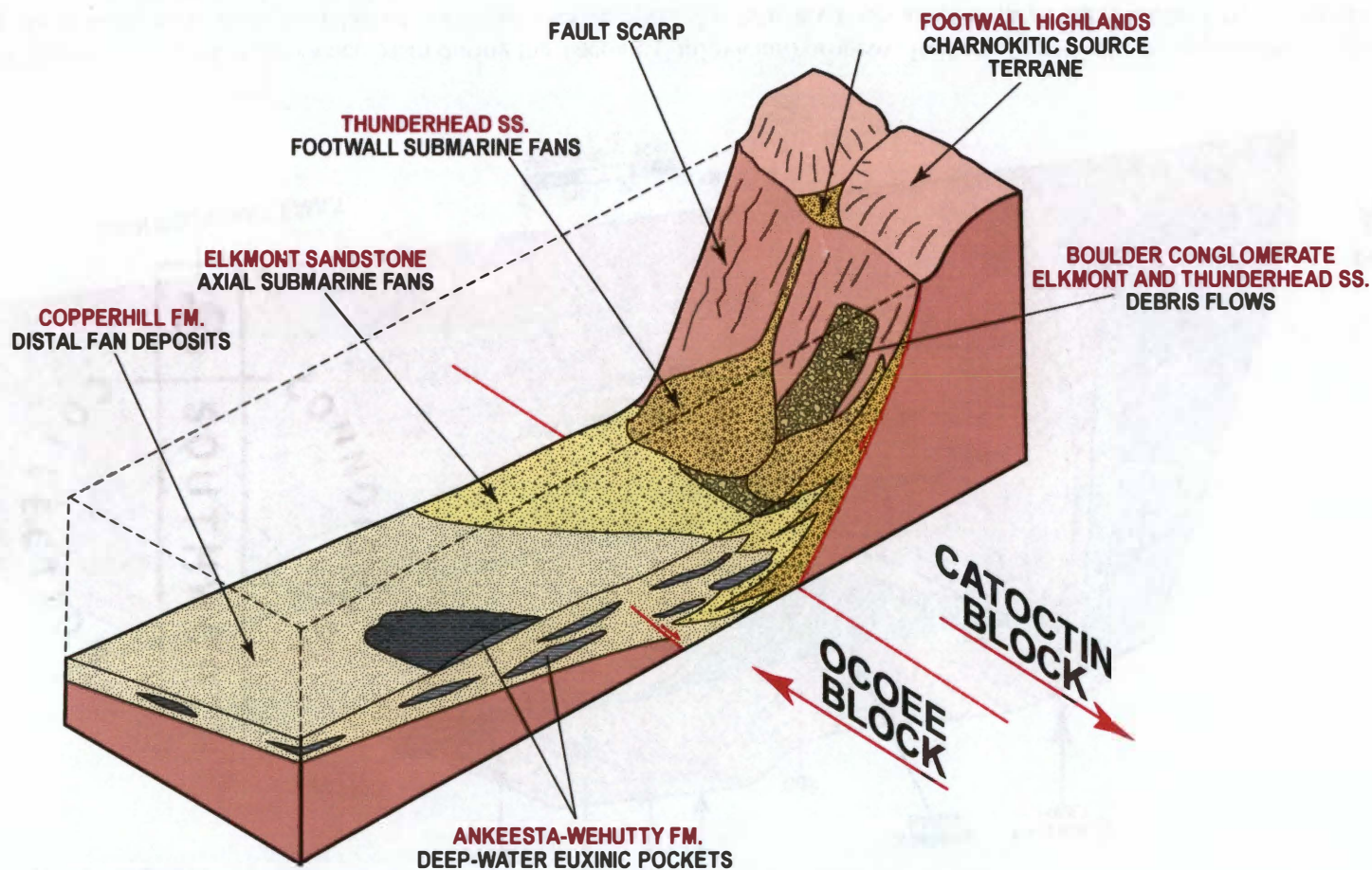


Figure 2-30. Schematic model of depositional environments of the Thunderhead, Elkmont, Copperhill, and Anakeesta-Wehuty Formation turbidites along the northeastern basin margin. The high relief of the Virginia Promontory from Figure 3-3 may have resulted from a major dextral transform fault between the Ocoee block and the Catoctin block during Late Neoproterozoic-Early Cambrian rifting. Modified from Einsele (2000).

hypotheses on OSG basin architecture and depositional environments, as well as the later effects of Paleozoic deformation. Their interpretations, however, were limited by confinement of the investigations to GSMNP and the immediate vicinity. Carter (1994) discussed in detail the depositional chronology of the OSG, which he utilized to construct basin models partially founded in these two earlier works and complemented by his extensive work both southwest and northeast of GSMNP. Many fundamentals of his work were also integrated into the models of this study. Numerous sedimentological aspects derived by this study, however are fundamentally different from previous studies.

Prior to the initial stages of rifting, the Wading Branch Formation occupied topographic depressions on the deeply weathered basement surface (Fig. 2-24). The first appearance of rift-related sedimentation is marked by the onset of Longarm Quartzite deposition. Snowbird units, with the exception of the Metcalf Phyllite and parts of the Pigeon Siltstone, represent a transgressive, predominantly shallow-water facies, which covered the entire depositional area prior to and concurrent with the initiation of cratonic rifting (Fig. 2-27). Snowbird strata recognized as far south as the Cartersville District in west-central Georgia (Costello et al., 1982; McConnel and Costello; 1984; Costello, 1993; Tull, in review; Plate 5) attest to its basin-wide deposition. By analogy with modern transgressive environments (Shaw, 1964; Middleton, 1973), shallow-water littoral facies transgressed the basin margins as continued rifting gave way to deeper-water deposits (Pigeon Siltstone and Metcalf Phyllite) in the basin interior (Fig. 2-26). Previous depositional models (Rast and Kohles, 1986) proposed that synrift Snowbird rocks were mostly confined to a geographically restricted depression (Gatlinburg basin), separating them from most GSG units (all but Cades Sandstone, rocks of Webb Mountain-Big Ridge, and Rich Butt Formation) by the proposed Unaka horst. Interpretations of this study agree that the Cades Sandstone was deposited atop SG units and was depositionally isolated from the tremendously thick GSG sequence to the east, but SG deposition is believed to have occurred basin-wide, though a relatively thick succession was likely deposited in the Pigeon Embayment, whereas a

relatively thin succession may have rested atop the Cataloochee Promontory (Fig. 2-26). To the extreme southwest and northeast ends of the basin, WCG strata resting conformably (locally unconformably) atop SG strata indicate that the depth of the basin and/or rate of subsidence near those margins never provided conditions suitable for GSG turbidite deposition. The Metcalf Phyllite, presently exposed west and southwest of the main SG body and traditionally interpreted as a deeper-water facies (King, 1964; Neuman and Nelson, 1965; DeWindt, 1975), with a southwestern sediment transport direction (DeWindt, 1975), was mostly deposited on the southward-facing rise (Metcalf Rise) near the mouth of the Pigeon Embayment (Fig. 2-27).

Continued rifting produced increasing subsidence and facilitated GSG deposition. GSG turbidites may have been concurrent with transgressive deposition of SG facies along the basin-margins (Walther, 1894; Middleton, 1973; Figs. 2-27 and 2-28). Although the inferred SG rocks are not presently exposed to the southeast, they may be preserved in the GSF footwall beneath the Blue Ridge-Piedmont crystalline thrust sheet (Fig. 2-29). Previous authors interpreted GSG rocks to have been deposited in a tectonically active graben following SG deposition, with GSG sediments derived from a northwestern basement horst separating GSG and older SG depositional centers (Rast and Kohles, 1986). They implied that the SG cover sequence deposited on the block prior to uplift must have provided detritus to lower GSG strata before erosion of tourmaline- and blue quartz-bearing granulite-facies or charnockitic basement rocks, which are indicative of most GSG sediments. In fact, SG-type quartzitic and shaly rock fragments are absent within lower GSG strata. GSG rocks are also completely devoid of epidote and sphene, which are diagnostic heavy minerals of the SG (Hadley and Goldsmith, 1963) and should have easily survived multicycle reworking and deposition (Rast and Kohles, 1986).

Conversely, the depositional model set forth here (Fig. 2-27) suggests that most GSG sediments were derived from northeastern highlands on the cratonic mainland (Fig. 2-30), east of the Pigeon Embayment. They were likely deposited by erosive turbidites over littoral SG facies throughout the basin (Fig. 2-27). The extremely thick Elkmont-Thunderhead-Copperhill

sandstones and conglomerates above the Greenbrier fault were likely derived from a northeastern source area where dextral transform faulting (Thomas, 1991) produced very high relief (Virginia Promontory; Figs. 2-27 and 2-30). This negates the necessity to cannibalize a thick sequence of older SG strata during deposition, although the nature of turbidites favors scouring and erosion of underlying sediments on a more local scale (Bouma, 1962).

The Rich Butt Sandstone (King et al., 1958), currently observed beneath the GBF in gradational contact with the Pigeon Siltstone, was likely deposited along the eastern margin of the Pigeon Embayment. Thickening of these GSG-type lithologies to the west and lateral gradation with the Pigeon Siltstone to the east suggests that it was transitional between SG and GSG depositional styles. The Cades Sandstone and the rocks of Webb Mountain and Big Ridge (King et al., 1958) were likely sourced from the northwestern and northern slopes of the Pigeon Embayment. An absence of detrital blue quartz, which is characteristic of other GSG units indicates a source area for the that was separated from the Rich Butt Sandstone and the rest of the GSG succession. With this exception noted, however, Cades-Webb Mountain-Big Ridge rocks are quite similar to other GSG lithologies and are interpreted to result from broadly similar turbidite depositional regimes. New stratigraphic correlations between the Cades Sandstone and Dean Formation south of Little Tennessee River (Geddes, 1995; this study) suggest that isolation of the Cades from most other GSG units is limited only by the southwestermost extent of the Cataloochee Promontory (Fig. 2-27). South of GSMNP, data from detailed mapping suggests that the Cades and Dean had a similar northwest source area and were deposited in a basin that was not divided by a substantial basement promontory. A slightly greater thickness (~500 m) of the Cades with respect to the Dean suggests that if remnants of a basement high were present, it was regionally insignificant. The structural juxtaposition of GSG strata above SG strata and basement rocks along the GBF necessitates most GSG deposition in a basin east of the Cataloochee Promontory (Clingman Basin) or to the south in the Ducktown Abyss (Copperhill and younger units).

The earliest example of OSG carbonates are the interbedded pisolitic dolostone and limestone lithologies that occur in the Anakeesta Formation (Hadley and Goldsmith, 1963). Carbonate clasts are common in stratigraphically higher Dean Formation conglomerates recognized in southeastern Tennessee (Carter, 1994; Geddes, 1995; this study) and flanking the Murphy syncline (Mohr, 1975; Ausburn et al., 1983; 1998). Dean Formation carbonate exists only as clasts or boulders in conglomerates, and may have been derived from slumping or debris slides of platform margin assemblages resting atop an unstable shelf to the northwest (Fig. 2-27). Carbonate in the Anakeesta Formation is commonly pisolitic and is interbedded with graded feldspathic sandstone, suggesting deposition in relatively shallow water along the northwest margins of the proposed Cataloochee basement promontory during times of high subsidence and/or low sedimentation rates. Graded beds in the sandstones separating these carbonates suggest that pulses of turbiditic sedimentation may have smothered the carbonate build-ups, though additional carbonate formed between periods of siliciclastic deposition.

The WCG is regionally extensive and is recognized conformably overlying both the GSG and SG throughout the Ocoee basin. The Shields Formation occupies the base of the WCG in GSMNP and surrounding vicinity, and clearly represents both the lateral and vertical transition between deeper-water catastrophic turbidite flows of the GSG and shallow platform sedimentation associated with the WCG. Graded beds and deep-water euxinic shale deposits are mostly absent in the Shields Formation (Neuman and Nelson, 1965), and sandstones and channel conglomerates have more mature compositions (vein quartz, quartz dominated matrix, feldspar and cannibalized lithic fragment abundances are significantly reduced with respect to units of the GSG). These characteristics suggest that source sediment could no longer be derived from high relief basin margins and surrounding topography, necessitating either a significant reduction in subsidence rates with respect to sedimentation rate or that erosion of a cratonic highland source area(s) to the northwest created a subdued region of minimal relief. At the time of Shields deposition along or near the platform margin, slumping of immature sediment that

was previously deposited basinward of the margin may have been the source for the less mature graded sandstones and conglomerates of the Cades Sandstone and Dean Formation. Carbonate clasts (up to boulder size) similar to limestone and dolomite of the WCG become increasingly prevalent toward the top of the Cades-Dean sequence, suggesting that source sediment for the uppermost portions of these units was at least partially derived from the developing, possibly unstable carbonate platform along the basin margin.

Numerous environmental factors facilitate deposition of fine-grained turbidites such as that characteristic of the lower Wilhite Formation. They are common in deep-water lower submarine fan environments (Mutti and Ricci Lucchi, 1975; Rupke, 1977; Walker, 1978) (Fig. 2-30), although no evidence currently exists to support a deep-water source for the Wilhite. Alternately, a reduction in grain size related to derivation from an erosionally subdued or more distal cratonic source to the northwest could produce these deposits. These factors, combined with cratonward migration of the environment during rift-induced transgression, may have juxtaposed fine-grained, but most likely shallower-water Wilhite sediments above coarser-grained, but relatively deeper-water turbiditic deposits of the GSG (Figs. 2-26, 2-27, and 2-28). Southeast-directed paleocurrents in the Nantahala Formation (Aylor, 1991), and lithologic similarities between the Nantahala and Wilhite (Hurst and Schlee, 1962; Fairley, 1965; Costello, 1993) suggest that the Nantahala is the deeper-water basinward equivalent of the Wilhite (Fig. 2-27).

The carbonates of the Sandsuck and upper Wilhite Formations consist of bedded micrite, massive dolostones, calcarenite, and intraformational breccia, and are perhaps the most controversial and variably interpreted units in the WBR. Breccia clasts are comprised of the aforementioned lithologies, but also contain shallower-water allochems such as pisoids, ooids, and oncoids. Whereas most workers have assigned OSG rocks to the Late Neoproterozoic based on observed stratigraphic relations and acritarch distributions (Hayes, 1895; Keith, 1904; King et al., 1958; Knoll and Keller, 1979; Walker and Rast, 1991), recent reports of Unrug and Unrug (1990, 1991) and Unrug et al. (1991, 2000) report Silurian to Mississippian depositional ages of

these units based on observed microfaunal suites from the Wilhite and Sandsuck Formations, that they interpret as Silurian and younger olistoliths shed from the platform margin into post-Taconic successor basins (Unrug et al., 2000). Observed stratigraphic relationships and metamorphic ages dates continue to suggest that these carbonates likely have a latest Neoproterozoic to Early Cambrian age.

Carter (unpublished) originally proposed that if a Late Proterozoic carbonate bank discontinuously fringed the Laurentian continental margin, a continuous supply of clastic sediment from the craton could be transported into deeper-water through channels between those build-ups. This would allow carbonate production on the bank to remain unaffected by the transient sediments and could account for the clastic and calcareous rock-types observed in the GSG-WCG sequence (Fig. 2-27). Initiation of carbonate deposition may have occurred as early as deposition of lower GSG sediments, as indicated by the presence of calcareous concretion-like clasts in lowermost GSG rocks such as the Thunderhead Sandstone (Fig. 2-12; Hurst, 1955; Hadley and Goldsmith, 1963; King, 1964; Neuman and Nelson, 1965). A shallow-water carbonate bank was certainly shedding olistoliths into deeper-water by the time of Cades-Dean deposition. The bulk of the carbonate strata, however, was deposited as part of the WCG.

WCG clastic facies and carbonate environments were likely laterally juxtaposed, allowing the lower Wilhite basinward slope to be the primary recipient of carbonate olistoliths and micrite derived from the bank (Fig. 2-27). The Murphy Marble in the Murphy belt sequence of western North Carolina may have been deposited as distal calcareous muds from the Ocoee carbonate bank (Carter, unpublished) as subsidence waned. Whereas the hypothesis of a discontinuous carbonate bank fringing the basin margin conforms to most of the evidence currently recognized, no direct evidence of the interpreted carbonate bank has been observed.

The Sandsuck Formation represents the final phases of WCG deposition. Mature quartz arenites and calcarenites, consisting of well rounded monocrystalline multicycle quartz grains, are interbedded with Sandsuck and Wilhite carbonates lower in the section (Hamilton, 1961; Carter,

1994). Contrastingly, upper Sandsuck and overlying Cochran-Unicoi (Chilhowee Group) strata comprise a sequence of rocks dominated by feldspathic graywacke, sandstone, and poorly sorted polymictic conglomerate. These strata imply that although the margin may have stabilized for a brief period during deposition of passive-margin-type sandstones and carbonate debris from the platform, renewed subsidence and/or uplift cratonward of the OSG basin (post-rift subsidence?, second pulse of rifting?) produced sufficient relief to supply immature clastic sediments to the upper WCG-lower Chilhowee Group sequence. The margin completely stabilized thereafter, and passive-margin sandstone and quartzite of the middle to upper Chilhowee Group marks the transition from rift-to-drift along the southeastern Laurentian margin (Rankin et al., 1989).

CONCLUSIONS

- 1) Detailed mapping in the study area indicates that the Anakeesta-Wehuty, Ammons, Dean, and Wilhite Formation form a conformable stratigraphic sequence separated from the Elkmont and Thunderhead Sandstones only by minimal displacement Alleghanian faulting.
- 2) The lithologic and stratigraphic similarities of the Cades Sandstone in the Rabbit Creek thrust sheet and the Dean Formation in the Greenbrier thrust sheet suggest that they are correlative. The Shields Formation shares many lithologic features with the Dean Formation and lies in the same stratigraphic position beneath the Wilhite Formation in the Miller Cove thrust sheet, though the lack of graded beds suggests that the Shields is time transgressive with though depositionally distinct from the Cades and Dean in the study area.
- 3) The Thunderhead Sandstone in the Greenbrier and Hangover Lead thrust sheets represents the lower and upper members of that unit, respectively. The upper member of

the Thunderhead is equivalent to the unnamed sandstone in GSMNP and the Copperhill Formation in the core of the Ducktown anticlinorium. The disappearance of the coarser-grained lower member and the increasing prevalence of the upper member to the southwest suggest a dominantly northeastern source of the Elkmont-Thunderhead-Copperhill sequence.

- 4) Like the Thunderhead Sandstone, the Anakeesta Formation in the Greenbrier thrust sheet and Hangover Lead thrust sheets are interpreted as the upper and lower members of that unit, respectively. The upper member in the Hangover Lead thrust sheet is equivalent to the Wehuttu Formation in the Ducktown anticlinorium and Murphy synclinorium.
- 5) To the north, OSG deposition likely occurred in two separate rift basins divided by a region of basement uplift. To the south, diminishment of that uplift allowed deposition in a single basin. The SG is interpreted as a lower boundary proximal onlap of a sequence transgressive toward the southeast and northeast margins of the basin. Ubiquitous graded bedding, lateral variations in average grain size, and a high feldspar content of most GSG units is related to deposition by turbidite flows originating from a relatively proximal, high relief, rapidly eroded source area to the northeast and/or northwest. WCG deposition occurred after a significant reduction in subsidence rates with respect to sedimentation rate and/or after the cratonic highland source areas had become erosionally subdued. Lateral continuity and intertonguing of OSG units suggests that the SG, GSG, and WCG lithologies experienced at least partially contemporaneous deposition.
- 6) Carbonate rocks of the WCG may have discontinuously fringed the Laurentian margin, which would allow a nearly infinite supply of clastic sediment from the craton to be transported to deeper water through channels between those build-ups.

- 7) Onset of Chilhowee Group deposition above the OSG during the Cambrian marks the rift-to-drift transition along the southeastern Laurentian margin.

CHAPTER III

STRUCTURAL GEOLOGY BETWEEN CITICO CREEK AND THE LITTLE TENNESSEE RIVER: A KEY TO THE STRUCTURE OF THE WESTERN BLUE RIDGE IN SOUTHEASTERN TENNESSEE, SOUTHWESTERN NORTH CAROLINA, AND NORTHERN GEORGIA

STRUCTURE AND METAMORPHISM BETWEEN CITICO CREEK AND THE LITTLE TENNESSEE RIVER

Most Ocoee Supergroup (OSG) and Chilhowee Group rocks immediately south of the Great Smoky Mountains National Park (GSMNP) reveal at least two and possibly three periods of deformation (Fig. 3-1). An early event, likely related to the Taconic (Blountian, Middle Ordovician) orogeny, produced folding, faulting, cleavage development, and Barrovian metamorphism, and a later event interpreted as the Alleghanian (Pennsylvanian-Permian) orogeny involved brittle faulting and folding. Structural relationships of the WBR between Citico Creek and the Little Tennessee River reveal a polydeformational history that is more complex than can be explained by two deformational events. Burial by later faulting and/or reactivation of early faults, premetamorphic, symetamorphic, and postmetamorphic folding, and pervasive deformation within a complex stratigraphic framework often requires an extensive understanding of regional structural relationships to delineate temporal relationships of deformational events.

Major faults

Six major faults (Great Smoky, Miller Cove, Rabbit Creek, Greenbrier, Salt Spring Mountain, Hangover Lead) and numerous smaller faults are exposed between Citico Creek and the Little Tennessee River (Fig. 3-2; Plate 1). Variable metamorphic, structural, and stratigraphic relationships within each thrust sheet attest to the complexity of deformation in the study area. Woodward et al. (1991) proposed that, rather than focusing merely on fault trace boundaries

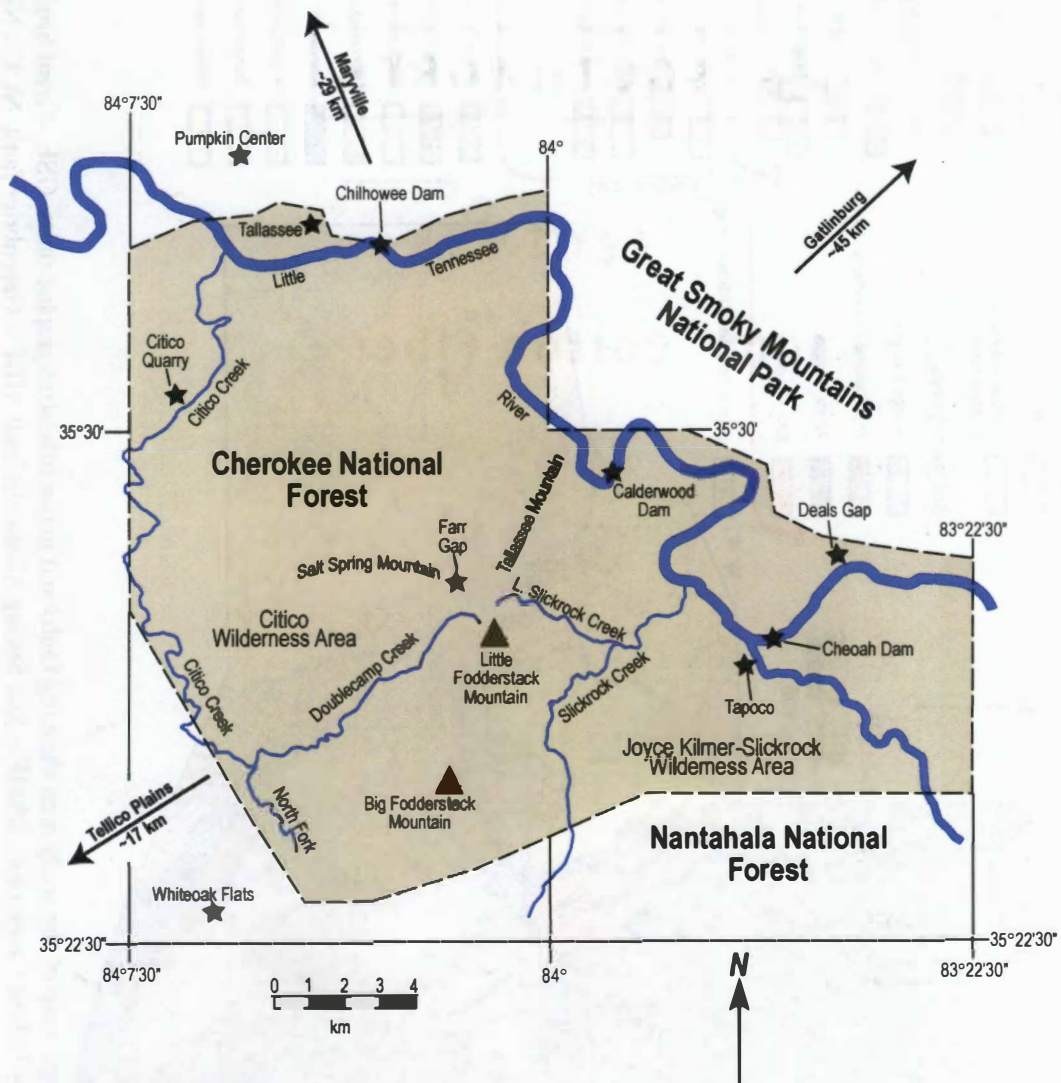


Figure 3-1. Location map showing the study area (light brown), streams, and geographic features discussed in the text.

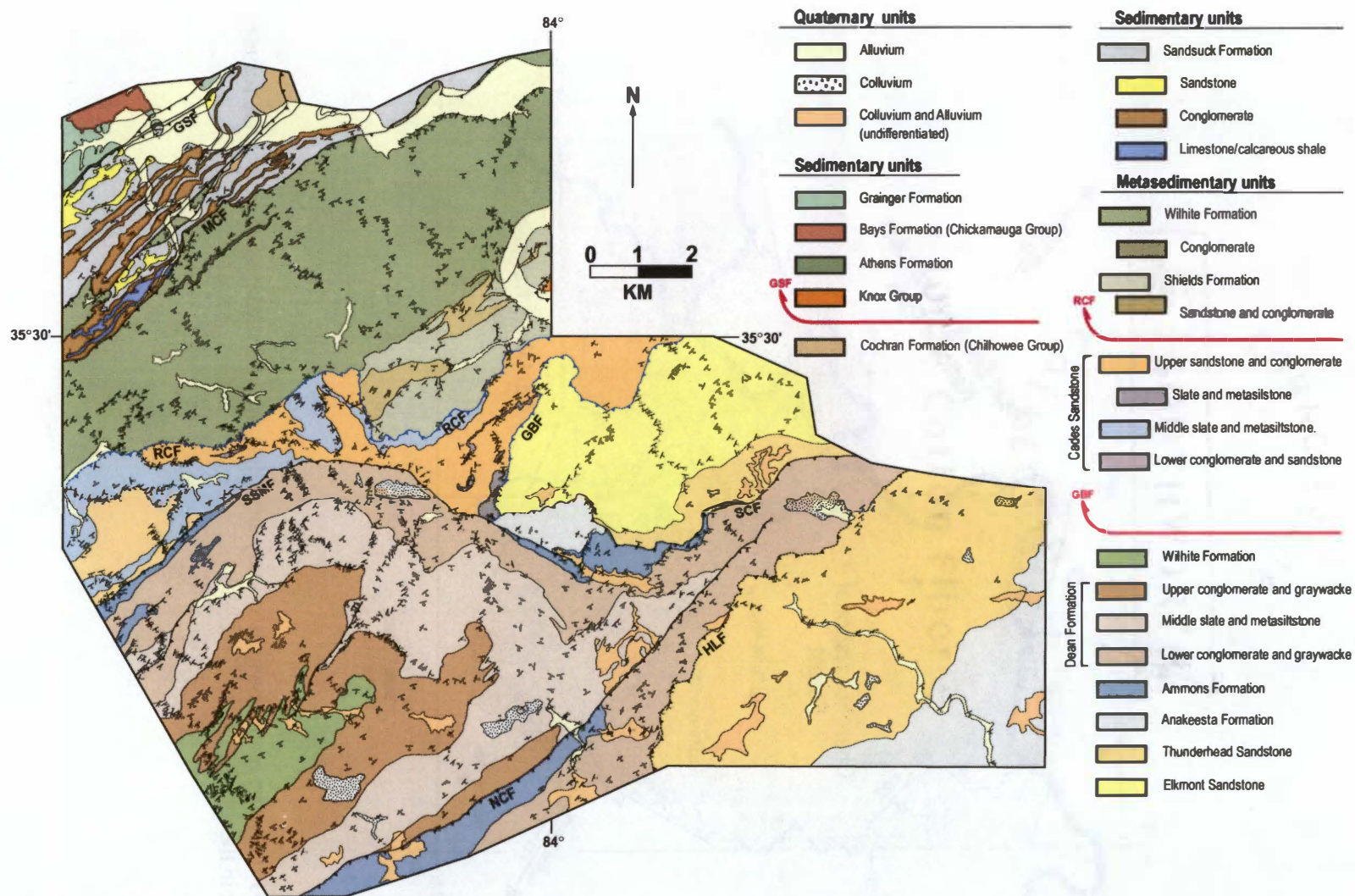


Figure 3-2. Reduced-size geologic map of the study area showing faults and major lithostratigraphic units. GSF - Great Smoky fault. MCF—Miller Cove fault. RCF—Rabbit Creek fault. SSMF—Salt Spring Mountain fault. GBF—Greenbrier fault. NCF—Nichols Cove fault. SCF—Slickrock Creek fault. HLF—Hangover Lead fault.

within a terrane, it is much more effective to focus on individual thrust sheets, especially in areas that have experienced polydeformation. Contrasting stratigraphic sequences, unit thicknesses, and deformational styles of the thrust sheets separated by major faults provide significant insight into both the depositional and deformational history of the WBR.

Great Smoky fault

The Alleghanian Great Smoky fault (GSF) represents the northwesternmost fault in the study area, and as the frontal Blue Ridge fault in this region (Hatcher et al., 1989), it thrusts Chilhowee Group and conformably underlying uppermost OSG (Sandsuck Formation) rocks over Paleozoic rocks of the Valley and Ridge province. In the GSMNP region, rocks as young as Cambrian (Rome Formation) are present in the GSF thrust sheet, and Cambrian-Ordovician (Knox Group) rocks occupy GSF hanging wall positions in the Shady Valley synclinorium of northeast Tennessee (Hardeman, 1960). The Alleghanian age of the GSF is based on brittle fault-related deformation of Mississippian (Grainger Formation) footwall rocks and ties to the Guess Creek fault. Hatcher et al. (1989) suggested that the GSF represents the basal surface of the Blue Ridge-Piedmont megathrust sheet, with a northwest-directed displacement of 300-350 km based on occurrences of Knox Group (?) horses in the Brevard fault zone and interpretation of magnetic, gravity, and seismic reflection data (Hatcher and Zietz, 1978, 1980; Cook et al., 1979; Cook and Oliver, 1981). Subsurface truncation of earlier structural features (Plate 3) during GSF emplacement is related to emplacement along a low-angle footwall ramp (Fig. 3-3; King, 1964; Cook et al., 1983; Hatcher et al., 1989), indicated by mapped patterns of the simple windows (Cades Cove, Tuckaleechee Cove, Wear Cove) in GSMNP and the Calderwood window in the study area (Plate 5; Neuman and Nelson, 1965; Hatcher et al., 1989).

Folding of the Great Smoky thrust sheet (Plate 3) is related to transport and emplacement over numerous interpreted duplexes of Valley and Ridge footwall rocks (Plate 3; Cook et al., 1983; Hatcher et al., 1989). Duplex structures from outcrop to map-scale are revealed in the

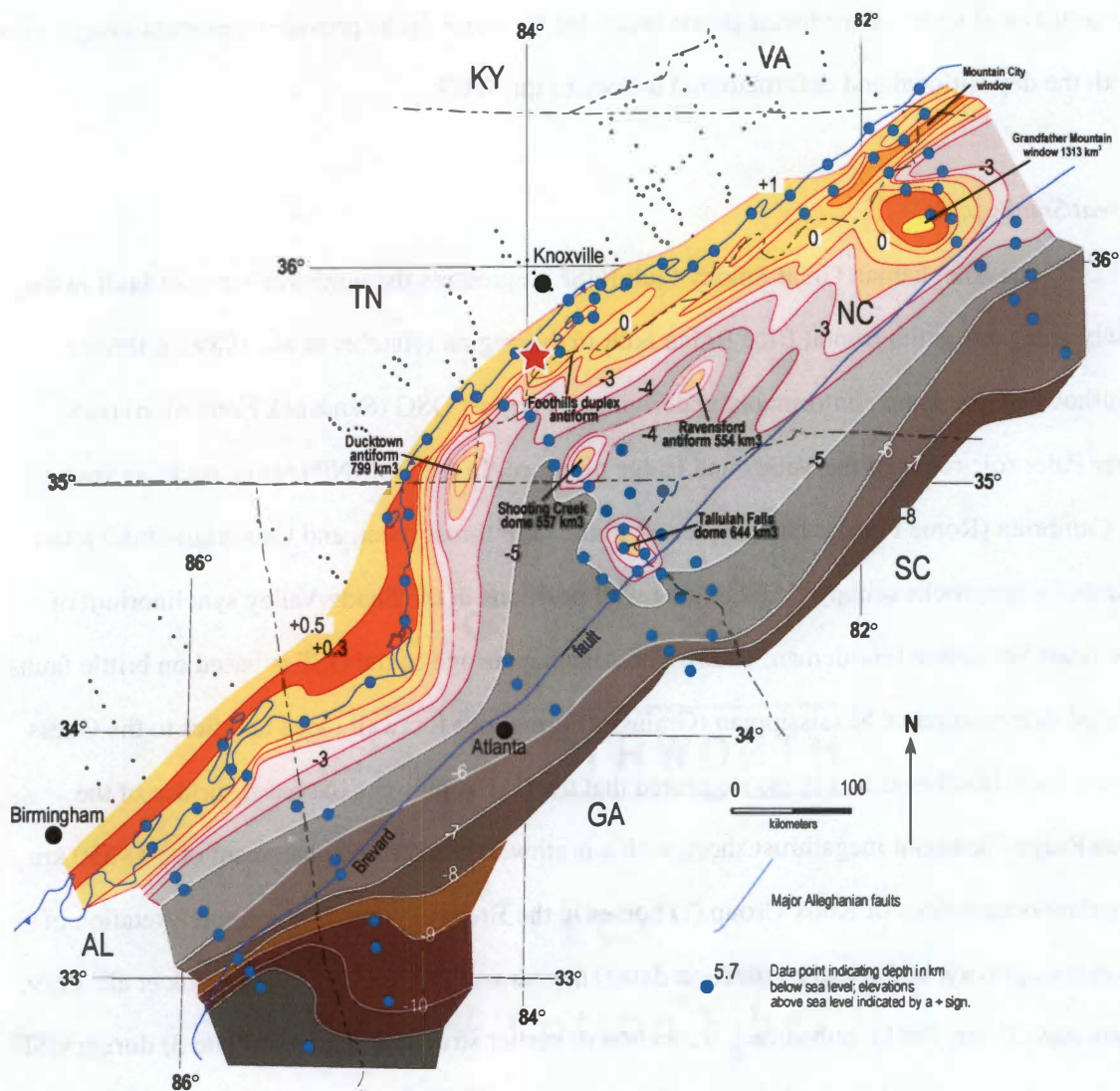


Figure 3-3. Structure contour map (in km) of the base of the Great Smoky thrust sheet (Blue Ridge-Piedmont megathrust sheet). Preliminary depth estimates based on seismic reflection and surface data in the southern Appalachians. Indicated volumes of closed structures were calculated by Camilio Montes using GeoSec 3D. Prominent synform-antiform pair along northwest leading edge corresponds to Miller Cove syncline and Foothills duplex, respectively. Red star indicates approximate location of this study. Modified from Hatcher et al. (1989).

Cades cove and Tuckaleechee Cove windows in GSMNP (Neuman and Nelson, 1965; Hatcher et al., 1989) and beneath the GSF in regional seismic lines (Costain et al., 1989). The Calderwood window in the study area reveals Knox Group rocks in the GSF footwall, but the limited aerial extent (~1.5 km²; Plate 1) of this structure does not reveal duplexes at map or outcrop scale. GSF footwall imbricates beneath the study area may contain Rome Formation, Conasauga Group, and Knox Group horses floored by the Guess Creek fault (Plate 3). These second-order structures beneath the Great Smoky thrust sheet are interpreted as the youngest folds (F_4) recognized in this region and were likely formed as a result of footwall imbrication during emplacement of the GSF (Hatcher et al., 1989).

Miller Cove fault

The Miller Cove fault (MCF) lies ~3 km southeast of the GSF, and separates unfoliated Chilhowee and conformably underlying (locally unconformably) upper Walden Creek Group (WCG; Sandsuck Formation) footwall units from anchizone to chlorite grade, penetratively deformed hanging wall rocks of the Walden Creek Group (WCG; Shields and Wilhite Formations; Plate 1). Separation of unmetamorphosed footwall rocks from chlorite-grade rocks in the hanging wall distinguishes the Miller Cove fault as a major late Paleozoic structure (King, 1964; Neuman and Nelson, 1965). Rocks in the Miller Cove thrust sheet mark the first appearance of chlorite grade regional metamorphism, suggesting a post-Taconic age of MCF thrust transport. Taconic metamorphic ages obtained from ⁴⁰Ar/³⁹Ar whole rock and muscovite cooling ages (Dallmeyer, 1978; Connelly and Dallmeyer, 1990, 1991), and U-Pb sphene and monazite growth (Alienikoff, 2004; Moecher et al., 2004) span ~50 Ma, from 480-430 Ma.

In the northwestern part of the study area, a structurally isolated package of Wilhite Formation slate and siltstone resting atop units of the Sandsuck Formation is interpreted to be a klippe of the MCF (Fig. 3-2; Plate 1). A high-angle brittle fault originally recognized by Wiener (unpublished) truncates the northeastern edge of the klippe. This late Alleghanian fault is

interpreted to have minimal displacement (≤ 0.5 km) based on stratigraphic offset of Sandsuck units in the hanging wall and footwall. Based on cross-section interpretation, emplacement of the MCF klippe requires folding of the MCF surface, but it may be ramp-related (i.e. fault bend folding) and is not interpreted to be a result of later deformation folding the MCF surface.

Previously, Neuman and Nelson (1965) interpreted the location of the MCF to lie northwest of the presently interpreted fault trace (Wiener, unpublished; this study). While the presence of a brittle fault has been confirmed at the location indicated by Neuman and Nelson (1965), it does not display the characteristic separation of metamorphosed rocks thrust over unmetamorphosed rocks. Stratigraphic evidence further supports relocation of the MCF. Conglomerates north of the Little Tennessee River previously correlated with the Wilhite Formation (Neuman and Nelson, 1965) were reassigned to the Sandsuck Formation by Wiener (unpublished). Intertonguing of these conglomerate bodies with other Sandsuck lithologies to the south (Plate 1) further indicates that the MCF of Neuman and Nelson (1965) was ultimately incorrect. Thus, the fault recognized by Wiener (unpublished) has been established as the MCF, and the subordinate brittle fault to the northeast indicated by Neuman and Nelson (1965) as the MCF has been renamed the Chilhowee Mountain fault (Plate 1).

Rabbit Creek fault

A major fault separating rocks of the Wilhite and Shields Formations from rocks of the Cades Sandstone, recognized ~4 km southeast of the MCF, is correlated with the Rabbit Creek fault (RCF) mapped by King (1964) and Neuman and Nelson (1965) in the western and central portions of GSMNP. Wiener (unpublished) and Geddes (1995) originally suggested the possibility of correlating this fault with the RCF in GSMNP. In the study area, the RCF follows a pronounced topographic lineament (Fig. 3-4), and a small window in the RCF hanging wall in the central-western portion of the Whiteoak Flats 7.5-minute quadrangle (Plate 1) indicates that the RCF footwall ramp has a relatively low-angle of dip, at least near the presently exposed surface.

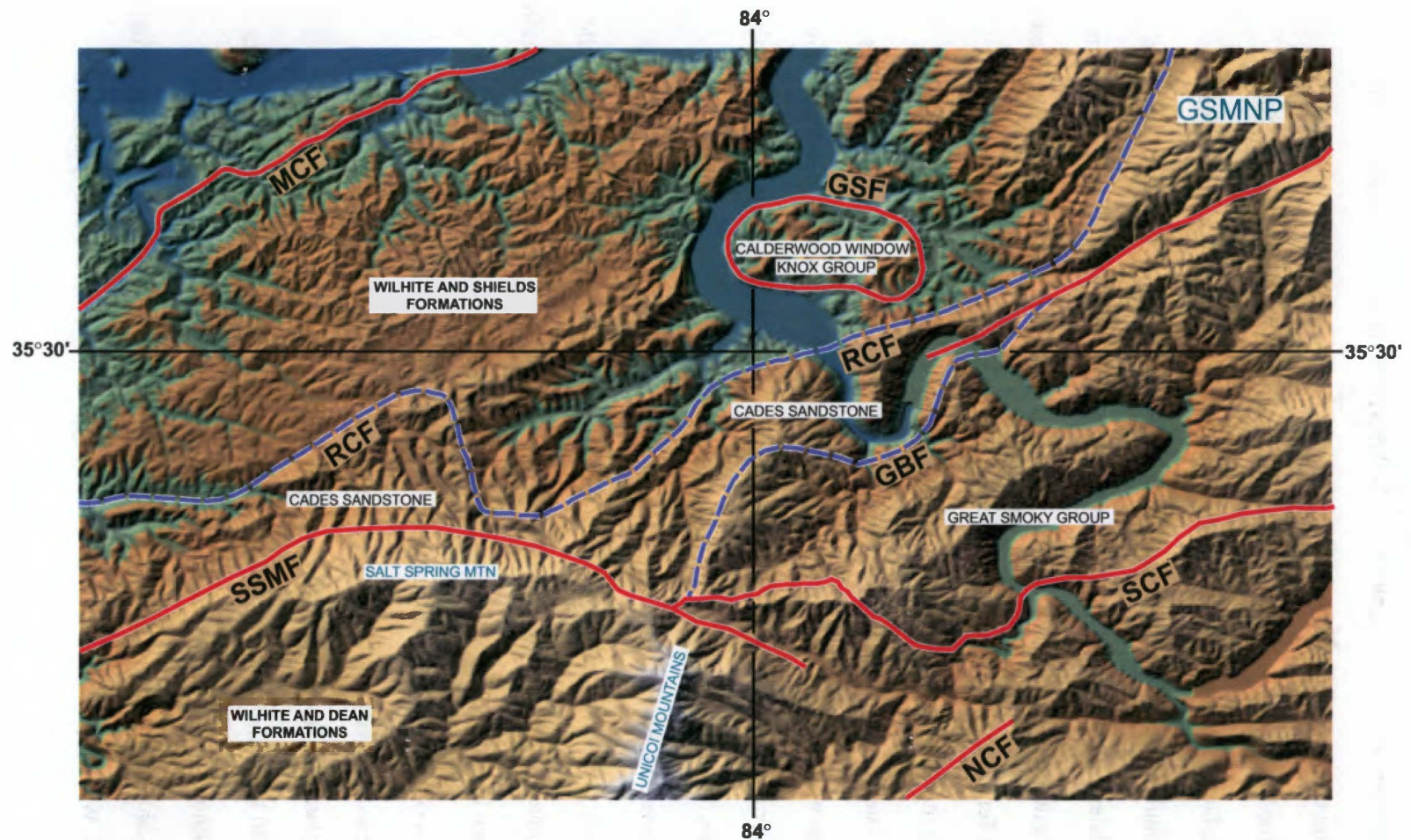


Figure 3-4. Digital elevation model (30 m resolution) of a portion of the study area showing the pronounced topographic lineaments produced by geologic features such as the Rabbit Creek fault (RCF), Salt Spring Mountain fault (SSMF), Greenbrier fault (GBF), and the Great Smoky fault (GSF) framing the the Calderwood window. GSMNP - Great Smoky Mountains National Park. NCF - Nichols Cove fault. MCF - Miller Cove fault. SCF - Slickrock Creek fault

Exposures of the RCF in the study area do not permit direct observation of the fault surface (Fig. 3-5), although exposures in close proximity to the fault reveal no mylonitic textures or other evidence of faulting that occurred under ductile conditions.

North of the Little Tennessee River, Neuman and Nelson (1965) and Walters (1988) recognized ductile fault fabrics and concordant foliation across the RCF trace, suggesting premetamorphic fault motion. While this study unveiled evidence that the fault trace southeast of the MCF correlates well with the RCF trace north of the Little Tennessee River, evidence for premetamorphic fault transport (mylonitic zones, undisturbed foliation, etc.) was not recognized south of the Little Tennessee River. Wiener (unpublished) recognized an increase in illite crystallinity across the fault trace. Further southwest, Geddes (1995) recognized brittle fault structures, fault-related deformation of slaty cleavage, and truncation of synmetamorphic folds in the RCF hanging wall. A stepwise increase in metamorphic grade across the fault trace, from anchizone and lower chlorite grade in the footwall to chlorite grade in the hanging wall, was also recognized (Geddes, 1995).

From observations both in GSMNP and south of the Little Tennessee River, it is likely that the RCF initially propagated prior to early Paleozoic peak metamorphism, producing ductile fault fabrics (mylonite) on or near fault surfaces and allowing observation of undisturbed foliation across the fault trace in GSMNP. The brittle nature of exposed fault zones and deformation of slaty cleavage associated with the RCF southwest of GSMNP, however, suggests it may have partially or wholly experienced brittle northwest-directed thrust reactivation in that region, most likely during late Paleozoic (Alleghanian) orogenesis. Truncation of the RCF by the Greenbrier fault ~40 km to the southwest (Plate 4; Martin, 1997) precludes an accurate estimate of displacement, although recent correlations (Geddes, 1995; this study) between the Cades Sandstone and the Shields Formation in the RCF footwall and changes in illite crystallinity across the fault trace (L.S. Wiener, personal communication) suggest 5-10 km of total displacement.



Figure 3-5. Road exposure of the Rabbit Creek fault in the northern extent of the Whiteoak Flats 7.5 minute quadrangle at the base of Salt Spring Mountain, showing sandstone and conglomerate of the Cades Sandstone in the hanging wall thrust over slate and siltstone of the Wilhite Formation (not visible) in the footwall.

Salt Spring Mountain and Greenbrier faults

Southeast of the RCF, a fault originally correlated with the Greenbrier fault (GBF) in GSMNP (Geddes, 1995; Martin, 1997) juxtaposes rocks of the WCG and conformably underlying GSG onto rocks of the Cades Sandstone in the Rabbit Creek thrust sheet (Plates 1 and 4). After examining the fault trace from both the southwest and northeast, I concluded that the fault trace recognized by Geddes (1995) and Martin (1997) is actually a post-metamorphic brittle fault (Fig. 3-6) along most of its extent. This fault follows a north-northeast trend prior to swinging into a more easterly trend along the northern slopes of Salt Spring Mountain (Plate 1). Northeast termination is believed to occur in Little Slickrock Creek, east of Salt Spring Mountain, in the northwest corner of the Tapoco 7.5 minute quadrangle (Plate 1). The relatively short fault trace length (~ 40 km) and shallow ramp angle inferred from topographic expression suggests that northwest-directed displacement was minor (1-2 km maximum). This later fault has been named the Salt Spring Mountain fault (SSMF).

North-northeast of the SSMF, another fault was recognized following the western and northern slope of Tallassee Mountain prior to crossing the Little Tennessee River and entering GSMNP. Initially, the southern terminus of this isolated fault segment was interpreted as being truncated by the SSMF. Due to lack of exposure, the brittle or ductile nature of this fault could not be confirmed. The fault trace appears to be overridden and buried on its southern end by the SSMF, however, and truncated on its northern end by a high angle brittle fault that follows a distinct topographic lineament across the western GSMNP region, subparallel to the early GBF trace (Fig. 3-4; Plate 5). Thus, this fault segment may represent an intact portion of the early GBF trace, now isolated by late Paleozoic brittle faulting to the north and brittle truncation and/or burial beneath an overriding thrust sheet (SSMF) to the south.

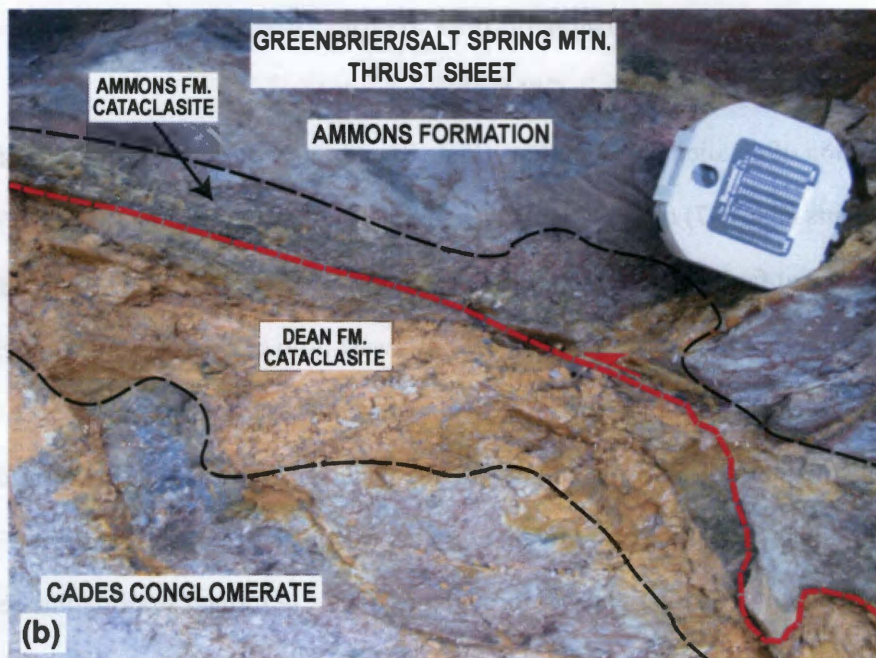
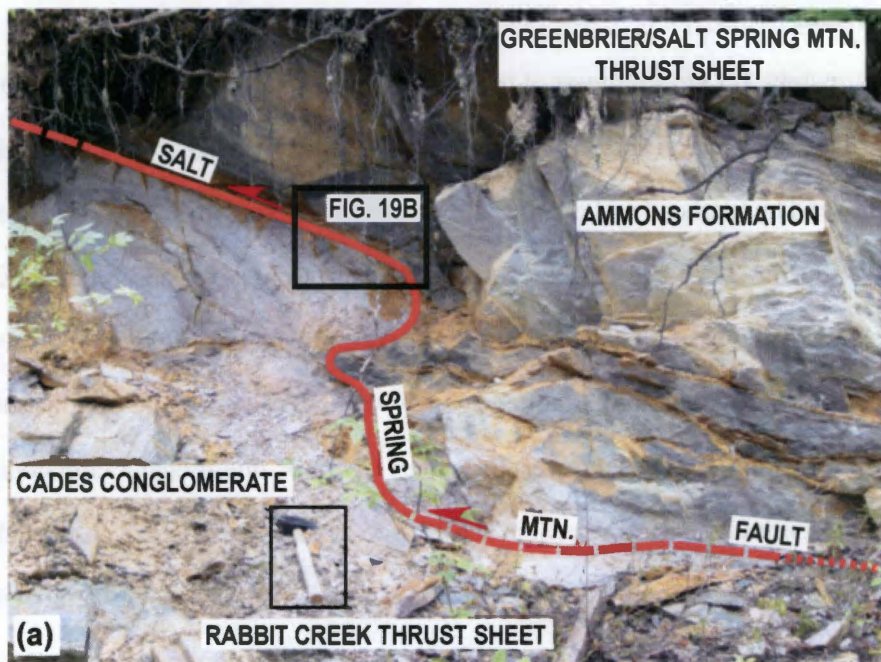


Figure 3-6. Exposure of the Salt Spring Mountain fault along Forest Service Road 2115 in the Whiteoak Flats 7.5 minute quadrangle, (a) showing Horse Branch slate (Ammons Formation) thrust over conglomerate of the Cades Sandstone (Rabbit Creek thrust sheet). Hammer (25 cm long) for scale. (b) Close-up of view of fault surface. Note the intense brittle deformation restricted to the fault surface and immediately surrounding area. No evidence for mylonitization was observed.

Hangover Lead fault

Approximately 3-5 km southeast of the SSMF-GBF system, the Hangover Lead fault separates lower Dean Formation and Ammons Formation footwall rocks from a relatively thick succession of lower Thunderhead and conformably overlying lower Anakeesta Formation rocks in the hanging wall (Fig. 2-2; Plate 1). Exposures of the fault were never observed, yet structural discontinuities between lower GSG (Thunderhead-Anakeesta) and upper GSG rocks (Ammons-Dean) produced initial speculation of a faulted contact within the succession. Southworth et al. (2005), while working in the southwestern part of GSMNP, interpreted a fault contact along the same discontinuity east-northeast of the Tapoco quadrangle (Plate 5). Correlation of this discontinuity with that of Southworth et al. (2005) suggests the presence of a moderate displacement (> 5 km) thrust fault traced from an unknown termination in the south through the southeastern portion of the Tapoco quadrangle, prior to its northern termination/truncation along the late Alleghanian Oconaluftee fault in GSMNP (King, 1964).

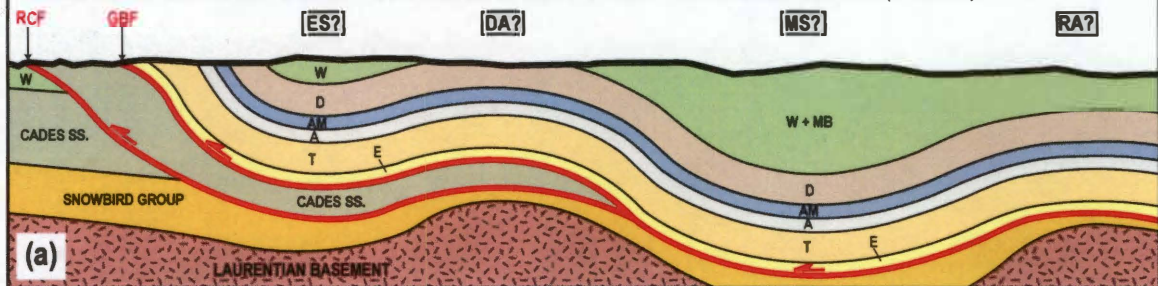
Construction of detailed cross sections (Plate 3) and schematic reconstructions of deformational events (Fig. 3-7) through the northeastern part of the study area (line C-C) suggest that the Hangover Lead fault initially propagated from or near the surface of the southeast limb of the Ducktown anticlinorium, or possibly on the northwest limb of a second order anticline parasitic to that regional structure. Prior to Alleghanian deformation, the entire sequence preserved in the Greenbrier thrust sheet, along with the underlying GBF surface, was folded into northwest vergent first- and higher-order folds following early Paleozoic emplacement (Fig. 3-5). Thus, late Paleozoic faults often propagated through previously deformed stratigraphic sections along kinematically well-oriented surfaces such as the Hangover Lead and Salt Spring Mountain faults, rather than reactivating a strongly folded surface such as the GBF. Utilization of the kinematically well-oriented surface on the southeast limb of the Ducktown anticlinorium suggests that the Hangover Lead fault occurred after Taconic folding but prior to late Alleghanian GSF emplacement.



Figure 3-7. Schematic diagram of the interpreted structural evolution of part of the WBR, which resulted in complex relationships observed in the northeastern portion of the study area. Unit thickness are relative. Folds shown are mostly regional in scale. Higher-order folds not shown for reasons of simplification. (a) The Greenbrier fault (GBF; red) and Rabbit Creek fault (RCF; red) are interpreted to occupy the same surface for some distance prior to bifurcation in the vicinity of the paleo-Epperson synclinorium or the paleo-Ducktown anticlinorium. (b) Just prior to or at Taconian peak metamorphism, further folding of the GBF sheet establishes precursor geometry that is kinematically favorable for propagation of the Hangover Lead fault (HLF) fault during the early Alleghanian orogeny. (c) Propagation and ramp transport of the HLF from the southeast limb or hinge of the Ducktown anticlinorium covers the majority of the southeast limb of the Epperson synclinorium. (d) Late Alleghanian propagation of the Great Smoky fault (GSF) truncates all earlier structural features. Related brittle faults (Slickrock Creek fault-SCF and Nichols Cove fault-NCF) may propagate as a late response to ramping difficulties encountered by the GSF as it is emplaced over duplexed Valley and Ridge footwall strata. W - Wilhite Formation. W+MB - Walden Creek Group and Murphy belt rocks. D - Dean Formation. AM - Ammons Formation. A - Anakeesta Formation. T - Thunderhead Sandstone. E - Elkmont Sandstone. ES - Epperson synclinorium. DA - Ducktown anticlinorium. MS - Murphy syncline. RA - Ravensford anticline.

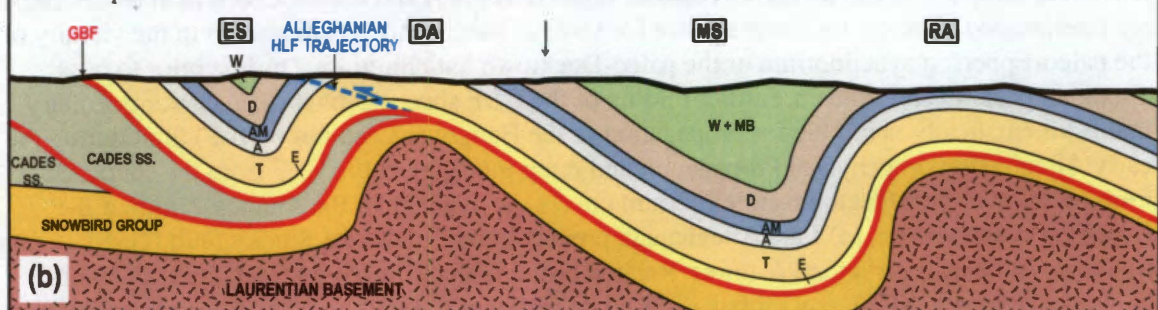
EARLY TACONIC OROGENY

EMPLACEMENT OF PRE-METAMORPHIC GBF (20-40 KM NORTHWEST-DIRECTED DISPLACEMENT). EARLY FOLDING RELATED TO EMPLACEMENT ALONG UNEVEN BASEMENT SURFACE. REGIONAL PRE-METAMORPHIC (F_2) FOLDS SUCH AS THE EPPERSON AND MURPHY SYNCLINORIA AND THE DUCKTOWN AND RAVENSFORD ANTICLINORIA MAY HAVE BEEN INFLUENCED BY THE GEOMETRY OF THE PRIMARY DEPOSITIONAL SURFACE (BASEMENT).



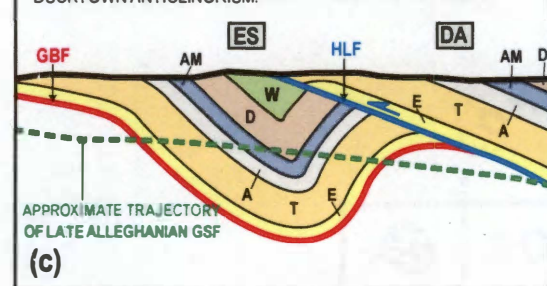
TACONIC OROGENY

REGIONAL F_2 FOLDS FORM AND/OR TIGHTEN AND BECOME NW VERGENT JUST PRIOR TO THE TACONIC METAMORPHIC PEAK.



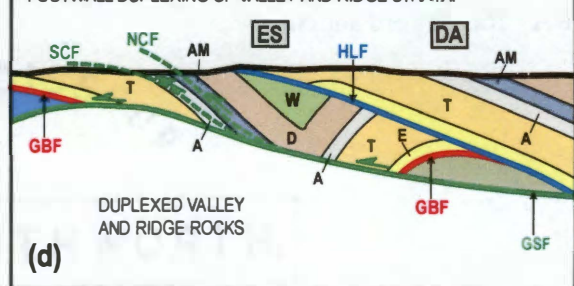
EARLY ALLEGHANIAN

HANGOVER LEAD FAULT PROPAGATES FROM NW LIMB OF DUCKTOWN ANTICLINORIUM.



LATE ALLEGHANIAN

EMPLACEMENT OF GSF, SCF, AND NCF. FOLDING OF GSF DUE TO FOOTWALL DUPLEXING OF VALLEY AND RIDGE STRATA.



Minor map-scale faults

Flats Creek fault

The Flats Creek fault, recognized in the eastern part of the study area, thrusts middle and lower Dean Formation in the hanging wall over middle Dean Formation slate and siltstone in the footwall. Geddes (1995) originally recognized this fault immediately southwest of the current study area (Plate 4), and proposed that it may continue northeast prior to being truncated by what he interpreted as the GBF (SSMF of this study). Mapping along Gold Branch did indicate fault-related duplication of units as suggested by Geddes (1995), but work ~1 km northeast along Forest Service Road 2115 revealed no evidence of this fault. Thus, the northeast termination of the Flats Creek fault is interpreted to lie just north of Gold Branch. The Flats Creek fault is estimated to have a trace length of ~3 km and a maximum total displacement of ~0.5 km based on stratigraphic offset. While direct observation of the fault surface was never accomplished due to poor exposure, mesoscale brittle faults and abnormally tight folds recognized by Geddes (1995) and myself within 100 m of the observed stratigraphic offset along Citico Creek suggests that the fault is likely brittle and may have tightened earlier F_2 folds during emplacement. Dissection of an earlier third-order anticlinal hinge parasitic to the second-order Whiteoak Flats syncline (F_2) further indicates that faulting occurred during late Paleozoic (Alleghanian) deformation.

Slickrock Creek and Nichols Cove faults

The Slickrock Creek fault, although minor in both extent and estimated displacement, represents a critical separation between what may be the most complete succession of basal GSG to lower WCG strata recognized in the Greenbrier thrust sheet. This brittle fault separates Elkmont and lower Thunderhead Sandstone in the footwall from Anakeesta, Ammons, and Dean formation units in the hanging wall. Reconstructions of the complex fault zone in the northeastern part of the study area (Fig. 3-5, Plate 1) suggest that the Slickrock Creek fault may be related to emplacement of the GSF during the terminal phase of the Alleghanian orogeny. Both this fault

and the Nichols Cove fault, although not interpreted to merge at depth, seem to be related by accommodation of displacement that was transferred from the GSF as it was transported over footwall ramps of the Foothills duplex.

The Nichols Cove fault is located approximately 1 km southwest of the Slickrock Creek fault, and separates the lower and middle Dean Formation in the footwall from Ammons and lower Dean formation rocks in the hanging wall in the southeastern portion of the study area (Plate 1). This fault, originally identified by Lesure et al. (1977) and later recognized by Slack et al. (1984), appears to have a high ramp angle (50 to 60°) near the surface and occupies the bedding surface contact between the lower Dean Formation and underlying Ammons Formation near its southwest termination (Plate 4). Geddes (1995) saw no evidence of faulting near the Dean-Ammons contact, necessitating a southwestern termination near the southern boundary of the Whiteoak Flats 7.5 minute quadrangle (Plate 4). Like the Slickrock Creek fault, the Nichols Cove fault appears to have accommodated displacement transferred from the GSF during the culminating phases of the Alleghanian orogeny. Based on cross-section interpretations, it appears that the Nichols Cove fault may have propagated as a listric fault prior to formation of the Slickrock Creek fault. Later motion along the Slickrock Creek fault then rotated the Nichols Cove fault block into its present position, producing the relatively high-angle ramp observed in the study area (Fig. 3-7; Plate 3). Because of interpreted temporal relations, it is likely that the Nichols Cove fault also cut through the leading edge of the Hangover Lead fault (Fig. 3-7; Plate 3).

Folds

At least three generations of tectonic folds (F_1 - F_3) and one generation of soft-sediment folds (F_0) were observed in the study area. Meso- and map-scale relationships of folds to axial-planar cleavage, transecting cleavage, faulting events, and deformational conditions (plastic vs. brittle) interpreted from preserved rheological state allow subdivision of fold generations.

Tectonic folds (F_1 - F_3) are present as first- and higher-order structures throughout the study area, while soft-sediment folds (F_0) were only recognized as fifth- and higher-order structures in the Miller Cove and Greenbrier-Salt Spring Mountain thrust sheets. F_3 folds are interpreted from seismic reflection data (Cook et al., 1983) and probably result from bending mechanisms, which produced second-order folds along the GSF surface as it was transported over a number of footwall duplexes (Plate 3; Hatcher et al., 1989).

F_0 folds

Soft-sediment folds (F_0) are commonly preserved in Wilhite Formation rocks in the Miller Cove thrust sheet and in Wilhite and Dean Formation rocks in the Greenbrier-Salt Spring Mountain thrust sheet. They usually exhibit wavelengths less than 4 cm and amplitudes up to 2.5 cm, although larger-scale (> 10 cm) folds were preserved locally. F_0 folds range from open to isoclinal, and are differentiated from tectonic folds by their positions between planar bedding surfaces that are relatively undeformed. Folds of this generation appear to be syndepositional, and likely result from deformation of prelithified, water-saturated sediment layers during downslope movement. Some of these folds may be rip-up clasts of prelithified sediment removed from their original depositional site, transported, deformed, and redeposited by high-energy turbidite flows (Middleton, 1993). The latter mechanism is indicated by folding of fine-grained slate fragments in thick, graded sequences of graywacke and conglomerate. Interpretations that these folds are tectonic and result from rheological contrasts during deformation seem inappropriate because of the random orientation of F_0 fold axes, axial surfaces, and vergence in a relatively small (≤ 3 m) area (Fig. 3-8)

F_1 folds

On the southern slopes of Salt Spring Mountain, ~0.5 km northwest of Jakes Best Creek, an open (interlimb angle $\sim 124^\circ$) mesoscale sub-concentric fold occurs with a wavelength of ~2 m, a nearly upright axial surface, and north-northeast axial trend and southwest plunge (Fig. 3-9a). Regional slaty cleavage transects the fold hinge and remains parallel throughout the entire

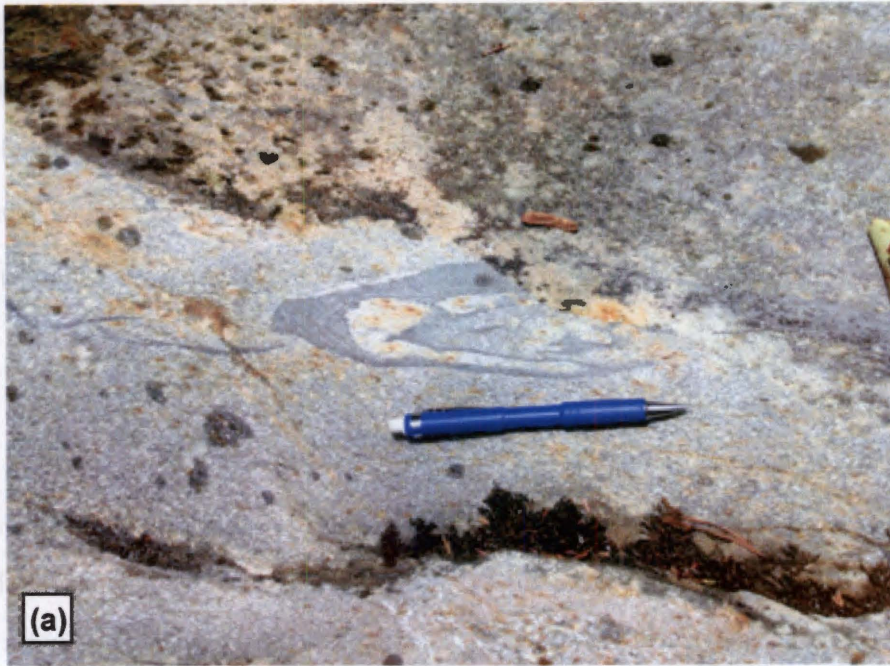


Figure 3-8. Soft-sediment isoclinal (sheath?) (F_0) folds in coarse graywacke of the Dean Formation (a) exposed in Doublecamp Creek, Whiteoak Flats 7.5 minute quadrangle. Pencil is ~20 cm long. (b) Abundant soft-sediment folds in Dean Formation conglomerate show random orientations of fold hinges in Doublecamp Creek, Whiteoak Flats 7.5 minute quadrangle. Lighter is ~10 cm long.

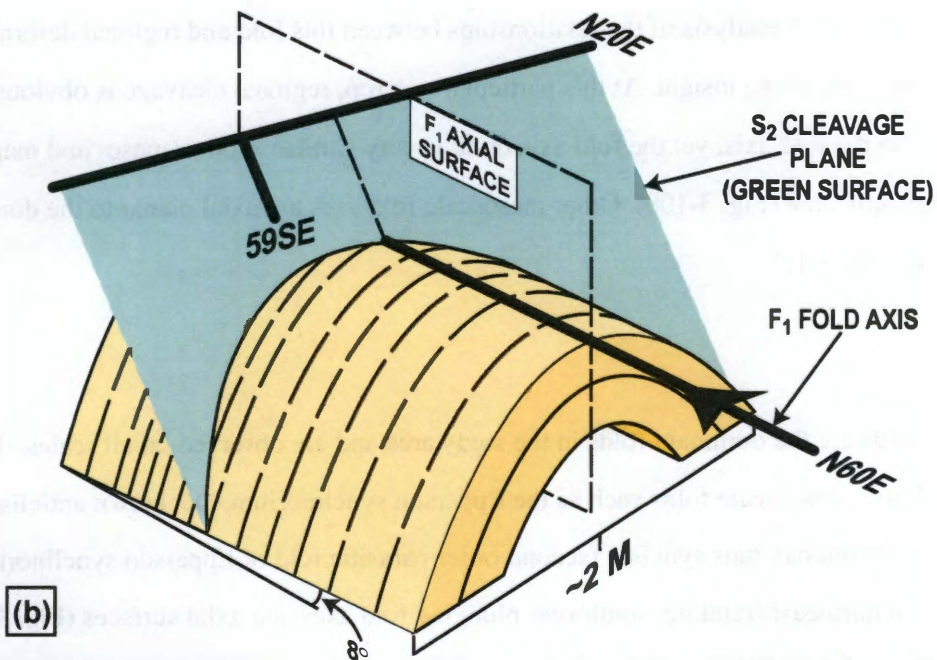


Figure 3-9. Photo and geometric illustration of the F_1 fold in the study area. (a) The only F_1 fold recognized in the study area, along Forest Service Road 2103 on the south slope of Salt Spring Mountain, Whiteoak Flats 7.5 minute quadrangle. Perspective of photo is looking straight down the fold hinge ($N60E$). Undeformed slaty cleavage visible on left half of photo, dipping to the bottom left and toward the viewer. (b) 3-D schematic illustration of the same fold showing relationship of undeformed slaty cleavage S_2 to the fold axis.

observed area of the structure. Transecting cleavage is not axial planar to the fold (Fig. 3-9b), nor is the cleavage itself folded or deformed in any recognizable manner, suggesting that the fold may be premetamorphic. A lack of vergence, the open interlimb angle, and the buckling mechanism (flexural slip?; Donath and Parker, 1964) appear to suggest deformation that occurred under brittle conditions. WBR premetamorphic faults and related folds often reveal mylonitized zones of shearing and plastic fold geometries (flexural flow; Donath and Parker, 1964) characteristic of deformation under more ductile, high temperature conditions. Thus, if formation of this fold did occur prior to regional metamorphism and development of slaty cleavage, it is unlikely to be directly related to final emplacement of the Greenbrier–Rabbit Creek–Dunn Creek premetamorphic fault systems (Plate 5). The F_1 folding event in the study area may be coeval with east-west trending premetamorphic folds exhibiting transecting slaty cleavage recognized by Hamilton (1961) and Carter (1994) northeast of GSMNP and in southwestern Tennessee, respectively.

Stereographic analysis of the relationships between this fold and regional deformation provides more interesting insight. At this particular outcrop, regional cleavage is obviously not axial planar to the fold axis, yet the fold axis trend is very similar to other meso- and map-scale folds in the study area (Fig. 3-10b). Other mesoscale fold axes are axial planar to the dominant foliation (S_2 ; Fig. 3-11).

F_2 folds

F_2 folds are the dominant folds in the study area and are observed on all scales. First- and second-order map-scale folds such as the Epperson synclinorium, Ducktown anticlinorium (Plate 5), and Whiteoak flats syncline (second order parasitic fold of Epperson synclinorium; Plate 4), have northeast-trending, southwest-plunging fold axes and axial surfaces (Fig. 3-12) that are parallel or sub-parallel to northeast regional cleavage trends (Fig. 3-11). Smaller (fourth and higher order) folds that are parasitic to these first- and second-order folds reveal the same axial trends, and are characterized as F_2 folds based on mesoscale observation of axial planar fanned cleavage (Fig. 3-13) or transecting cleavage (S_2 ; Fig. 3-14). F_2 fold wavelengths and amplitudes range from ~2 cm to greater than 12 km and from 1 cm to greater than 5 km, respectively. First

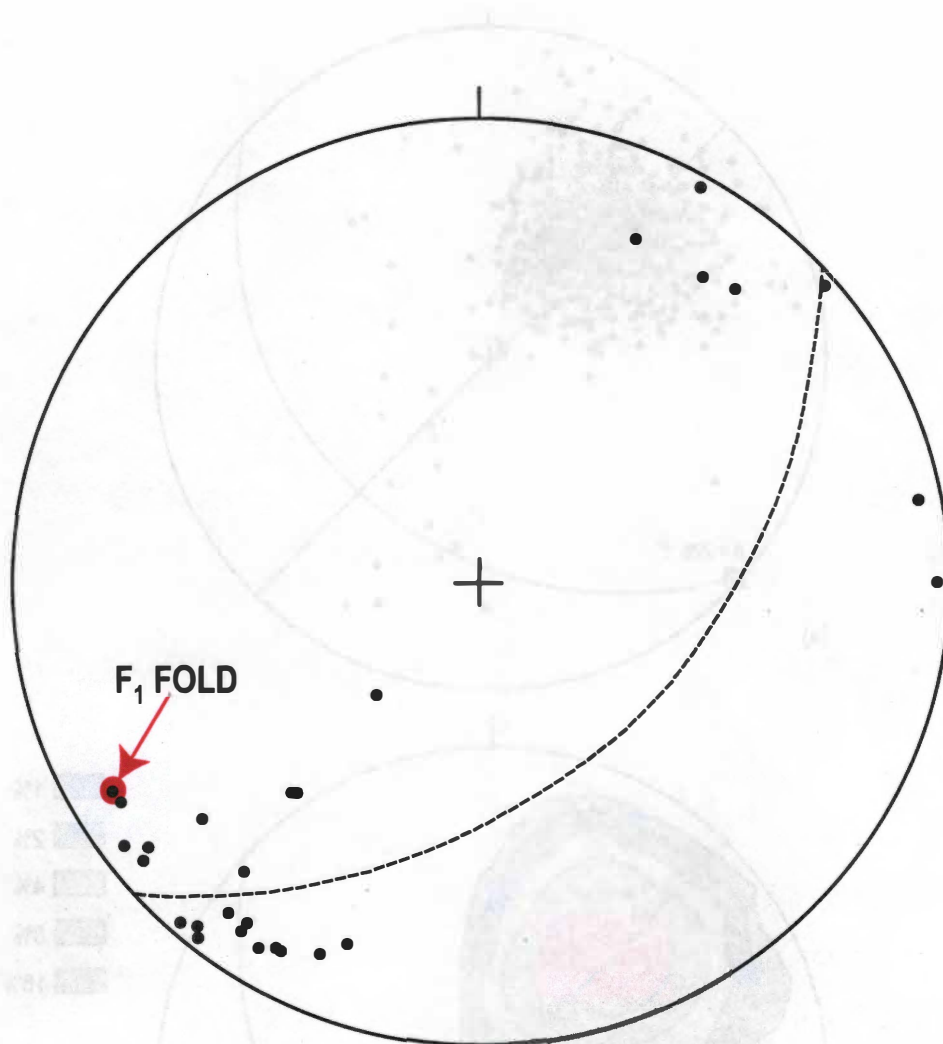


Figure 3-10. Stereoplot of 28 fold (F_1 and F_2) axes, with corresponding calculated girdles (dashed black lines; N47E/54SE). Calculated mean principal direction is 222, 7°. The trend and plunge of the only F_1 fold observed in the study area is indicated by a red circle surrounding plotted point in order to show the similarity of orientation between this fold generation and the dominant fold generation (F_2).

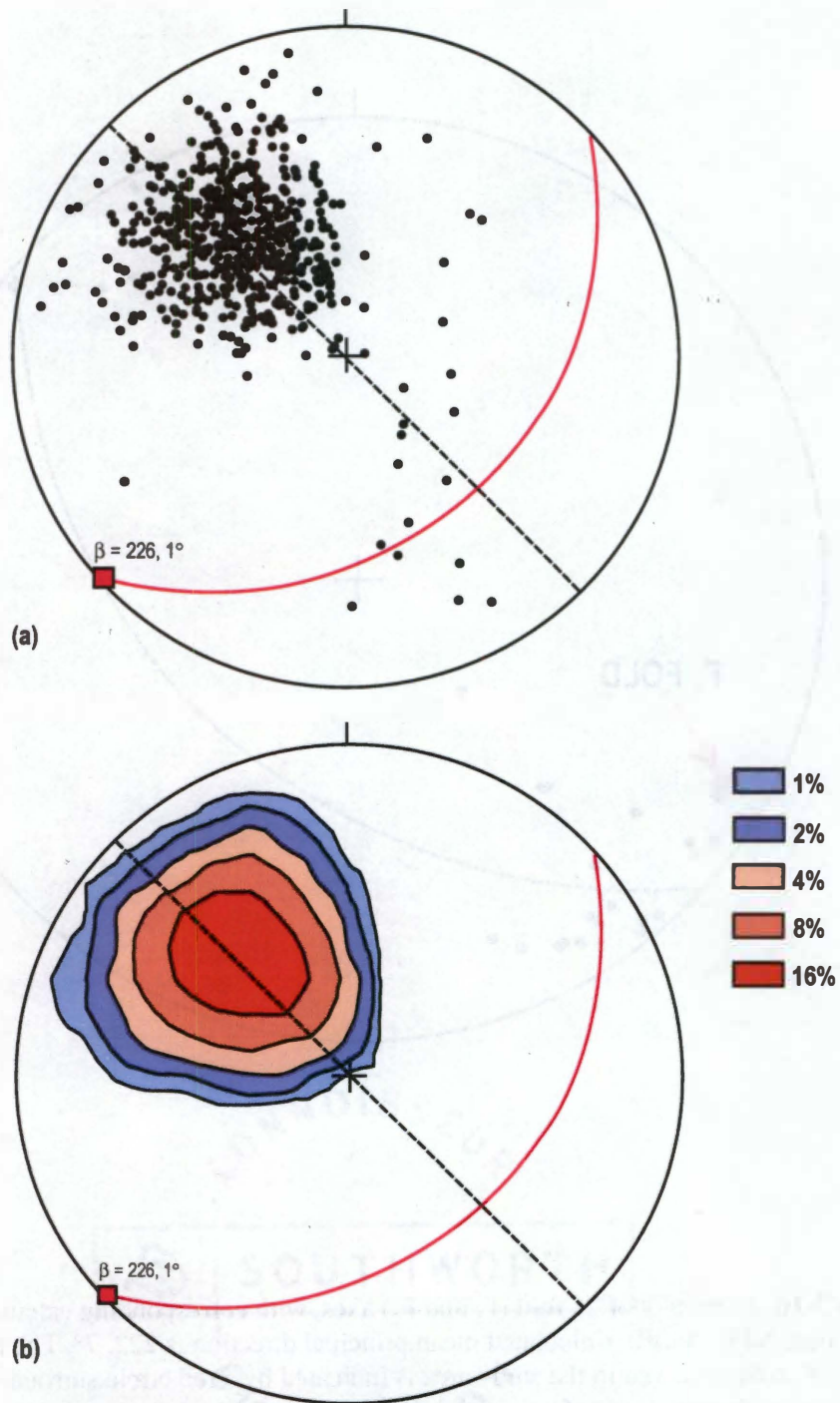


Figure 3-11. Stereoplots of 776 poles to foliation (S_2) surfaces, with corresponding mean great circles (solid red lines; N47E/42SE), calculated girdles (dashed black lines; N44W/89NE), and calculated beta axis (red squares; 226, 1°). (a) Poles to foliation (S_2) in the study area. (b) Contoured lower hemisphere equal area projection of poles to foliation in the study area. Contours represent 1%, 2%, 4%, 8%, and 16% per 1% area.

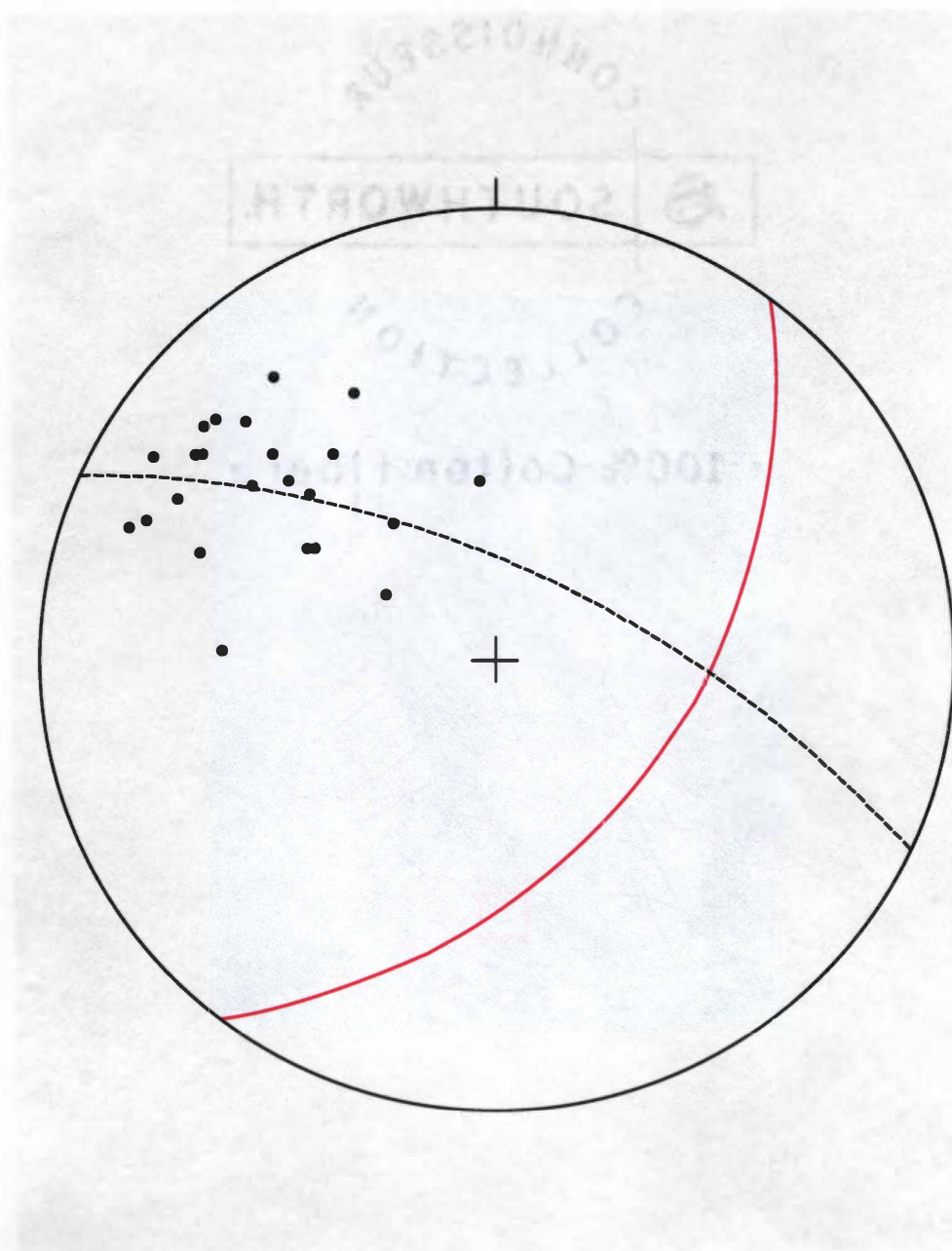


Figure 3-12. Stereoplot of poles to the axial surface of F_2 folds in the study area, with corresponding mean great circles (solid red lines; N37E/76SE), calculated girdles (dashed black lines; N66W/72SE).



Figure 3-13. Slightly divergently fanned slaty cleavage (S_0 ; black lines) in a northwest vergent F_2 fold in highly sulfidic (note yellowish-orange weathering) and graphitic Ammons Formation slate (thinner beds) and siltstone (thicker beds) along Citico Creek, Whiteoak Flats 7.5 minute quadrangle. The axial surface of this fold dips steeply to the southeast, which is characteristic of F_2 folds in the study area. Slickenlines (not visible in photo) were noted on some bedding (S_0 ; purple lines) surfaces, yet very faint thickening of layers from the limbs to the hinge suggest that flexural slip is the predominant mechanism, but a limited amount of flexural flow may also be involved in the folding process. Compass (inside red box) shown for scale. Width of photo is ~2.5 m.



Figure 3-14. Slickenlines formed on an extremely thin graphitic bedding surface of a sample of sulfidic Dean Formation conglomerate taken from the limb of an open fold near Doublecamp Creek, Whiteoak Flats 7.5 minute quadrangle. Slickenline long axes were perpendicular or sub-perpendicular to the axis of the fold prior to removal of this sample. These lineations are most prevalent along the finer-grained surface of the a thin graphitic slate layer (almost a coating), yet not as well developed where graphitic surface is absent. It is not known whether the graphitic surface better facilitated layer parallel slip or was simply a better surface to record the occurrence of that process. Metal ruler for scale is 6 in. long.

and second order F_2 folds generally have upright to moderately southeast dipping axial surfaces (Fig. 3-10) that are steeper in northwest anticlinal limbs and southeast synclinal limbs due to the northwest vergence.

F_2 folds observed in the study area formed by both flexural slip and flexural flow buckling mechanisms (Donath and Parker, 1964). A flexural-slip mechanism is indicated in F_2 folds with slickenlines (Fig. 3-15) along bedding surfaces and constant layer thickness from the limbs to the fold hinge, which indicate that folding was accomplished by slip on bedding surfaces, rather than by flow of material from the limbs to the hinge of the fold. Flexural-slip folds are mostly observed in relatively coarser-grained, thicker bedded units, although some less tightly folded, thinner bedded slate and siltstone lithologies deformed by flexural slip mechanisms were observed (Fig. 3-13).

Planar structures (S-surfaces)

Bedding (S_0)

Depositional layering (S_0) represents the earliest fabric recognized in the study area. The character of S_0 is entirely dependent on lithology. Finer-grained slates only locally reveal banding, making the orientation of S_0 difficult to ascertain. When observed in these rocks, S_0 is thinly laminated (5- 20 mm thick) to thinly bedded (1-2 mm thick). Siltstone lithologies are more commonly banded, often with alternating of light-gray to white (coarser-grained) and dark-gray to black (finer-grained) beds that are thinly to medium-bedded. S_0 in siltstone was rarely observed as a surface of preferential parting. Sandstone, graywacke, and conglomerate lithologies often reveal thick- to massive-bedding, though localized thin beds occur in sandstone and graywacke of the Dean, Elkmont, and Ammons Formations. Coarser-grained lithologies only preferentially part along S_0 surfaces, because of the poor development or absence of regional cleavage (S_2), usually at the top or bottom boundary of graded beds, where weakness exists between the competent coarser-grained units and incompetent finer-grained units. Stereoplots of S_0 in the study area define a mean great circle oriented N60E/14SE and a beta axis of 220/5° (Fig. 3-16). The only prevalent linear feature noted in the study area was a cleavage (S_2)-bedding (S_0) intersection lineation (L_{2x0}), which was notably parallel to F_2 fold axes (Figs. 3-10 and 3-17).



Figure 3-15. Northwest vergent, open F_2 buckle fold with a moderately southeast dipping axial surface and transecting to slightly divergent axial planar slaty cleavage (S_2 ; black lines) in interbedded slate and sandstone of the Wilhite Formation along Doublecamp Creek, Whiteoak Flats 7.5 minute quadrangle. Lack of apparent bedding layer thickness change between the limbs and hinge of the fold indicate a passive (layer-parallel) slip fold mechanism. Note that cleavage is only well developed in finer-grained slate layers, while coarser-grained sandstone layers of the same bedding thickness show no obvious cleavage.

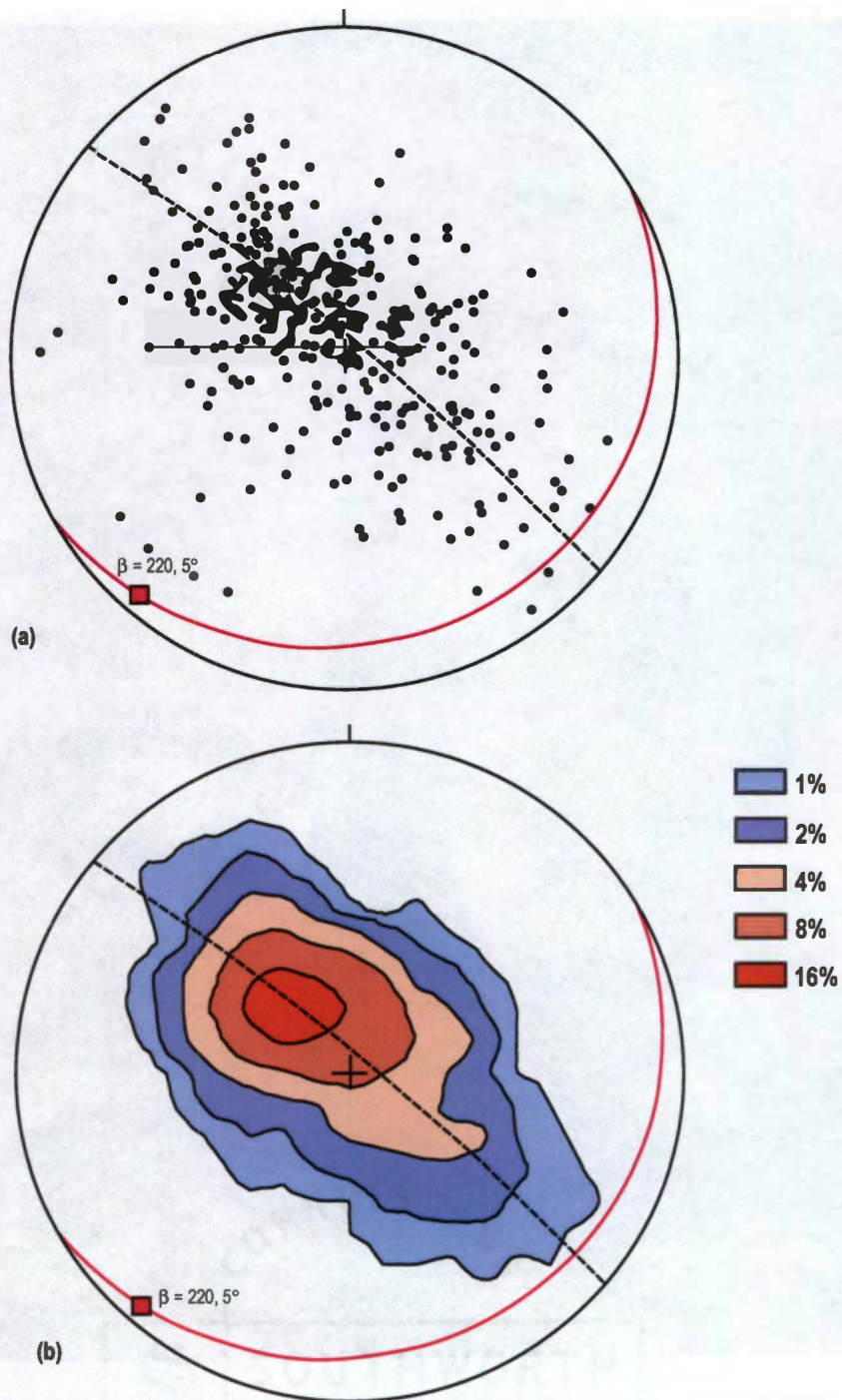


Figure 3-16. Stereoplots of 552 poles to bedding (S_0) surfaces, with corresponding mean great circles (solid red lines; N60E/14SE), calculated girdles (dashed black lines; N50W/85NE), and calculated beta axis (red squares; 220, 5°). (a) Contoured lower hemisphere equal area projection of poles to bedding in the study area. Contours represent 1%, 2%, 4%, 8%, and 16% per 1% percent area. (b) Scatter plot of poles to bedding in the study area.

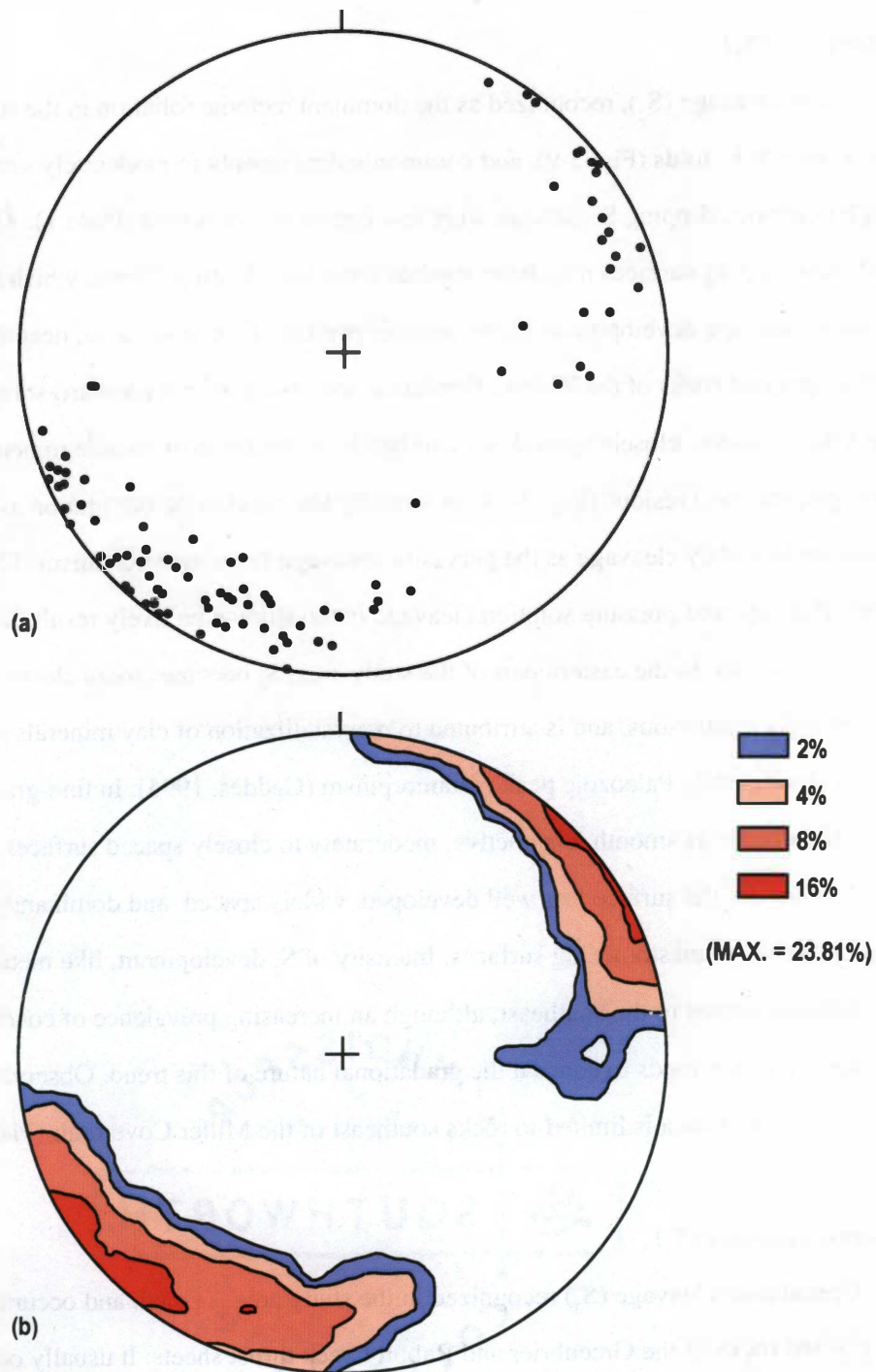


Figure 3-17. Stereoplots of 91 cleavage (S_2)-bedding (S_1) intersection lineations (L_{2x0}). Calculated mean principle direction is $222, 7^\circ$. (a) Scatter plot of intersection lineations (L_{2x0}). (b) Contoured lower hemisphere equal area projection stereoplots of cleavage (S_2)-bedding (S_1) intersection lineations (L_{2x0}). Contours represent 2%, 4%, 8%, and 16% per 1% area.

Slaty cleavage (S_2)

Slaty cleavage (S_2), recognized as the dominant tectonic foliation in the study area, is axial planar to F_2 folds (Fig. 3-9), and commonly dips steeply to moderately southeast, although northwest dipping S_2 surfaces were less commonly observed (Plate 1). Occurrences of northwest dipping surfaces may have resulted from later folding events, which followed widespread cleavage development. In the western portion of the study area, near the Miller Cove fault, finer-grained rocks of the Wilhite Formation sometimes reveal pressure-solution cleavage (S_{2a}) as discontinuous, closely spaced (<1 cm) bands of insoluble (insoluble minerals generally include opaques, etc.) residue (Fig. 3-18) in virtually the exact same orientation as S_2 . It appears to locally replace slaty cleavage as the pervasive cleavage-forming mechanism. This suggests that slaty cleavage and pressure solution cleavage in the study area likely result from the same deformational event. In the eastern part of the study area, S_2 becomes more closely spaced and often seemingly continuous, and is attributed to recrystallization of clay minerals to chlorite and muscovite during early Paleozoic peak metamorphism (Geddes, 1995). In fine-grained rocks, S_2 surfaces often occur as smooth, disjunctive, moderately to closely spaced surfaces. In coarser-grained lithologies, the surface less well developed, widely spaced, and dominantly occurs as rough disjunctive or anastomosing surfaces. Intensity of S_2 development, like metamorphic grade, recognizably increased to the southeast, although an increasing prevalence of coarser-grained units in that direction tends to conceal the gradational nature of this trend. Observation of S_2 surfaces in the study area is limited to rocks southeast of the Miller Cove fault (Plate 1).

Crenulation cleavage (S_3)

Crenulation cleavage (S_3) recognized in the study area is zonal, and occurs very locally in fine-grained rocks of the Greenbrier and Rabbit Creek thrust sheets. It usually occurs as tiny (< 5mm in width) kink-type folds that crinkle the S_2 surface (Fig. 3-19). S_3 is always observed suborthogonal to both S_0 and S_2 , which distinguishes it as a separate deformational event. No examples of S_3 were observed near or in the limbs or hinge of mesoscale folds.

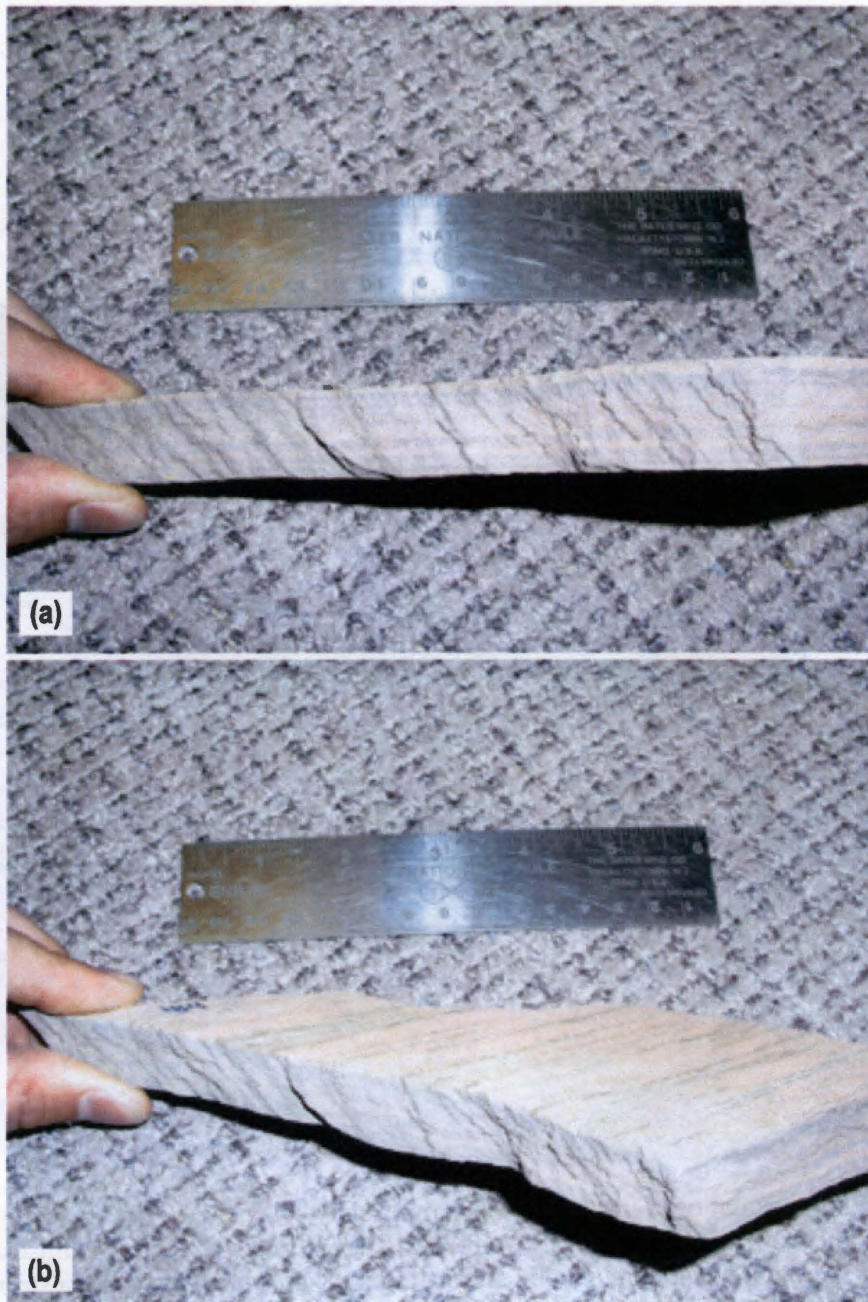


Figure 3-18. Pressure solution cleavage (S_{1a}) in Wilhite Formation siltstone collected in the Greenbrier thrust sheet, Whiteoak Flats 7.5 minute quadrangle. (a) Bedding (S_0) is perpendicular to bottom of photograph, present as thin laminations, and is cut sub-orthogonally by disjunctive, rough, anastomosing surfaces of insoluble residue identified as pressure solution cleavage (S_{1a}). (b) Dark, discontinuous banding on top surface (bedding, S_0) shows that pressure-solution cleavage is discontinuous in three-dimensional space, though the rough, anastomosing character of S_{1a} is not as apparent on the bedding surface.



Figure 3-19. Zonal crenulation cleavage (S_3) deforming slaty cleavage surface (S_2) in Wilhite Formation siltstone from an exposure near Doublecamp Creek in the Greenbrier thrust sheet, Whiteoak Flats 7.5 minute quadrangle. Faint alternating light-green and dark-green stripes are bedding (S_0).

WESTERN BLUE RIDGE STRUCTURAL REVISIONS IN AND SOUTH OF GSMNP

The complex structural evolution of the WBR, which presents a number of obstacles for deducing primary depositional relationships, is the result of multiple metamorphic and deformational events. While the complete chronologic picture still remains somewhat unclear, re-evaluation of pre-existing work coupled with newly emerging data provides significant insight into the Paleozoic tectonic conditions along the southeastern Laurentian margin.

Based on the lack of deformed cleavage near the fault zones, undisturbed isograds across the fault traces, and the presence of ductile fabrics near the fault surfaces, the GBF, RCF, and Dunn Creek fault (DCF) systems and related folds are recognized as the major premetamorphic structural features in the WBR (Hamilton, 1961; Hadley and Goldsmith, 1963; King, 1964; Neuman and Nelson, 1965). All three of these faults appear to have experienced dominantly brittle dissection by later Paleozoic thrusting, although the original(?) thrust fault trace of the RCF sheet appears to be significantly more intact than either the GBF or DCF.

Greenbrier–Oconaluftee–Salt Spring Mountain fault system

The complex nature of the Greenbrier fault in GSMNP was revealed by the work King et al. (1958). They recognized that it subdivides the OSG into two major stratigraphic sequences. In the GBF hanging wall in GSMNP the GSG conformably overlies the SG and in the footwall the SG is conformably overlain by the unclassified formations of King et al. (1958), including the Rich Butt Sandstone and the rocks of Webb Mountain and Big Ridge. In GSMNP, the Greenbrier was originally interpreted as a premetamorphic fault based on observations of ductile fault fabrics, transection of regional metamorphic isograds, and recognition that the fault does not deform regional cleavage (Hadley and Goldsmith, 1963; King, 1964; Milton, 1983; Connelly and Dallmeyer, 1990; Woodward et al., 1991; Connelly and Woodward, 1992). These observations led early investigators (Hadley and Goldsmith, 1963; King, 1964) to suggest that the GBF initially propagated as a northwest-directed low-angle bedding thrust accommodated by weak zones at or

near the GSG-SG contact. This interpretation was based primarily on the group separation across the fault trace and the lack of observed basement rocks in the hanging wall of the GBF. At that time, however, complex depositional and deformational relationships remained obscure.

Based on the initial correlation by Geddes (1995) between the premetamorphic GBF recognized in GSMNP and the brittle fault (SSMF) recognized on the northwest limb of the Epperson synclinorium (Plate 4, 5), Carter (unpublished) suggested that the brittle fault segment represented reactivation of the premetamorphic GBF that may have moved in conjunction with the post-metamorphic Great Smoky-Miller Cove or Oconaluftee fault systems. Reactivation of the GBF by the Oconaluftee fault in western GSMNP was implied by Neuman and Nelson (1965) and others based on the high ramp angle inferred from the fault trace and the brittle fault-related deformation observed north of the Little Tennessee River. The Oconaluftee fault in GSMNP is a west-northwest-trending high-angle dextral strike-slip fault and locally low-angle thrust fault that laterally offsets GSG units in the hanging wall of the GBF prior to tracing in to parallelism with the main GBF trace. The brittle deformational style of the Oconaluftee fault lies in sharp contrast to ductile deformation recognized along the premetamorphic GBF surface, and seems to suggest that the Oconaluftee fault is a manifestation of brittle GBF reactivation. Recently, Southworth et al. (2005) recognized isolated segments of the earlier ductile GBF truncated by a later brittle fault trace correlated with the Oconaluftee southeast of Cades Cove, not only indicating some form of brittle truncation but also suggesting that the early GBF and the later brittle fault do not occupy the same fault surface.

Excellent exposures of a major brittle fault (SSMF; Fig. 3-6) southeast of the RCF in the current study area confirm postmetamorphic motion south of the Little Tennessee River, and suggest that the fault recognized in the study area is most likely analogous to the postmetamorphic brittle Oconaluftee fault recognized by Southworth et al. (2005) in GSMNP. The SSMF south of the Little Tennessee River, like the Oconaluftee fault in GSMNP, isolates a fault segment interpreted as the early GBF. Unlike the Oconaluftee, however, the SSMF

appears to override and bury rather than truncate the early GBF segment. A possible corollary segment of the GBF may be isolated in the same circumstances approximately ~35 km to the southwest (Plate 4). There a splay off the GBF interpreted by Martin (1997) is very similar to the termination of the SSMF in Little Slickrock Creek (Plate 1). Consequently, the splay may represent the southern termination of the SSMF, indicating that the GBF may reappear for a short distance prior to truncation by the MCF (Plate 4). If correct, this interpretation would further validate hypotheses that faulting near or subparallel to the early GBF did not reactivate the ductile fault surface, but rather truncated and overrode it by utilizing kinematically better oriented brittle fault surfaces.

Southwest-plunging structure in the SSMF-GBF hanging wall exposes sequentially younger strata east of the fault, so that in the Foothills, upper GSG and Wilhite rocks in the core of the Epperson synclinorium comprise the GBF hanging wall. In the Foothills, regional NE-SW trending-folds are synmetamorphic as indicated by their axial-planar slaty cleavage. Some structures, including the first-order Epperson synclinorium and its adjacent second-order Rafter anticline (Plate 4), are truncated by the SSMF-GBF system, indicating that final fault motion is postmetamorphic in southeastern Tennessee. Thus, brittle faulting in southeast Tennessee and GSMNP near the premetamorphic GBF probably did occur, but reactivation of the early GBF during later Paleozoic orogenesis is not likely.

The relatively minor displacement (1-2 km) interpreted for the SSMF in the study area suggests that the SSMF and GBF are likely subparallel and probably have similar trace locations in southeast Tennessee. Utilizing stratigraphic correlations between the Cades Sandstone and Dean Formation, Geddes (1995) estimated a minimum GBF displacement (now SSMF and GBF) to be ~1 km (3,300 ft) throw and ~2 km (6,600 ft) heave, although truncation of the GBF by the MCF ~40 km to the southwest (Martin, 1997) makes any displacement estimates difficult to constrain. Basin-scale reconstructions, however, suggest that GBF displacement must be

regionally significant, although it is likely less than that estimated for the GBF in eastern GSMNP (23 km; Hadley and Goldsmith, 1963; 40 km; Montes, 1997).

Dunn Creek–Rabbit Creek–Line Springs fault system

The Dunn Creek fault (DCF) was first recognized by Hamilton (1961) in the Jones Cove and Richardson Cove quadrangles north of GSMNP. It accommodated north-northwest-directed ductile thrusting of SG rocks (Pigeon Siltstone and Roaring Fork Formation) over footwall rocks of the WCG. Much like the GBF, the DCF often represents a separation between two respective OSG groups, although at its northeastern extent, as displacement decreases, the Pigeon Siltstone occupies both the hanging wall and footwall. To the southwest, the DCF is dextrally offset by late Paleozoic strike-slip faulting, possibly related to motion that occurred along the Oconaluftee fault system (King, 1964).

Hamilton's (1961) map patterns suggest that along most of the extent, the DCF is a steeply-dipping thrust fault, which dips steeply to moderately southward near the surface; to the east, it appears to become less steep. Most enigmatic to the Jones Cove and Richardson Cove area are the exposures of Webb Mountain and Big Ridge rocks that were left unclassified by King et al. (1958). These rocks most closely resemble those of the GSG. Preliminary studies (Hamilton, 1961; Hadley and Goldsmith, 1963; King, 1964; Neuman and Nelson, 1965), however, never observed what they interpreted as GSG rocks below the Greenbrier thrust sheet. Thus, stratigraphic relationships of the Webb Mountain and Big Ridge rocks to the regional OSG framework remained unclear.

King et al. (1958) speculated that these rocks represented a klippe of the Greenbrier thrust sheet 4-5 km to the south. This interpretation was also presented for the Rabbit Creek thrust sheet southwest of Tuckaleechee Cove, yet these explanations were utilized only to explain the juxtaposition of GSG rocks above SG rocks, which may or may not be in fault contact. The Cades Sandstone (Rabbit Creek thrust sheet) and Webb Mountain rocks resemble GSG rocks, but the

lack of characteristic blue quartz clasts in coarser units of both formations and their correlative positions of structural juxtaposition within rocks of the SG initially suggests that they are at least approximate stratigraphic equivalents. Rocks on the leading edge of the GBF in both cases contain abundant rutiled blue quartz clasts, so the suggestion that rocks of the Rabbit Creek thrust sheet or those of Webb Mountain-Big Ridge are klippen of the Greenbrier thrust sheet is likely invalid.

Woodward et al. (1991) followed the interpretations of King et al. (1958) and Hamilton (1961) by retrodeforming the Rabbit Creek and Webb Mountain rocks as klippe of the Greenbrier thrust sheet, because they did not remap these areas. This interpretation led them to suggest the presence of a regional scale ramp anticline at the leading edge of the Greenbrier thrust sheet in order to account for evidence of coeval premetamorphic folding and faulting in the Jones Cove-Richardson Cove region. Premetamorphic folds (F_1) of Hamilton (1961), Carter (1994), and this study were not observed to be of regional (first or second order) magnitude as suggested by Woodward et al. (1991).

Hamilton (1961) observed structural conformity (similar orientation of bedding) between the rocks on Webb Mountain and those of the surrounding Pigeon Siltstone along the southern extent of the contact, leading him to suggest that the sequence was likely unfaulted. On the northern edge of the structure, Webb Mountain and Big Ridge rocks are thrust over Pigeon Siltstone via the Webb Mountain fault. The premetamorphic nature of the Webb Mountain fault was suggested because cleavage is not rotated or deformed on either side of the fault trace. Hamilton (1961) interpreted the Webb Mountain fault to be a south-dipping thrust fault near the surface before becoming listric and eventually south-dipping further to the south. Consequently, folding of the fault surface would likely have to be post-metamorphic.

If the stratigraphic sequence between the Pigeon siltstone and the rocks of Webb Mountain and Big Ridge were interpreted to be intact, as Hamilton (1961) originally suggested, this would necessitate a logical correlation between the Webb Mountain-Big Ridge rocks and the

Rich Butt Sandstone observed conformably overlying the Pigeon Siltstone to the east. Like GSG rocks on the leading edge of the Greenbrier thrust sheet in GSMNP, however, the Rich Butt also contains abundant blue (rutilated) quartz clasts (Hadley and Goldsmith, 1963), again necessitating that GSG rocks in the Greenbrier thrust sheet and the Rich Butt Sandstone in the footwall of the GBF had a different source area than rocks exposed in the Rabbit Creek thrust sheet and Webb Mountain-Big Ridge region.

Remapping and study of new exposures (roadcuts) unavailable to King et al. (1958) and Hamilton (1961) on Webb Mountain by Hatcher and Carter (1996) produced more refined interpretations of the structural style of these units. Along the southern margin, they observed clear evidence for south-dipping postmetamorphic brittle faulting, (Fig. 3-20), rather than north-dipping premetamorphic faults as suggested by Hamilton. (1961). Instead, Hatcher and Carter (1996) suggested that the rocks on Webb Mountain and Big Ridge were actually windows through the Dunn Creek thrust sheet. Premetamorphic folding of these rocks was thus linked to footwall deformation during transport along the DCF.

DISCUSSION

In the western region of GSMNP, the RCF facilitates northwest-directed transport of the Cades Sandstone over rocks of the Walden Creek Group (Wilhite and Shields Formations). Southeast of Cades Cove, highly tectonized Metcalf Phyllite (Snowbird Group) rocks are imbricated with thrust slices of the Cades Sandstone in the footwall of the GBF (Plate 5). This imbricated map pattern led Neuman and Nelson (1965) to suggest that the Cades Sandstone and Metcalf Phyllite were intertongued, since map relationships appeared to suggest that the Cades was both overlain by and underlying the Metcalf Phyllite. Lithologic and detrital component comparisons between the Cades Sandstone and the only unit recognized to demonstrably lie in this particular stratigraphic position (Rich Butt Sandstone) suggests that these correlations are invalid and these units likely had different source regions. Map patterns in the Kinzel Springs

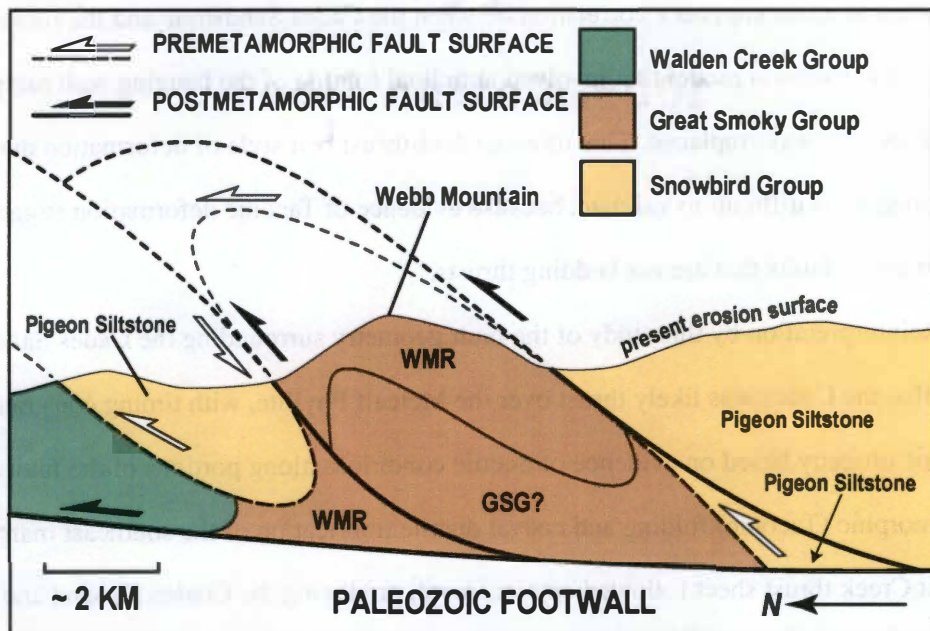


Figure 3-20. Cross section interpretation of Hatcher and Carter (1995) based on remapping in the Jones Cove and Richardson Cove quadrangles north of GSMNP that were originally mapped by Hamilton (1961). Early Taconic propagation of the Dunn Creek fault results in Pigeon siltstone in the hangingwall thrust over Walden Creek Group rocks (Shields, Wilhite, and Sandsuck Formations) and conformably underlying Great Smoky Group rocks (Webb Mountain and Big Ridge rocks) in the footwall. Taconic peak orogenesis folds the Dunn Creek fault, likely coeval with folding of the Greenbrier fault and possibly less extensive folding of the Rabbit Creek fault. During the Late Paleozoic Alleghanian orogeny, the inability of the Dunn Creek fault to accomodate displacement due to folded surface results in propagation of high-angle brittle faults which dissect the early Dunn Creek fault surface. Original drafting by Mark Carter, 1997. GSG- Great Smoky Group. WMR-Webb Mountain rocks.

7.5 minute quadrangle and compiled maps of the western GSMNP do suggest that the Cades Sandstone lies mostly above the Metcalf Phyllite, although the structural vs. stratigraphic nature of the contact between these units was not well delineated by previous studies.

Woodward et al. (1991) recognized a curved regional antiform with an axis that trends northeast through the center of the Rabbit Creek thrust sheet prior to curving into a more east-northeast trend along the anticlinal axis of the Webb Mountain rocks (Plate 5). They used this interpretation to again suggest a correlation between the Cades Sandstone and the rocks of Webb Mountain in a structural model that involved anticlinal folding of the hanging wall ramp as the RCF-DCF system was emplaced. This foreland fold-thrust belt style of deformation during the Taconic orogeny is difficult to validate, because evidence of Taconic deformation suggests ductile conditions along faults that are not bedding thrusts.

Reinterpretation by this study of the fault geometry surrounding the Cades Sandstone suggests that the Cades was likely thrust over the Metcalf Phyllite, with timing constrained to the Taconic orogeny based on evidence of ductile conditions along portions of the fault zone. Synmetamorphic (Taconic) folding and coeval ductile imbrication of the southeast margin of the Rabbit Creek thrust sheet followed emplacement, producing the Coalen Ground and Parson Branch faults (Plate 5). This later stage may represent footwall deformation related to ramping of the Greenbrier thrust sheet into its present position. Final emplacement of the GBF likely covered the southeasternmost extent of the RCF.

Stratigraphic relations in the Rabbit Creek thrust sheet in southeast Tennessee elucidate regional fault geometry and kinematics of fault reactivation in this region. The Cades Sandstone, unclassified by King et al. (1958) because of obscure contact relations with other OSG units, was interpreted by Walters (1988) to be correlative with the Elkmont and Thunderhead Sandstones in the western GSMNP. He suggested that the Cades is exposed in the overturned forelimb of a recumbent nappe, floored by the RCF, with the fold axis and opposing limb truncated by the Oconaluftee-Greenbrier fault system. Along strike to the south, Cades Sandstone-

Dean Formation lithologies comprise the RCF thrust sheet, and are folded into the 3rd-order synmetamorphic Blue Mountain anticline (Plate 4). This indicates that the RCF hanging wall is not composed of only Cades Sandstone, as previously suggested, but is instead a fault-bounded composite of GSG strata in the core of a southwest-plunging fold. Combined, these stratigraphic and structural relations imply a sequence of events in southeastern Tennessee initiated by the emplacement of the Rabbit Creek and Greenbrier faults before regional synmetamorphic folding. Later brittle reactivation along the RCF transected and readjusted the synmetamorphic folds into their present configuration (Plate 4). Because the SSMF apparently broke the synclinal trough between the Blue Mountain and Rafter anticlines in the RCF hanging wall to accommodate more displacement, it must have been out-of-sequence to the postmetamorphic RCF.

Reactivation of the early RCF in southeast Tennessee suggests that post-emplacement Taconic deformation was insufficient in folding the RCF into a kinematically poorly oriented surface and negates later reactivation. Inversely, folding of the GBF throughout the WBR prevented brittle reactivation. Instead, faults such as the Oconaluftee and SSMF accommodated fault transport along surfaces that are independent of the early GBF surface. Likewise, folding of the DCF prevented reactivation of the early fault surface that was later dissected by high-angle Alleghanian brittle faulting.

CONCLUSIONS

- 1) Rocks of the study area are deformed by at least three periods of faulting and folding (F_1 - F_2) and one regional metamorphic cleavage-forming event (S_2). The only F_1 fold in the study area is transected by slaty cleavage (S_2 ; pressure solution and recrystallization) that is axial-planar to F_2 folds. S_2 , S_{2a} (pressure-solution), and F_2 folds are related to Taconic (480-430 Ma) Barrovian metamorphism based on $^{40}\text{Ar}/^{39}\text{Ar}$ and $^{40}\text{K}/^{39}\text{Ar}$ metamorphic mineral cooling ages and the axial-planar relationship of S_2 and S_{2a} to F_2 . Crenulation cleavage (S_3) is suborthogonal to and deforms S_2 , suggesting it occurred later.

- 2) The GBF and RCF here were initially emplaced prior to Taconic peak metamorphism under dominantly ductile conditions. The GBF was folded (F_2) coveval with peak Taconic metamorphism, which prevented late Paleozoic reactivation of that structure. The brittle HLF likely propagated from the hinge or southeast limb of the Ducktown anticlinorium (first-order F_2) during early Alleghanian orogenesis. The brittle SSMF and possibly coeval Oconaluftee faults cut the folded GBF surface to accommodate Alleghanian thrust displacement, while the RCF was reactivated. During the latest stages of the Alleghanian orogeny, emplacement and bending of the Great Smoky thrust sheet above the Foothills duplex (Valley and Ridge horses) produced second- and higher-order F_3 folds.
- 3) Rocks on the leading edge of the GBF in western and northern GSMNP contain abundant rutilated blue quartz clasts, so it is unlikely that rocks of the Rabbit Creek thrust sheet or those of Webb Mountain-Big Ridge are klippen of the Greenbrier thrust sheet. A foreland fold-thrust belt style of deformation during the Taconic orogeny is difficult to validate, because evidence of Taconic deformation suggests ductile conditions along faults that are not bedding thrusts.
- 4) Reinterpretation by this study of the fault geometry surrounding the Cades Sandstone suggests that the Cades was likely thrust over the Metcalf Phyllite, with timing constrained to the Taconic orogeny due to evidence of ductile conditions along portions of the fault zone. Synmetamorphic (Taconic) folding and coeval ductile imbrication of the southeast margin of the Rabbit Creek thrust sheet followed emplacement, producing the Coalen Ground and Parson Branch faults.

5) Stratigraphic and structural relations imply a sequence of events in southeastern

Tennessee initiated by the emplacement of the Rabbit Creek and Greenbrier faults before regional synmetamorphic folding. Later brittle reactivation along the RCF transected and readjusted the synmetamorphic folds into their present configuration. Because the SSMF apparently broke the synclinal trough between the Blue Mountain and Rafter anticlines in the RCF hanging wall to accommodate more displacement, it must have been out-of-sequence to the postmetamorphic RCF.

CHAPTER IV

CARBONATE GEOCHEMISTRY OF THE SANDSUCK FORMATION, WALDEN CREEK GROUP: SOUTHEASTERN TENNESSEE CONSTRAINTS ON TIMING OF DEPOSITION

INTRODUCTION

The Ocoee Supergroup (OSG) is the major lithostratigraphic unit in the southern Appalachian western Blue Ridge (WBR; Figs. 4-1 and 4-2). Traditionally, the OSG is interpreted as an ~15 km thick sequence of Neoproterozoic-Cambrian synrift strata (Fig. 2-2) deposited during the breakup of Rodinia (Hatcher, 1972; Rast and Kohles, 1986; Aleinikoff et al., 1995). Contrary to traditional interpretations, recently reported paleontological evidence suggests a middle Paleozoic (Silurian-Mississippian) age for all or part of the OSG. Nowhere in the OSG outcrop area does a complete, unfaulted section exist, although the basal unit of the OSG, the Snowbird Group, lies nonconformably on Middle Proterozoic (Grenvillian) basement granites and gneisses. The Walden Creek Group, the uppermost component of the OSG, conformably grades upward into the fossiliferous Lower Cambrian Chilhowee Group (Fig. 2-2; Neuman and Nelson, 1965; Carter, 1994; Weiner, unpublished; this study). Unrug and Unrug (1990, 1991) and Unrug et al. (2000) suggested a Late Silurian or younger age of the Walden Creek Group based on microfossil reports from the Wilhite Formation (Walden Creek Group) east of the Miller Cove fault (Fig. 4-2). If correct, a distinctly younger age (mid-Paleozoic instead of Neoproterozoic) would necessitate new depositional, metamorphic, and structural interpretations of the WBR. A mid-Paleozoic age for the Walden Creek Group remains suspect based on mapped structural and stratigraphic relationships (Hamilton, 1961; King, 1964; Neuman and Nelson, 1965; Carter, 1994; Martin, 1997; Wiener, unpublished, this study), Taconic (480-430 Ma) metamorphic age dates obtained from numerous OSG samples (Butler, 1972; Connelly and Dallmeyer, 1990; Moecher et al., 2004), reports of soft-bodied fossils (Broadhead et al., 1991), and an inability to independently reproduce mid-Paleozoic microfaunas (Broadhead et al., 1991). Earlier mapping,

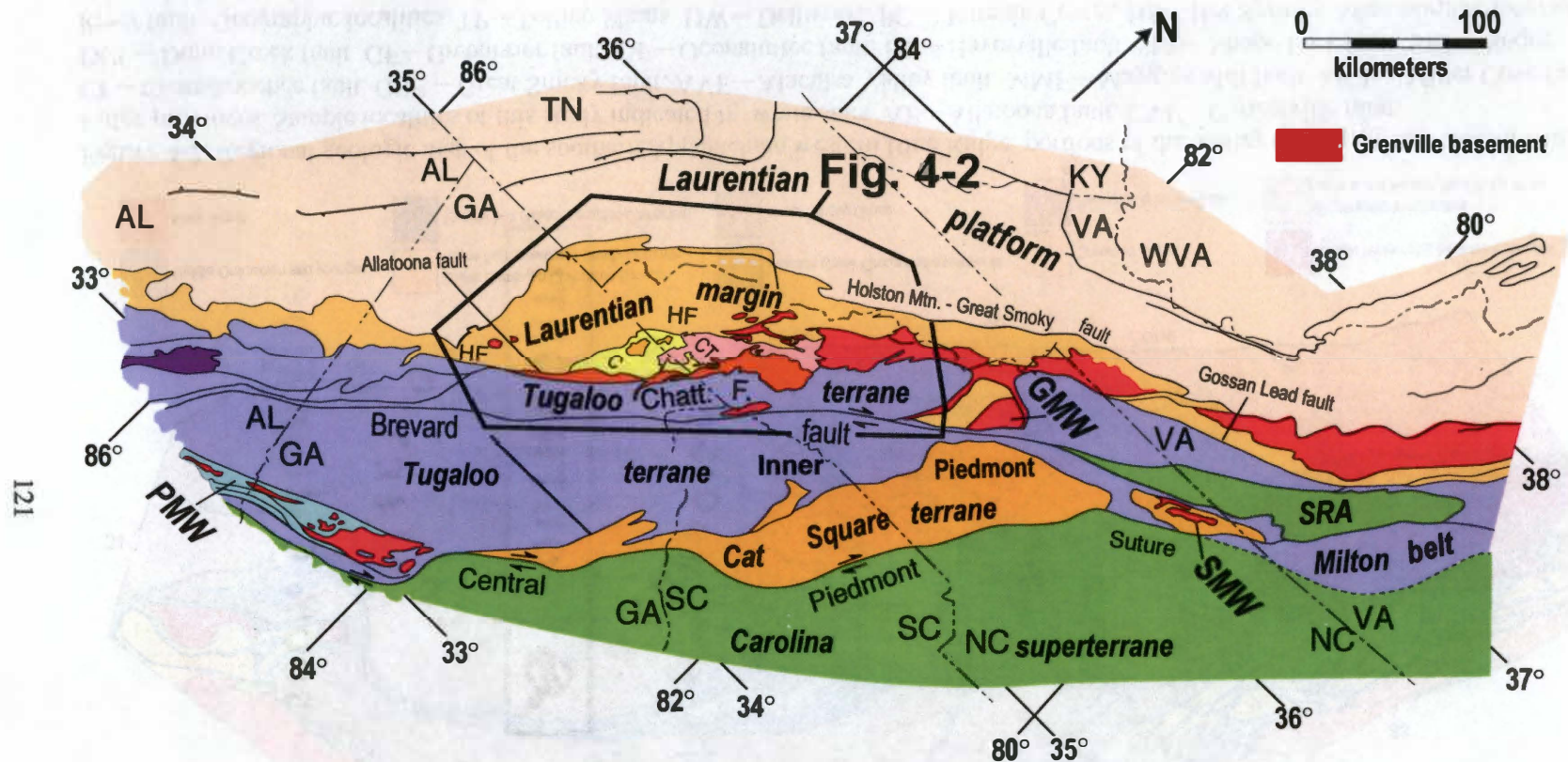


Figure 4-1. Major tectonic elements of the southern Appalachians showing the location of the western Blue Ridge (Laurentian margin). GMW—Grandfather Mountain window. SRA—Smith River Allochthon. SMW—Sauratown Mountains window. PMW—Pine Mountain window. Chatt F.—Chattahoochee fault. HF—Hayesville fault. C—Cowrock terrane. CT—Cartoogechaye terrane. DGB—Dahlonega gold belt (Modified from Hatcher, 2002).

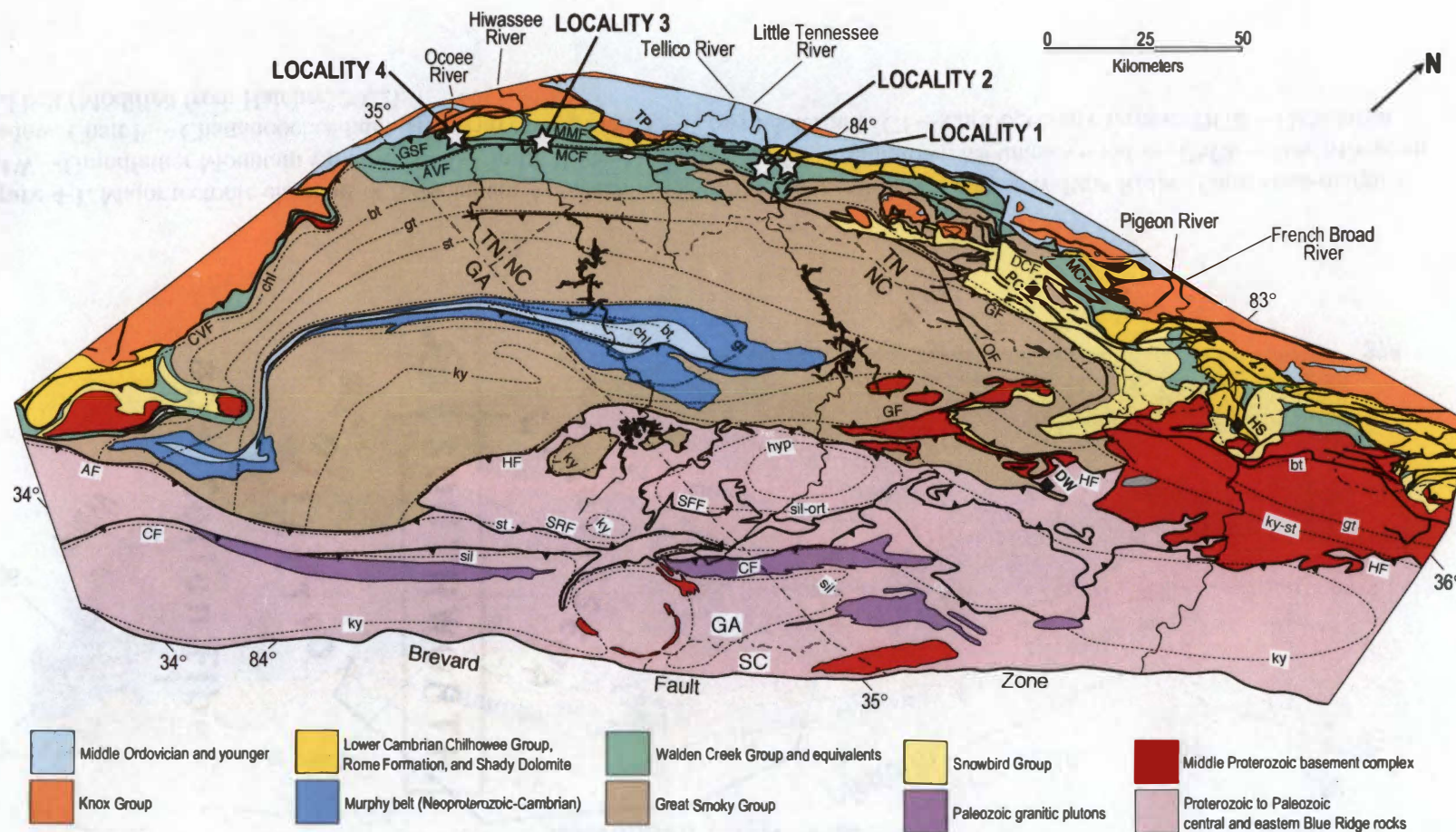


Figure 4-2. Regional geologic map of the southern Appalachian western Blue Ridge, portions of the Valley and Ridge and eastern Blue Ridge provinces. Sample localities of this study indicated by white stars. AF—Allatoona fault. CVF—Cartersville fault. CF—Chattahoochee fault. GSF—Great Smoky fault. AVF—Alaculsa Valley fault. MMF—Maggies Mill fault. MCF—Miller Cove fault. DCF—Dunn Creek fault. GF—Greenbrier fault. OF—Oconaluftee fault. HF—Hayesville fault. SFF—Shope Fork fault. SRF—Soque River fault. Geographic localities, TP—Tellico Plains. DW—Dellwood. PC—Pittman Center. HS—Hot Springs. Metamorphic isograds, chl—chlorite. bt—biotite. gt—garnet. st—staurolite. ky—kyanite. hyp—hypersthene. sil—sillimanite. sil-ort—sillimanite to K-feldspar.

however, suggests that some of the Unrug et al. (2000) sample localities are in the Sandsuck Formation (Carter, 1994; Geddes, 1995; Wiener, unpublished), which lies stratigraphically above the Wilhite at the top of the Walden Creek Group. Detrital zircon analyses by Bream et al. (2004) produced only Grenvillian and older zircons (1.2, 1.3, 1.4 Ga) from Sandsuck Formation rocks at Chilhowee Dam and Springtown (Localities 1 and 3 of this study), suggesting that no Ordovician or younger deposits are present, contrary to interpretations by Unrug et al. (2000).

Conflicting paleontological and stratigraphic/structural data necessitate utilization of an alternative methodology to resolve this dilemma. Here we attempt to place constraints on the age of the Walden Creek Group from C, O, and Sr isotopic data derived from carbonates of the Sandsuck Formation (uppermost Walden Creek Group).

WALDEN CREEK GROUP

The Walden Creek Group is the uppermost stratigraphic package in the OSG. It is composed predominantly of shale and siltstone with interbedded, often discontinuous horizons of polymictic and quartz-pebble conglomerate, carbonate breccia, and less common layers of quartzite, limestone, dolomite, and dolomitic siltstone. Northeast of Great Smoky Mountains National Park (GSMNP), a relatively undeformed section nearly 3,000 m thick likely represents the most complete Walden Creek sequence recognized (King et al., 1958; Hamilton, 1961). Here, the Wilhite Formation is conformably overlain by the Sandsuck Formation (Hamilton, 1961), which is conformably overlain by the Chilhowee Group to the southwest (King, 1964; Neuman and Nelson, 1965; Carter, 1994; Rackley, 1951; Phillips, 1952).

King et al. (1958) originally subdivided the Walden Creek Group into four formations (Licklog, Shields, Wilhite, Sandsuck). Southwest of GSMNP, however, only the upper three members of the WCG are exposed. The dark-gray siltstone, shale, and minor interbedded sandstone and conglomerate of the basal Licklog Formation (King et al., 1958) are only recognized near Tuckaleechee and Cades Cove in western GSMNP and as a sparse, discontinuous

unit north and east of GSMNP (Neuman and Nelson, 1965). The Shields Formation consists predominantly of argillaceous shale, coarse-grained feldspathic sandstone, and lenses of polymictic conglomerate. Polymictic conglomerates are often ungraded, dominated by vein quartz pebbles, and occur in paleochannels. Lithologies of the Shields Formation were placed in the Walden Creek Group by King et al. (1958), but are more similar to lithologies of the upper Great Smoky Group. The Wilhite Formation was originally recognized by Hamilton (1961), who subdivided the formation into two components. The Dixon Mountain Member, conformably overlies the Shields Formation, consists of micaceous or sandy banded and unbanded siltstone, with interbeds of feldspathic sandstone and light-gray quartzite. The Yellow Breeches Member (Hamilton, 1961), conformably overlying the Dixon Mountain Member, contains interbedded limestone, dolomite, sandstone and calcareous siltstone. The uppermost unit in the WCG, the Sandsuck Formation, consists of light- to medium-gray siltstone, dark-gray, fine- to medium-grained sandstone, polymictic conglomerate, carbonate breccia, dolomitic siltstone, and dark-gray micritic limestone (Hamilton, 1961; Carter, 1994; Martin, 1997; Wiener, unpublished; this study). Complex intertonguing of these facies and their discontinuous nature makes the Sandsuck Formation one of the most depositionally complex units recognized in the OSG.

Middle Paleozoic Age of the Walden Creek Group

Unrug et al. (2000) proposed a Silurian or younger age for the Walden Creek Group based on 14 sample localities south of GSMNP. They utilized the geologic maps of Neuman and Nelson (1965), and interpreted their sample localities to lie wholly within the Wilhite Formation, in the hanging wall of the Miller Cove fault. Detailed mapping southwest of GSMNP by Costello (1993), Carter (1994), Geddes (1995), Martin (1997), Wiener (unpublished), and this study, however, indicates that Neuman and Nelson's (1965) mapped location of the Miller Cove fault is incorrect, and the fault was relocated to the southeast (Plates 1 and 4). In this scenario, rocks in the Miller Cove fault footwall are mapped as Sandsuck Formation that grades upward into the

conformably overlying Cochran Formation (basal Chilhowee Group), and the Wilhite Formation is entirely restricted to areas southeast of the Miller Cove fault. Thus, the Wilhite Formation of Unrug et al. (2000) is actually Sandsuck Formation.

According to Unrug and Unrug (1990, 1991) and Unrug et al. (2000), these sample localities produced Middle Ordovician-Devonian ostracodes (*Aechmina sesquipedalis*, *Ulrichia*), Middle Ordovician to Middle Early Mississippian foraminifera (*Psammospaera cava*, *Blastamina polymorpha*, *Stegnammina moremani*, and others), Silurian or younger fenestellid bryozoa, phosphatized brachiopod valves, clasts of crinoidal limestone, and other microfauna commonly observed in Paleozoic rocks. These microfauna suggest a Silurian or younger (Mississippian or younger at Locality 5 of their study) age for the Sandsuck Formation, which contrasts sharply with stratigraphic, map, and metamorphic evidence that alternately suggests a Neoproterozoic-lowermost Cambrian age for that unit (Hamilton, 1961; King, 1964; Neuman and Nelson, 1965; Butler, 1972; Connelly and Dallmeyer, 1990; Broadhead et al., 1991; Carter, 1994; Martin, 1997; Moecher et al., 2004; Wiener, unpublished, this study).

ISOTOPIC CHEMOSTRATIGRAPHY

Carbon isotope curves of marine inorganic carbon have been established with some degree of accuracy for much of Earth history (Burke et al., 1982; Derry et al., 1989, 1992, 1994; Asmerom et al., 1991; Kaufman et al., 1993, 1996; Jacobsen and Kaufman, 1999; Veizer et al., 1999; others; Fig. 4-3). Secular variation of marine carbon isotopes is related to changes in the proportions of different components of the carbon cycle (Marshall, 1992), or more specifically by burial flux of marine organic carbon, ventilation of the deep sea, weathering of organic-rich rocks, concentration of atmospheric CO₂, global cycles of glaciation, and possibly the impacts of methane clathrate formation or release (Ripperdan, 2001). The secular ⁸⁷Sr/⁸⁶Sr curve (Fig. 4-4) is also useful for stratigraphic correlation. Constant emergence of new data increases stratigraphic resolution and distinguishes secular variations that were previously unresolvable

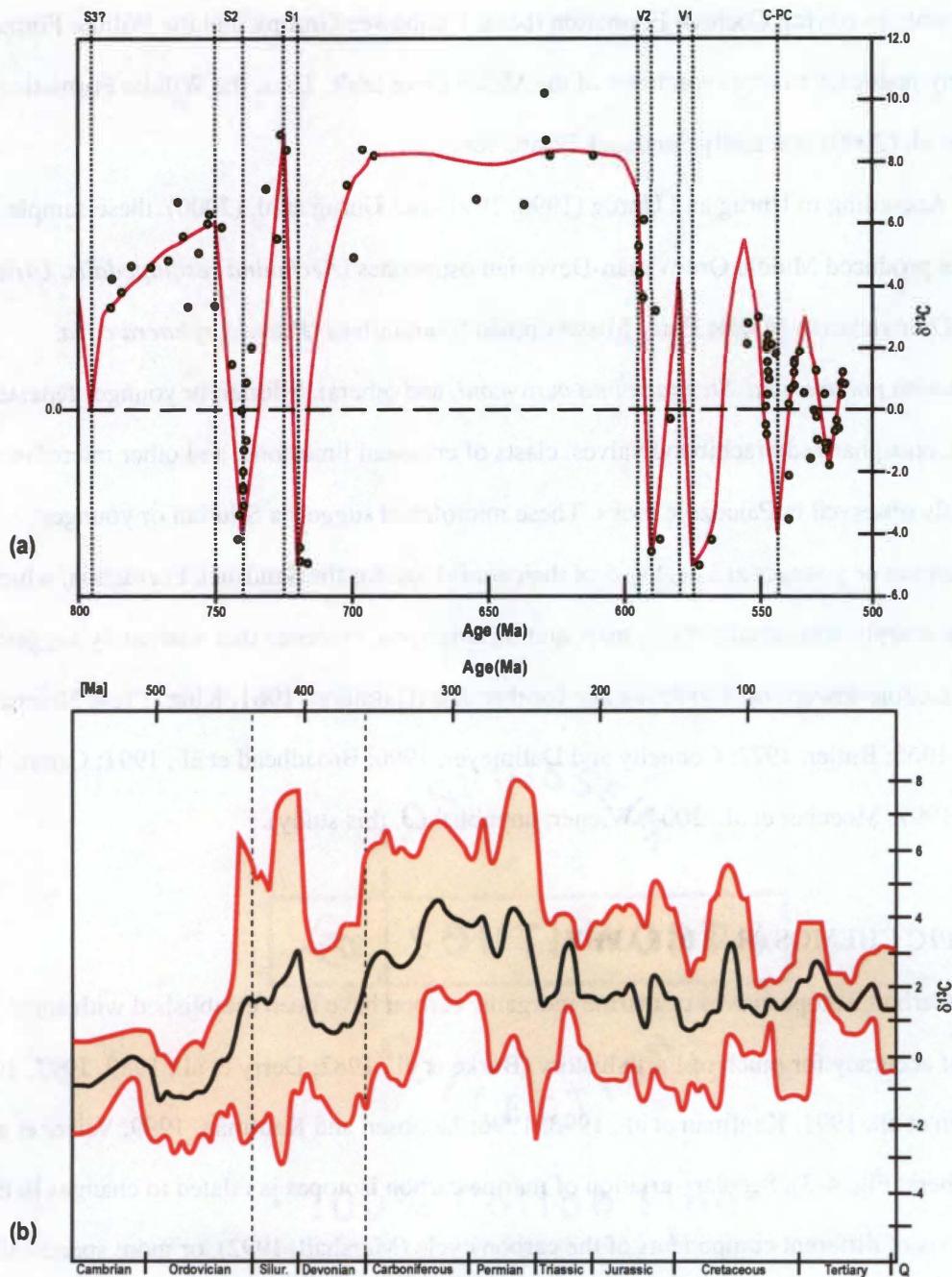


Figure 4-3. Temporal variation of $\delta^{13}\text{C}$ from early Neoproterozoic-Recent. (a) Established $\delta^{13}\text{C}$ isotope curve for the Neoproterozoic to Early Cambrian. Extreme positive and negative excursions interpreted to result from periods of extensive glaciation. S3 - possible Sturtian glaciation. S2, S3 - upper and lower Sturtian glaciations. V1, V2 - upper and lower Vendian glaciations. C-PC - Cambrian-Precambrian boundary. Red line based on data from Kaufman and Knoll (1995). Modified from Jacobsen and Kaufman (1999). (b) Phanerozoic $\delta^{13}\text{C}$ trend for LMC (low-magnesium calcite) shells. Black line is running mean. Shaded area around the running mean includes 95% of all data. Modified from Veizer et al. (1999).

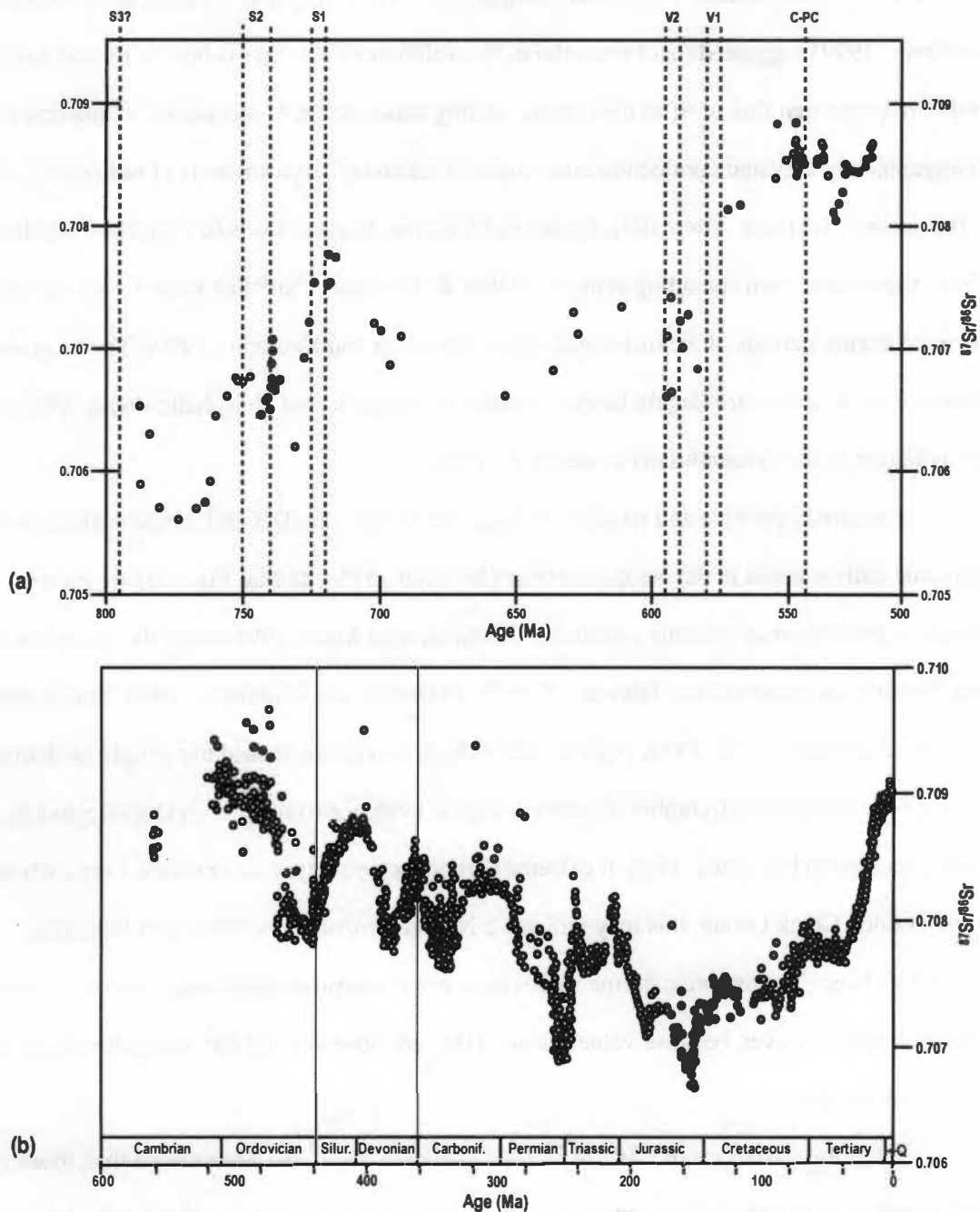


Figure 4-4. Temporal variation of $^{87}\text{Sr}/^{86}\text{Sr}$ from early Neoproterozoic–Recent. (a) Established $^{87}\text{Sr}/^{86}\text{Sr}$ isotope curve for the Neoproterozoic to Early Cambrian. Secular variation is likely related to Sr flux to the oceans from weathering of continental crust (high $^{87}\text{Sr}/^{86}\text{Sr}$), and input from submarine hydrothermal systems (low $^{87}\text{Sr}/^{86}\text{Sr}$). Symbols S3?, S2, S1, V2, V1, C-PC, same as Fig. 4-3. Modified from Jacobsen and Kaufman (1999). (b) Phanerozoic $^{87}\text{Sr}/^{86}\text{Sr}$ trend based on 4055 brachiopod shells, belemnites, conodonts, and 9 samples of micrite. Sources of data may be seen in Veizer et al. (1999; p. 66). Modified from Veizer et al. (1999).

(Veizer et al., 1999; others). Veizer and Compston (1976), Veizer et al., (1983), and Jacobsen and Kaufman (1999) suggested that Precambrian Sr evolution in seawater is largely related to changes in the hydrothermal flux of Sr to the oceans. During supercontinent formation, weathering of topographically elevated continental crust supplies relatively large amounts of radiogenic ^{87}Sr to the oceans via rivers. Alternately, breakup of these landmasses leads to significant addition of ^{86}Sr to the oceans from spreading centers. Unlike $\delta^{13}\text{C}$ values, $^{87}\text{Sr}/^{86}\text{Sr}$ values do not appear to fluctuate during periods of extensive glaciation (Jacobsen and Kaufman, 1999). The most accurate Phanerozoic Sr trends are largely based on analysis of calcitic and phosphatic shells, which are not available in the Precambrian (Veizer et al., 1999).

Extremely positive and negative $\delta^{13}\text{C}_{\text{PDB}}$ (+8 to -6‰; PeeDee Belemnite) values of marine inorganic carbon noted in the Neoproterozoic (between ~575-725 Ma; Fig. 4-3) are mostly unique to pre-Paleozoic oceanic conditions (Kaufman and Knoll, 1995), with the exception of Late Ordovician excursions as large as -7 to 7‰ (Marshall and Middleton, 1990; Middleton et al., 1991; Brenchley et al., 1994; others). While these exceptions should not simply be dismissed, there is no structural/stratigraphic or paleontological evidence to suggest an Ordovician age for units discussed in this study. Thus, if extreme carbon isotope ratios are obtained from carbonates in the Walden Creek Group, this may indicate a Neoproterozoic rather than mid-Paleozoic depositional age. Not finding extreme values does not chemostratigraphically confirm a mid-Paleozoic age, however, because values close to 0‰ are observed in both Neoproterozoic and mid-Paleozoic times.

Temporal variations of $^{87}\text{Sr}/^{86}\text{Sr}$ isotope ratios are much less pronounced than those of the carbon isotope curve (Jacobsen and Kaufman, 1999). For the objectives of this study, however, Neoproterozoic $^{87}\text{Sr}/^{86}\text{Sr}$ values of 0.706500-0.707400 from 750-575 Ma notably lower than those observed from the Silurian to Devonian times ($^{87}\text{Sr}/^{86}\text{Sr}$ = 0.707750 to 0.709000).

METHODS

Sample selection

Fourteen sample localities described in Unrug et al. (2000) were evaluated and four carbonate localities (Fig. 4-2) were chosen for geochemical analysis based on stratigraphic thickness (greater stratigraphic thicknesses are interpreted to represent larger time intervals), dominant lithology (fine-grained micritic lithologies are less likely than sparry calcite or other carbonate lithologies to exhibit alteration of primary isotope compositions), degree of metamorphism (all four sample localities are anchizone or below), and the location of each section within areas of high resolution geologic mapping, thus eliminating additional and possibly unnecessary interpretations of stratigraphic and structural relationships.

Locality 1 (Chilhowee Dam; Fig. 4-2; Plate 1) is located in the Tallassee, TN 7.5 minute quadrangle along US 129 near Chilhowee Dam. This unit is dominated by poorly sorted polymictic conglomerate (Fig. 4-5). Clasts are dominantly quartz or feldspar (usually weathered) in a coarse-grained feldspathic sandstone matrix. Minor clast components include blue quartz, dark slate, and siltstone similar to those Great Smoky Group, micritic and pisolitic limestone, dolomite, calcareous siltstone/slate, and, rarely, leucogranite. Attempts were made to select lithologically varied carbonate clasts during sampling. According to Unrug et al. (2000), samples collected at Locality 1 (Locality 5 of Unrug et al., 2000) were derived from carbonate clasts in polymictic conglomerates and contain mid-Paleozoic microfauna, including the ostracode *Aechmina sesquipedalis* (Lundin, 1965; Mississippian or younger).

Locality 2 (Citico Quarry; Plate 1) is located in an abandoned quarry in the southwestern corner of the Tallassee 7.5 minute quadrangle. This section is ~12.0 m thick and is composed of medium- to thin-bedded interbedded dark-gray to blue-gray, fine-grained micritic limestone and calcareous siltstone (Fig. 4-6), with subordinate pisolitic limestone and carbonate breccia at distinct horizons. The mid-Paleozoic fauna of Locality 2 (Locality 6 of Unrug et al., 2000) was reportedly obtained from slaty argillite and olistolith blocks.

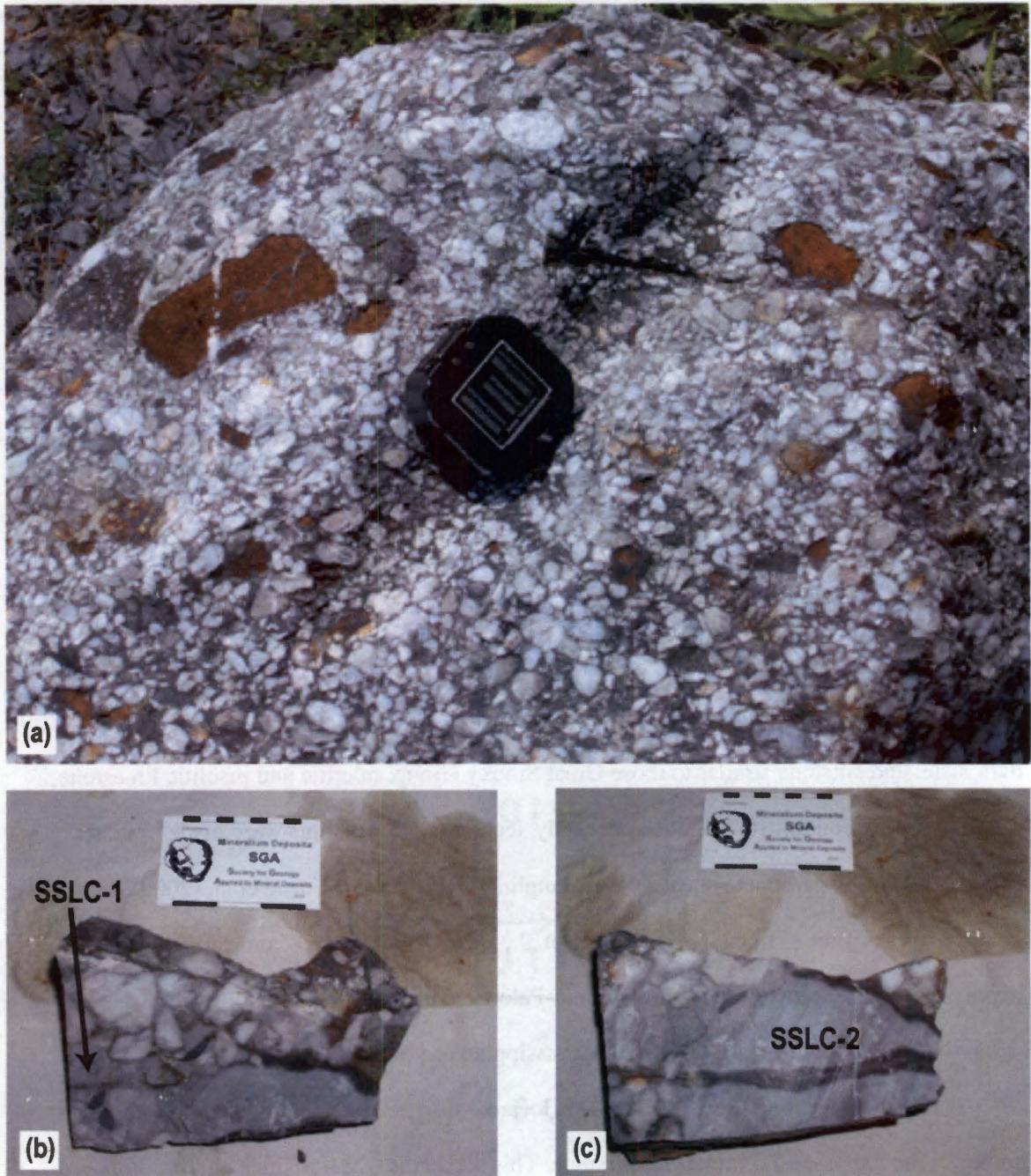


Figure 4-5. Polymictic conglomerate of the Sandsuck Formation from Locality 1 at Chilhowee Dam. (a) Sandsuck Formation conglomerate is dominated by vein quartz clasts. Large carbonate clasts are weathered orange-red. Compass (~9 cm wide) for scale. (b) Sawed sample from Locality 1, showing the location of clast SSLC-1. (c) Sawed slab showing the location of clast SSLC-2, the large gray limestone clast that composes ~65% of the samples.



Figure 4-6. Carbonate lithologies at locality 2 (Citico Quarry). (a) Matrix-supported boulders of pisolitic and micritic carbonate possibly incorporated into a large olistolith block near the top of the exposed section. Sledge hammer for scale ~1 m in length. (b) Characteristic dark-gray, thin- to medium-bedded micritic carbonate with interbedded calcareous siltstone and shale. Field assistant for scale ~1.8 m tall.

Locality 3 (Springtown; Plate 5) is located near Springtown (Servilla), Tennessee in the McFarland 7.5 minute quadrangle. This locality preserves two contrasting Sandsuck Formation carbonate units in the Maggie's Mill fault block. The first is an approximately 10.0 m-thick section of interbedded calcareous siltstone and micritic limestone, but access to the abandoned quarry containing the only well-exposed section was not obtained from landowners. A carbonate breccia, containing 4-5 lithologically distinct carbonate phases as clasts (up to 10 cm in diameter) within a mostly calcite-cemented sandy matrix, is exposed higher in the section approximately 75 m east of the quarry (Fig. 4-7). Petrographic examination revealed matrix surrounding clasts to have approximately equal parts calcite and silica cement. Samples proposed to contain mid-Paleozoic fauna were all obtained from clasts of the carbonate breccia (Unrug et al., 2000).

Locality 4 is located along US 64 in the Ocoee River Gorge (Plate 5). This section is ~5 m thick, and is entirely composed of thin- to medium-bedded, dark-gray micritic limestone and calcareous shale. Quartz and calcite veins, though present, are not abundant. This locality was suggested to contain Paleozoic foraminifera, yet Unrug et al. (2000) provided no detailed description of fossils or lithologies from which they were obtained.

At Localities 2 and 4, the entire carbonate section was measured and described (Fig. 4-8). At Localities 1 and 3, lack of a preserved continuous carbonate section (Locality 1) or lack of access to continuous section (Locality 3) prevented sample collection at prescribed stratigraphic intervals. Instead, carbonate clasts of varied lithologies were sampled from a polymictic conglomerate (Locality 1) and carbonate breccia (Locality 3). Photos taken at each outcrop (Fig. 4-6) show the precise location of collection sites to allow better reproducibility of data in future studies.

Petrographic methods

The preparation and analytical techniques employed by this study to obtain isotopic data are slightly modified from those of Kaufman et al. (1990), Kaufman and Knoll (1995), and

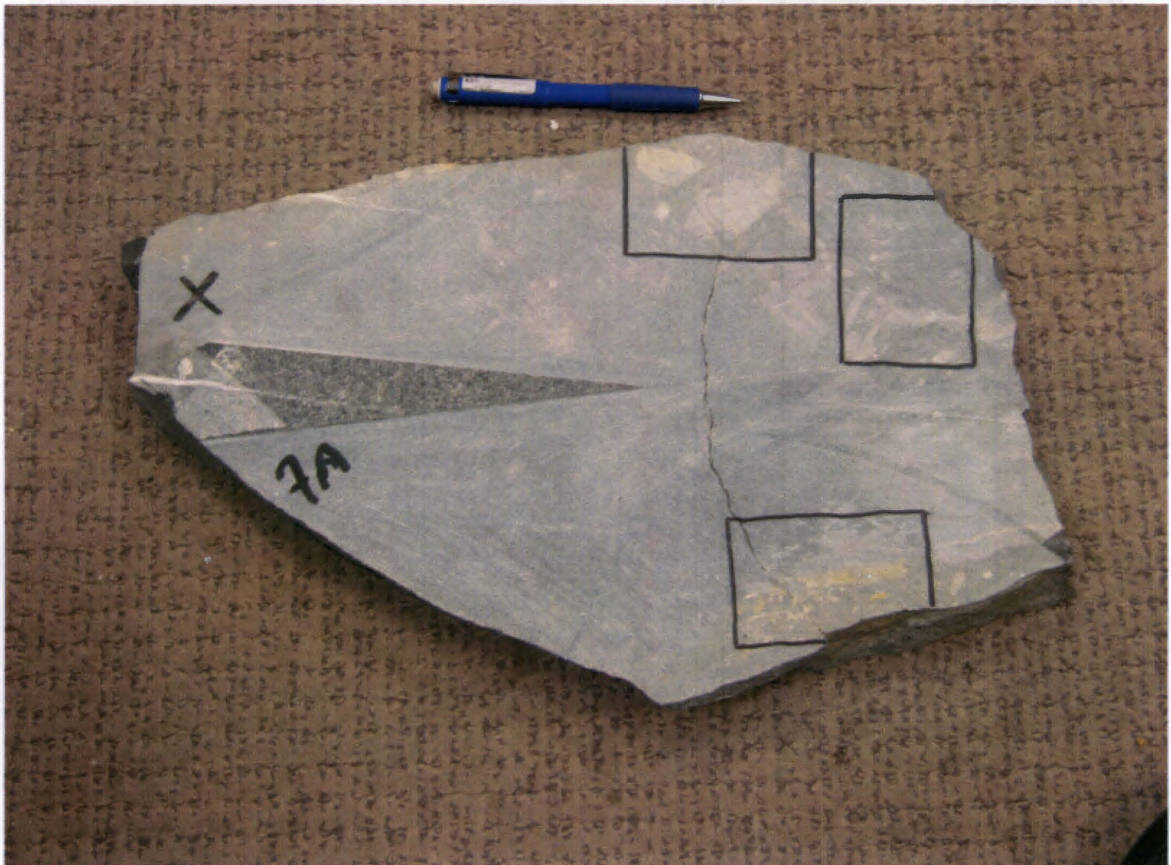


Figure 4-7. Sawed slab of Sandsuck Formation carbonate breccia at Locality 3 (Springtown). Sample regions for petrographic and geochemical analysis are shown in black rectangles. Matrix is dominantly siliclastic grains with calcite and silica cement. Pencil for scale ~18 cm long.

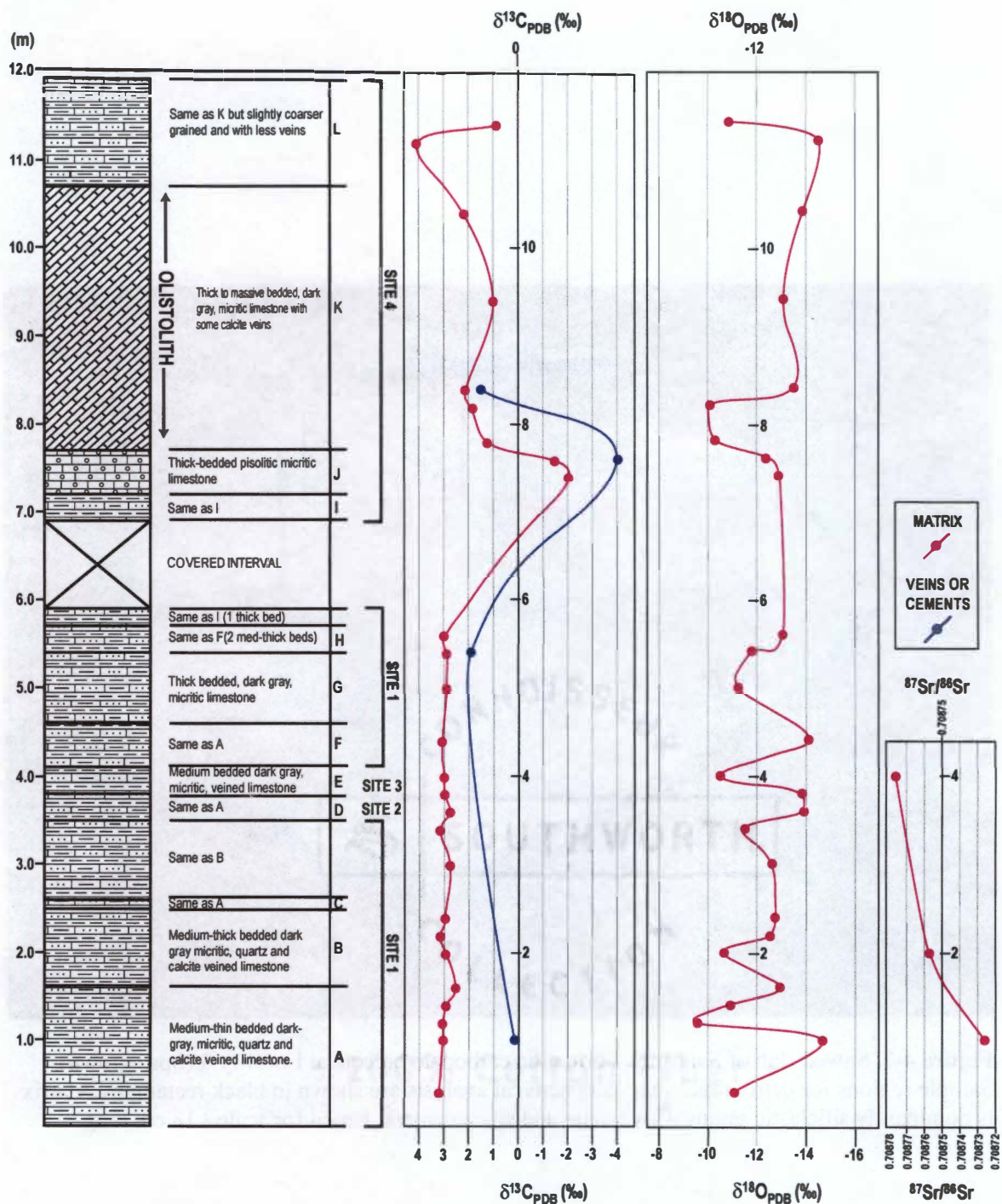


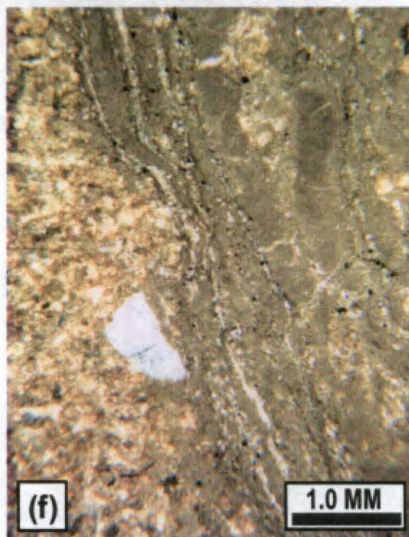
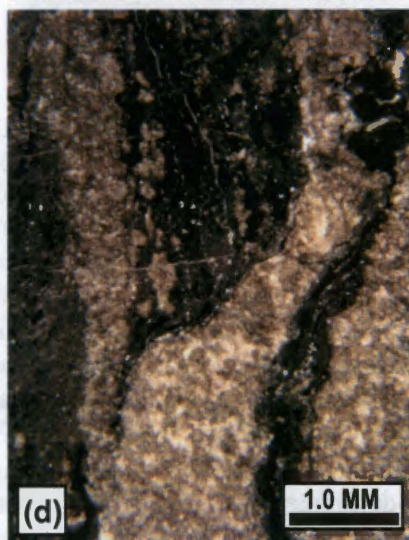
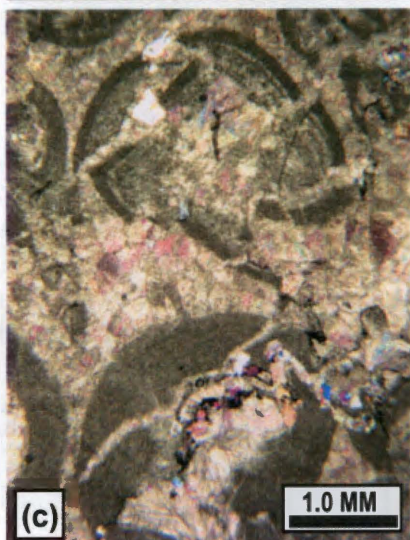
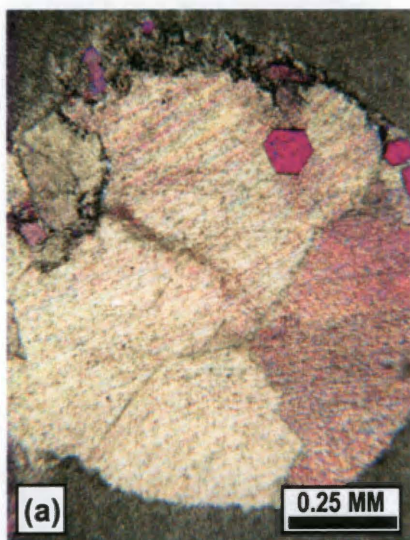
Figure 4-8. Measured stratigraphic carbonate section at Locality 2 (Citico Quarry), with corresponding C, O, and Sr isotope curves. Note $\delta^{13}\text{C}$ variation near 7.5 m interval, where lower $\delta^{13}\text{C}$ values are interpreted to result from alteration of original carbonate isotope values by relatively high fluid rock ratios. Sr values obtained for only three samples.

Kah et al. (1999). Each sample was cut into two mirror-image billets; one thin section chip for petrographic examination and one thick section for cathodoluminescence (CL) examination. Petrographic examination (Fig. 4-9) focused on identifying multiple phases in the thin sections and noting those phases that are likely to retain primary or near primary isotopic compositions (i.e., phases not containing or in close proximity to veins, cement, or other diagenetic fabrics, weathered zones, or any other likely altered carbonate phases; Marshall, 1992; Kaufman and Knoll, 1995).

Prior to CL examination, the thick section was hand polished using 400, 600, and 1000 grit powder on glass polishing plates before receiving a final polish using 0.5 micron powder on an automated polishing wheel. The polishing process focuses on removing saw marks and any remnant surface contamination. After polishing is complete, each sample is placed in a vacuum chamber stage on a petrographic microscope for examination using cathodoluminescence. Under CL, highly luminescent phases result from areas with high concentrations of Mn and low Fe (Hemming et al., 1989), which may suggest diagenetic alteration (Fig. 4-10; Kaufman and Knoll, 1995). Areas of dull luminescence, however, may still be diagenetically altered if excessive quantities of quenching ions (mostly Fe^{2+}) are incorporated during diagenesis (Marshall, 1992).

Petrographic examination reveals variable alteration of carbonate fabrics and all samples reveal some degree of recrystallization. Certainly veins, coarse calcite spar (usually cement), and scattered matrix recrystallization (micrite to sparite) suggests that some alteration of primary fabrics has occurred. Fine- to medium-grained micrite and pisoids with excellent fabric retention and generally dull luminescence (Fig. 4-10a), however, suggest that wholesale recrystallization is not present in all samples. Further, CL examination of contacts between matrix and vein or cement phases mostly reveals sharp boundaries with little evidence for fluid interaction between juxtaposed phases. Thus, phases in each sample petrographically determined to have the highest potential for preserving isotopic values were microdrilled to avoid other unwanted phases.

Figure 4-9. Photomicrographs of carbonate and siliciclastic lithologies of Sandsuck Formation samples. (a) Neomorphic, equant calcite cement partially replaced by euhedral to sub-euhedral quartz in the nucleus of an unlaminated micritic pisolite under cross-polarized light and gypsum plate, Locality 2 (Citico Quarry) . (b) Deformed, concentrically laminated pisolite with nucleus of undulatory monocrystalline quartz being replaced by neomorphic calcite that is usually twinned. Matrix is microspar and minor micrite under cross-polarized light, Locality 2 (Citico Quarry). (c) Concentrically laminated, fractured and deformed pisolites in sparry calcite matrix of a carbonate breccia clast under cross-polarized light and gypsum plate, Locality 3 (Springtown). (d) Micritic limestone clast of carbonate breccia. Micrite shows very thin depositional laminations and pervasive replacement by sparry calcite. Dissolution of micrite concentrated along stylolite surfaces. Cross-polarized light, Locality 3 (Springtown). (e) Concentrically laminated composite pisolite with rounded quartz lithoclast and oolite nuclei being dissolved along lower right edge by a stylolite. Note recrystallization of surrounding micritic matrix focused mostly near stylolites. Cross-polarized light and gypsum plate. Locality 3 (Springtown). (f) Lithologic contact between recrystallized calcite and quartz cement matrix (above) and partially recrystallized, mostly micritic, thinly laminated limestone (below) under cross-polarized light and gypsum plate, Locality 4 (Ocoee Gorge).



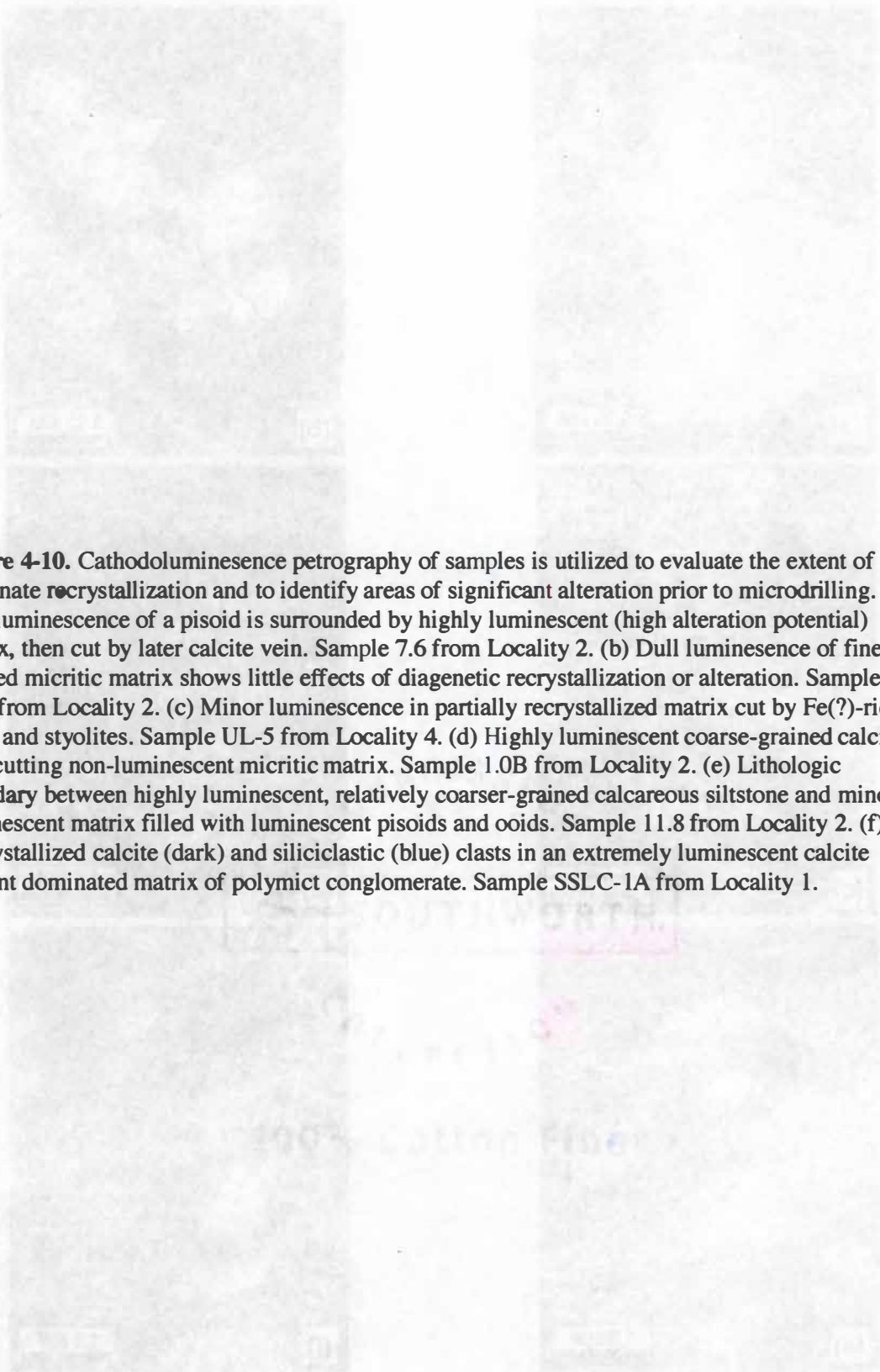
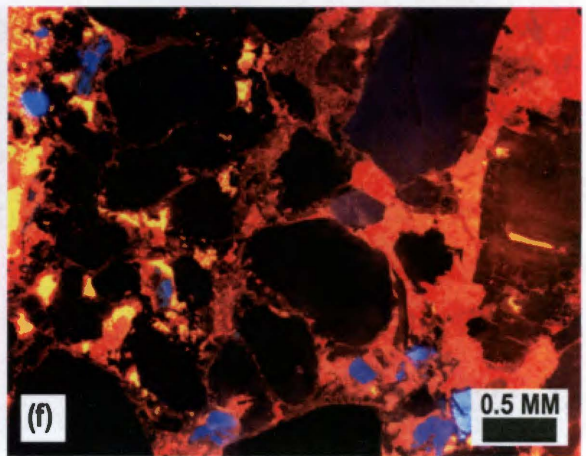
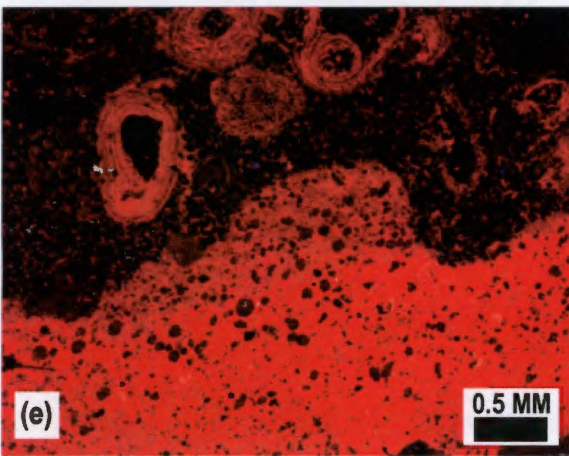
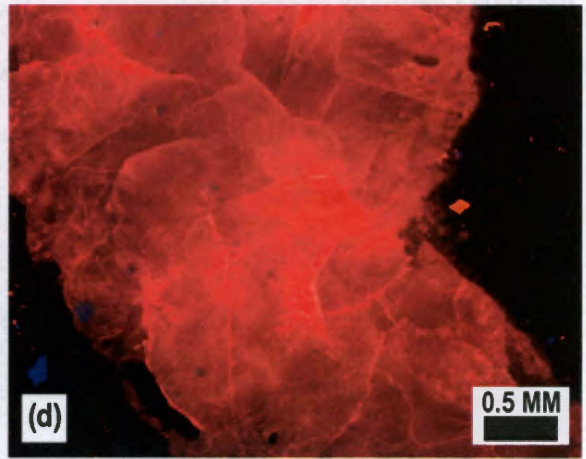
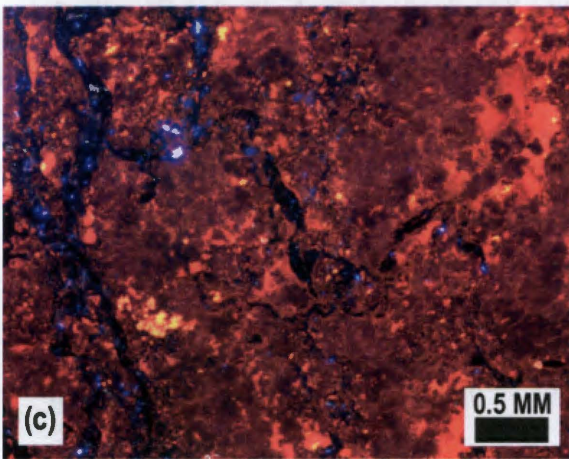
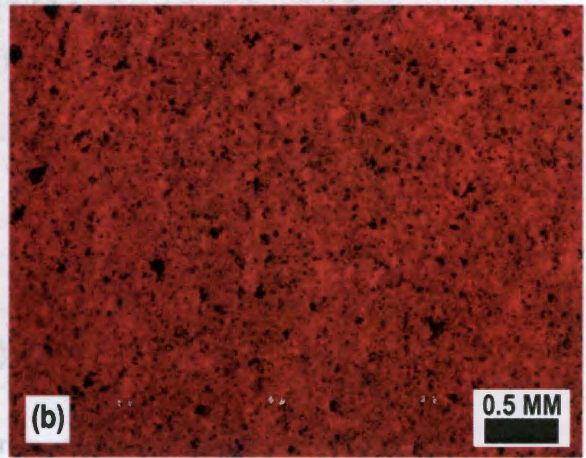
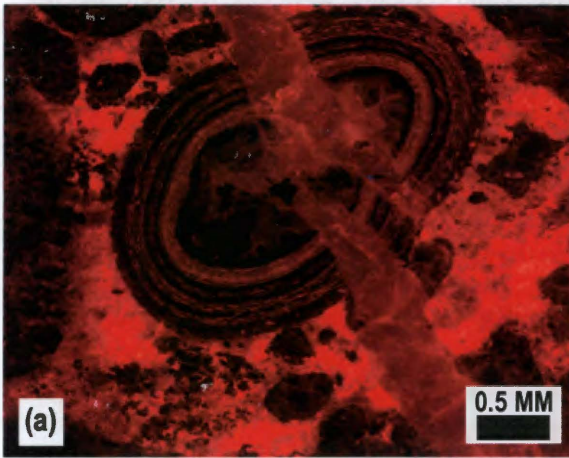


Figure 4-10. Cathodoluminescence petrography of samples is utilized to evaluate the extent of carbonate recrystallization and to identify areas of significant alteration prior to microdrilling. (a) Dull luminescence of a pisoid is surrounded by highly luminescent (high alteration potential) matrix, then cut by later calcite vein. Sample 7.6 from Locality 2. (b) Dull luminescence of fine-grained micritic matrix shows little effects of diagenetic recrystallization or alteration. Sample 7.4A from Locality 2. (c) Minor luminescence in partially recrystallized matrix cut by Fe(?) -rich veins and stylolites. Sample UL-5 from Locality 4. (d) Highly luminescent coarse-grained calcite vein cutting non-luminescent micritic matrix. Sample 1.0B from Locality 2. (e) Lithologic boundary between highly luminescent, relatively coarser-grained calcareous siltstone and minorly luminescent matrix filled with luminescent pisoids and ooids. Sample 11.8 from Locality 2. (f) Recrystallized calcite (dark) and siliciclastic (blue) clasts in an extremely luminescent calcite cement dominated matrix of polymict conglomerate. Sample SSLC-1A from Locality 1.



Additionally, some likely altered phases, such as veins and cements, were also microdrilled for analysis to delimit the geochemical character of those components.

Analytical Methods

Powdered samples from microdrilling were divided into 3 ~5-10 mg splits for major element (Ca, Mg, Fe, Mn, Sr), C and O isotope, and $^{87}\text{Sr}/^{86}\text{Sr}$ isotope analyses, respectively. Powder for major elemental determinations was reacted with ~5 ml 2% HNO_3 , centrifuged to remove the solute, diluted, and analyzed for ppm Ca, Mg, Fe, Mn, and Sr using an ICP-AES at the State University of West Georgia by Dr. Linda C. Kah and Dr. Julie K. Bartley. The dilution effect was compensated in the calculation. Carbonate powders were analyzed for C and O isotopic components using a Finnigan MAT Carboflo common acid bath device for automated analysis of small (2.0-8.0 mg) samples at the University of Tennessee. In this process, samples were reacted with 110% H_3PO_4 at 120° C for ~15 minutes. The evolved gases were then cryogenically purified using an ethanol-dry ice slurry at ~ -80° C and then liquid nitrogen at -170° C to separate water from carbon dioxide. Liberated CO_2 was analyzed by a Finnigan MAT Delta Plus IRMS (dual inlet) where isotope ratios were determined. Standards (ANU-M2) with known $\delta^{13}\text{C}$ (PDB) and $\delta^{18}\text{O}$ (SMOW) values were run prior to and during analysis between every four unknown samples to identify any memory effects imparted by the common acid procedure. $^{87}\text{Sr}/^{86}\text{Sr}$ analyses were performed by Dr. Paul D. Fullagar using a VG Sector 54 mass spectrometer, in the Department of Geological Sciences at the University of North Carolina, Chapel Hill. $^{87}\text{Sr}/^{86}\text{Sr}$ values are reported relative to 0.710250 for standard NBS-987.

ANALYTICAL RESULTS

All results from major element and isotopic analysis are shown in Table 1. $\delta^{13}\text{C}_{\text{PDB}}$ values for the four sample localities range from 5.87‰ for micritic limestone at Locality 4 to -6.46‰ for limestone clasts in the carbonate breccia at Locality 3. Clasts from Locality 3 also exhibit

Table 1. Isotopic and major element analyses for Sandsuck Formation carbonates.

LOCALITY 1 (CHILHOWEE DAM)

Sample	$\delta^{13}\text{C}_{\text{PDB}}$	% Error	$\delta^{18}\text{O}_{\text{PDB}}$	% Error	$^{87}\text{Sr}/^{86}\text{Sr}$	% Error	Ca (ppm)	Mg (ppm)	Mg/Ca	Mn (ppm)	Fe (ppm)	Sr (ppm)	Mn/Sr	Mn/Fe	Lithology	Notes
SSLC-1A	-4.98	NA	-17.70	NA	NA	NA	370346	1477	0.00	17619	8545	1667	10.56869	2.06196	sparte cement	qtz-feldspar dominated clast w/ cc cem.
SSLC-2A	-5.54	NA	-18.14	NA	NA	NA	355355	14470	0.04	14280	10844	1511	9.45211	1.31692	micrite clast	sparry calcite filling voids
SSLC-3A	-3.52	NA	-13.14	NA	NA	NA	383206	3352	0.01	5388	5858	1435	3.75584	0.91969	micrite-polite	replacement sparry calcite
SSM-1A	NA	NA	NA	NA	NA	NA	343015	13232	0.04	9334	27584	3481	2.68129	0.33838	sparte cement	major recrystallization

LOCALITY 2 (CITICO QUARRY)

Sample	$\delta^{13}\text{C}_{\text{PDB}}$	% Error	$\delta^{18}\text{O}_{\text{PDB}}$	% Error	$^{87}\text{Sr}/^{86}\text{Sr}$	% Error	Ca (ppm)	Mg (ppm)	Mg/Ca	Mn (ppm)	Fe (ppm)	Sr (ppm)	Mn/Sr	Mn/Fe	Lithology	Notes
CQ-0.4	3.184	0.020	-11.031	0.023	NA	NA	387649	5603	0.01	110	2808	2573	0.04265	0.03907	micrite	minor recrystallization
CQ-1.0A	3.017	0.016	-14.646	0.019	0.708726	0.0009	389247	1767	0.00	105	2098	6389	0.01639	0.04990	micrite	
CQ-1.0B	0.151	0.018	-14.764	0.013	NA	NA	369295	9387	0.03	179	2578	16349	0.01097	0.06957	calcite vein	
CQ-1.2	3.042	0.022	-9.543	0.018	NA	NA	379040	12266	0.03	286	1640	3954	0.07238	0.17449	micrite	fine-grained, dull
CQ-1.4	2.908	0.027	-10.923	0.028	NA	NA	391611	1440	0.00	128	1891	4611	0.02771	0.06755	micrite	fine-grained, dull
CQ-1.6	2.527	0.025	-12.912	0.017	NA	NA	386430	1407	0.00	270	5510	5968	0.04521	0.04810	micrite	fine-grained, dull
CQ-2.0	2.930	0.028	-10.648	0.030	0.708757	0.0008	377840	11749	0.03	282	2358	5054	0.05575	0.11947	coarse micrite	microveins unavoidable
CQ-2.2	3.134	0.026	-12.551	0.025	NA	NA	394133	578	0.00	106	1588	3468	0.03054	0.06667	micrite	homogenous, dull
CQ-2.4	2.936	0.025	-12.712	0.034	NA	NA	391594	1206	0.00	198	422	6313	0.03132	0.06857	coarse micrite	little recrystallization, dull
CQ-3.0	2.734	0.029	-12.593	0.033	NA	NA	384642	6588	0.02	92	828	3910	0.02359	0.11132	micrite	minor (5%) qtz grains
CQ-3.4	3.145	0.015	-11.496	0.016	NA	NA	392245	536	0.00	52	1857	5191	0.00998	0.02791	micrite	fine-grained, dull
CQ-3.6	2.734	0.023	-13.902	0.027	NA	NA	391174	1472	0.00	144	2059	4824	0.02975	0.06971	micrite	moderate recrystallization, microveins
CQ-3.8	2.957	0.010	-13.804	0.015	NA	NA	388023	1998	0.01	198	3332	6000	0.03303	0.05947	coarse micrite	unavoidable lumin. clasts, microveins
CQ-4.0	2.987	0.025	-10.471	0.027	0.708776	0.0007	395489	0	0.00	74	699	3739	0.01967	0.10526	micrite	minor recrystallization
CQ-4.4	3.058	0.018	-14.076	0.018	NA	NA	389194	1355	0.00	103	2320	6725	0.01525	0.04420	coarse micrite	moderate recrystallization, microveins
CQ-5.0	2.861	0.016	-11.189	0.013	NA	NA	394272	0	0.00	82	843	4902	0.01711	0.09750	micrite	sharp vein/matrix contact
CQ-5.4A	2.867	0.011	-11.756	0.012	NA	NA	389590	1454	0.00	127	2841	5614	0.02262	0.04471	coarse micrite	
CQ-5.4B	1.890	0.011	-13.467	0.022	NA	NA	370427	11986	0.03	214	3458	11101	0.01931	0.06200	calcite vein	
CQ-5.6	2.955	0.023	-13.025	0.026	NA	NA	394387	275	0.00	85	635	4557	0.01871	0.13420	micrite	minor (5%) qtz grains
CQ-7.4	-2.057	0.021	-12.867	0.026	NA	NA	391011	4107	0.01	2084	125	1759	1.18428	16.62069	micrite	homogenous, dull-moderate lumin.
CQ-7.6A	-1.484	0.018	-12.434	0.022	NA	NA	393854	940	0.00	1038	831	3128	0.33193	1.24887	sparte cement	very luminescent
CQ-7.6B		0.027	-12.643	0.033	NA	NA	389920	2603	0.01	577	4155	2165	0.26667	0.13225	coarse clast	moderately luminescent
CQ-7.8	1.225	0.010	-10.259	0.013	NA	NA	393180	1893	0.00	1508	126	2873	0.52499	11.95000	coarse, pisolitic	heterogenous, abundant veins
CQ-8.2	1.805	0.005	-10.097	0.012	NA	NA	390430	2786	0.01	2061	644	3258	0.63255	2.44114	coarse, pisolitic	heterogenous, abundant veins
CQ-8.4A	2.093	0.010	-13.490	0.013	NA	NA	391609	1857	0.00	301	1990	4075	0.07398	0.15154	coarse sparite	lumin. fractures b/c crystals
CQ-8.4B	1.488	0.025	-10.086	0.034	NA	NA	378509	14079	0.04	325	663	3189	0.10187	0.48980	coarse sparite	heterogenous, abundant veins
CQ-9.4	0.987	0.015	-13.060	0.023	NA	NA	394150	631	0.00	641	418	4020	0.15934	1.53208	sparte cement	mostly recrystallized
CQ-10.4	2.154	0.019	-13.834	0.029	NA	NA	392609	1530	0.00	181	516	4825	0.03761	0.35169	coarse micrite	dull lumin.
CQ-11.2	4.052	0.022	-14.476	0.023	NA	NA	395825	0	0.00	578	442	3155	0.18330	1.30909	micrite	fine-grained, few microveins
CQ-11.4	0.846	0.011	-10.858	0.019	NA	NA	396183	0	0.00	382	399	3036	0.12589	0.95676	coarse micrite	homogenous, microveins
CQ-11.6	-1.528	0.069	-12.002	0.139	NA	NA	379853	12685	0.03	303	813	3441	0.08805	0.37283	sparte/micrite	heavily recrystallized
CQ-11.8	0.436	0.008	-9.166	0.019	NA	NA	392261	3078	0.01	577	157	3245	0.17773	3.68376	coarse, pisolitic	heterogenous, moderate recrystallization

Table 1 (Continued).

LOCALITY 3 (SPRINGTOWN BRECCIA)

sample	$\delta^{13}\text{C}_{\text{PDB}}$	% Error	$\delta^{18}\text{O}_{\text{PDB}}$	% Error	$^{87}\text{Sr}/^{86}\text{Sr}$	% Error	Ca (ppm)	Mg (ppm)	Mg/Ca	Mn (ppm)	Fe (ppm)	Sr (ppm)	Mn/Sr	Mn/Fe	Lithology	Notes
B-3A-A	0.906	0.017	-13.792	0.020	0.708834	0.0008	NA	NA	NA	NA	NA	NA	NA	NA		
B-3A-B	-6.456	0.033	-13.503	0.033	0.708895	0.0007	NA	NA	NA	NA	NA	NA	NA	NA		
B-3A-C	1.923	0.027	-12.850	0.032	0.708816	0.0008	NA	NA	NA	NA	NA	NA	NA	NA		
B-4A	-6.324	0.015	-10.734	0.015	0.708947	0.0008	NA	NA	NA	NA	NA	NA	NA	NA		
B-5A-A	1.087	0.023	-14.218	0.033	0.708820	0.0008	NA	NA	NA	NA	NA	NA	NA	NA		
B-5A-B	-3.720	0.018	-12.54	0.035	0.708836	0.0007	NA	NA	NA	NA	NA	NA	NA	NA		
B-5B-A	-4.864	0.022	-13.292	0.025	0.708843	0.0008	NA	NA	NA	NA	NA	NA	NA	NA		
A-1B	0.009	0.012	-13.997	0.020	0.708893	0.0007	NA	NA	NA	NA	NA	NA	NA	NA		
B-1A-A	-2.391	0.009	-12.307	0.025	0.708887	0.0007	NA	NA	NA	NA	NA	NA	NA	NA		
B-1B	-2.648	0.028	-12.713	0.029	0.708899	0.0008	NA	NA	NA	NA	NA	NA	NA	NA		
B-3A	1.378	0.009	-13.439	0.025	0.708813	0.0007	NA	NA	NA	NA	NA	NA	NA	NA		
A-1A-A	-4.897	0.019	-13.527	0.028	0.708801	0.0006	NA	NA	NA	NA	NA	NA	NA	NA		
A-1A-B	-4.258	0.023	-13.102	0.030	0.708911	0.0007	NA	NA	NA	NA	NA	NA	NA	NA		
A-2A	0.642	0.027	-13.095	0.029	0.708894	0.0008	NA	NA	NA	NA	NA	NA	NA	NA		

LOCALITY 4 (COOEE RIVER GORGE - US 64)

sample	$\delta^{13}\text{C}_{\text{PDB}}$	% Error	$\delta^{18}\text{O}_{\text{PDB}}$	% Error	$^{87}\text{Sr}/^{86}\text{Sr}$	% Error	Ca (ppm)	Mg (ppm)	Mg/Ca	Mn (ppm)	Fe (ppm)	Sr (ppm)	Mn/Sr	Mn/Fe	Lithology	Notes
IL-1	5.314	0.010	-16.733	0.015	0.709045	0.0007	396878	594	0.00	279	1401	717	0.38950	0.19943	coarse micrite	moderate recrystallization
IL-2	5.865	0.011	-15.554	0.014	0.70951	0.0008	397780	505	0.00	71	878	656	0.10769	0.08046	coarse micrite	minor recrystallization, microveins
IL-5	5.052	0.019	-14.015	0.021	0.710601	0.0006	394513	3074	0.01	97	1199	439	0.22179	0.08120	micrite	
IL-7	4.704	0.029	-14.228	0.067	NA	NA	392911	1386	0.00	125	4606	665	0.18750	0.02708	micrite	minor (5%) quartz grains

the greatest range of $\delta^{13}\text{C}$ observed at any locality (-6.46‰ to 1.38‰). Locality 4 revealed both the most positive values and also the narrowest range of $\delta^{13}\text{C}$ variation (4.70‰ to 5.87‰). $\delta^{13}\text{C}$ values of carbonate clasts from Locality 1 range from -5.54‰ to -3.52‰ , representing the most consistently ^{13}C depleted samples in the study. Locality 2, which represents the most complete and thickest carbonate section analyzed, revealed $\delta^{13}\text{C}$ values ranging from -4.02‰ to 4.05‰ . The lower value, however, was obtained from a calcite vein sampled to document $\delta^{13}\text{C}$ compositions of possible sources of alteration (calcite veins) as a control. The lowest $\delta^{13}\text{C}$ value obtained from a matrix sample at Locality 2 is -2.06‰ .

Results of $^{87}\text{Sr}/^{86}\text{Sr}$ analysis, limited to selected samples from Localities 2, 3, and 4, range from 0.708726 at Locality 2 to 0.710601 at Locality 4. Locality 4 exhibits the greatest variability of any locality, with $^{87}\text{Sr}/^{86}\text{Sr}$ ranging from 0.709045 to 0.710601. Most notable is the limited range of $^{87}\text{Sr}/^{86}\text{Sr}$ values from carbonate breccia clasts at Locality 3 (0.708801 to 0.708899).

EVALUATION OF POST-DEPOSITIONAL FLUID INTERACTION (ALTERATION)

Post-depositional alteration associated with fluid-rock interactions has the ability to alter primary isotopic and elemental abundances of rocks. The approximate or relative degree of alteration should be assessed as a means of reporting the least altered depositional values. Taylor (1977), Haskin (1984), and Nablelek (1987) developed equations based on mass balance relationships, fluid-rock distribution coefficients, and isotope fractionation factors to quantify the chemical evolution of fluids during mineral-fluid interactions. Banner and Hanson (1990) synthesized previous fluid-rock interaction studies (Banner et al., 1988; Meyers, 1989; Montanez and Read, 1989; Gao, 1990) into a comprehensive study outlining the theory and calculation of expected variations of isotopic and trace element concentrations during water-rock interaction, with particular emphasis on carbonate diagenesis. The variables that control the geochemical composition of diagenetic carbonates are original composition of the sediment, the amount of fluid present in the system compared to the amount of rock, fluid-rock distribution coefficients, whether the system exhibits open or closed behavior, rock porosity, and isotope fractionation

factors. Based on modeling results, established variation trends (Banner and Hanson, 1990) allow construction of covariation diagrams displaying recognized changes in absolute abundance of trace and major elements, as well as isotopic variation with increasing water-rock interaction during diagenesis. Thus, sample values plotted on covariation diagrams model expected evolution of C, O, and Sr isotopic values during fluid-rock interaction and may provide additional insight for understanding the potential for alteration in a given suite of samples. Even so, samples indicated by petrographic examination, CL analysis, and covariation discrimination to have little or no potential for alteration, still may not represent primary isotopic values.

Covariation diagrams of each sample locality show a range of possible diagenetic alteration. Because $^{87}\text{Sr}/^{86}\text{Sr}$ analysis was not done at Locality 1 and major element analysis was not done for locality 3, only two diagrams could be constructed for each of these localities. Various investigators (Banner and Hanson, 1990; Kaufman and Knoll, 1995; Jacobsen and Kaufman, 1999) have suggested that the Mn/Sr ratio is generally a good indicator of the degree of diagenetic alteration, because marine calcites are commonly enriched in Sr while diagenetic carbonates are commonly enriched in Mn. According to Jacobsen and Kaufman (1999), a Mn/Sr value < 2 often indicates little alteration of carbon isotope ratios, although they noted that even at relatively low Mn/Sr values (~ 1), large shifts in isotopic values may have taken place. Mn/Sr > 2 almost always indicates alteration of Sr isotope compositions. Plots of Mn/Sr values (Fig. 4-11) indicate that samples from Locality 1 (Chilhowee Dam) have a high potential for alteration, while those from localities 2 and 4 (Citico Quarry, Ocoee Gorge) have a relatively low potential for alteration. Taking into account variation of Mn/Sr (x-axis) with respect to $^{87}\text{Sr}/^{86}\text{Sr}$ and $\delta^{13}\text{C}$ values at Localities 1 (no $^{87}\text{Sr}/^{86}\text{Sr}$), 2, and 3 (Figs. 4-12 and 4-13) and $^{87}\text{Sr}/^{86}\text{Sr}$ with respect to $\delta^{18}\text{O}$ values at all Localities 2, 3, and 4 reveals that samples show a large range of possible degrees of alteration (Fig. 4-14).

During diagenesis, both ^{13}C and ^{18}O tend to become depleted, although the abundance of oxygen in water-rich fluids allows ^{18}O in carbonate minerals to exchange with fluid ^{18}O during

Figure 4-11. Mn/Sr values of samples from Chilhowee Dam (Locality 1), Citico Quarry (Locality 2), and Ocoee Gorge (Locality 4). Samples from Citico Quarry and Ocoee Gorge show Mn/Sr well below 2, suggested by numerous studies to indicate little alteration of $\delta^{13}\text{C}$ values. Samples from Chilhowee Dam show extremely high Mn/Sr values, suggesting that they have likely undergone some diagenetic alteration. Samples from Springtown Quarry (Locality 3) are not shown because no Mn/Sr data have been obtained from those

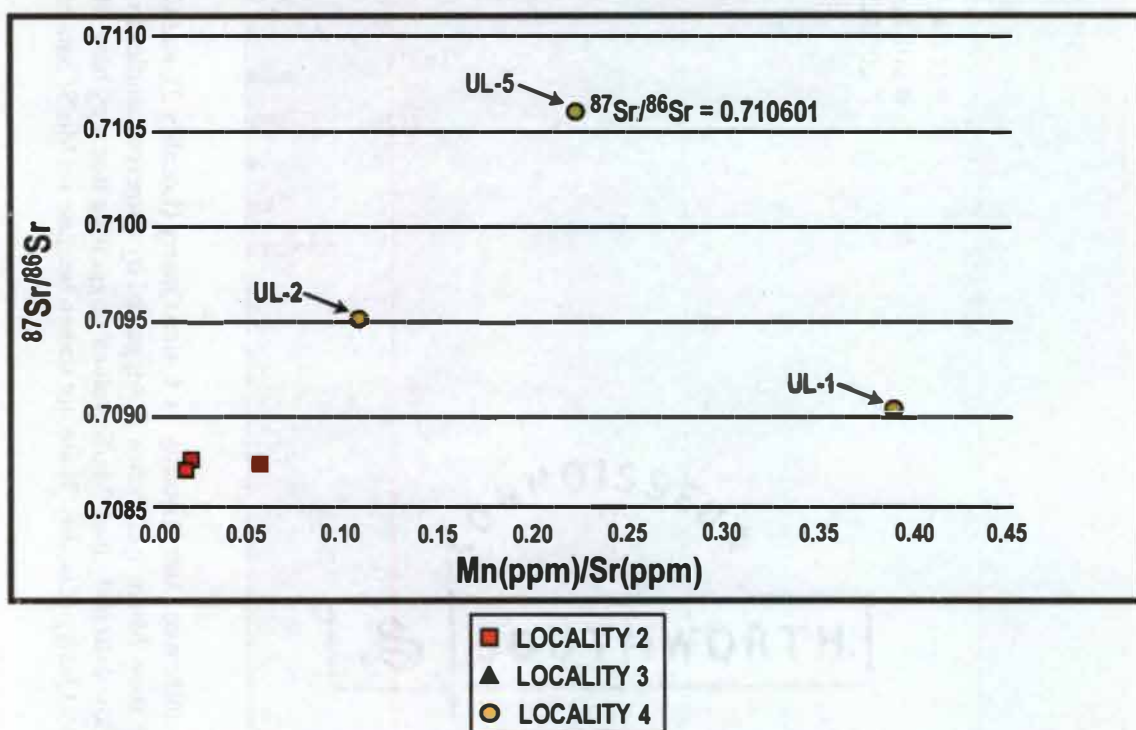


Figure 4-12. $^{87}\text{Sr}/^{86}\text{Sr}$ vs. Mn/Sr covariation diagram. Samples from Citico Quarry (Locality 2) are clustered, and show the least potential for being altered. All three samples from Ocoee Gorge (Locality 4; UL-1, UL-2, UL-5) exhibit the highest potential for alteration of $^{87}\text{Sr}/^{86}\text{Sr}$, notable since those samples reveal the highest $^{87}\text{Sr}/^{86}\text{Sr}$ values of all samples examined in this study ($^{87}\text{Sr}/^{86}\text{Sr} = 0.709045\text{--}0.710601$).

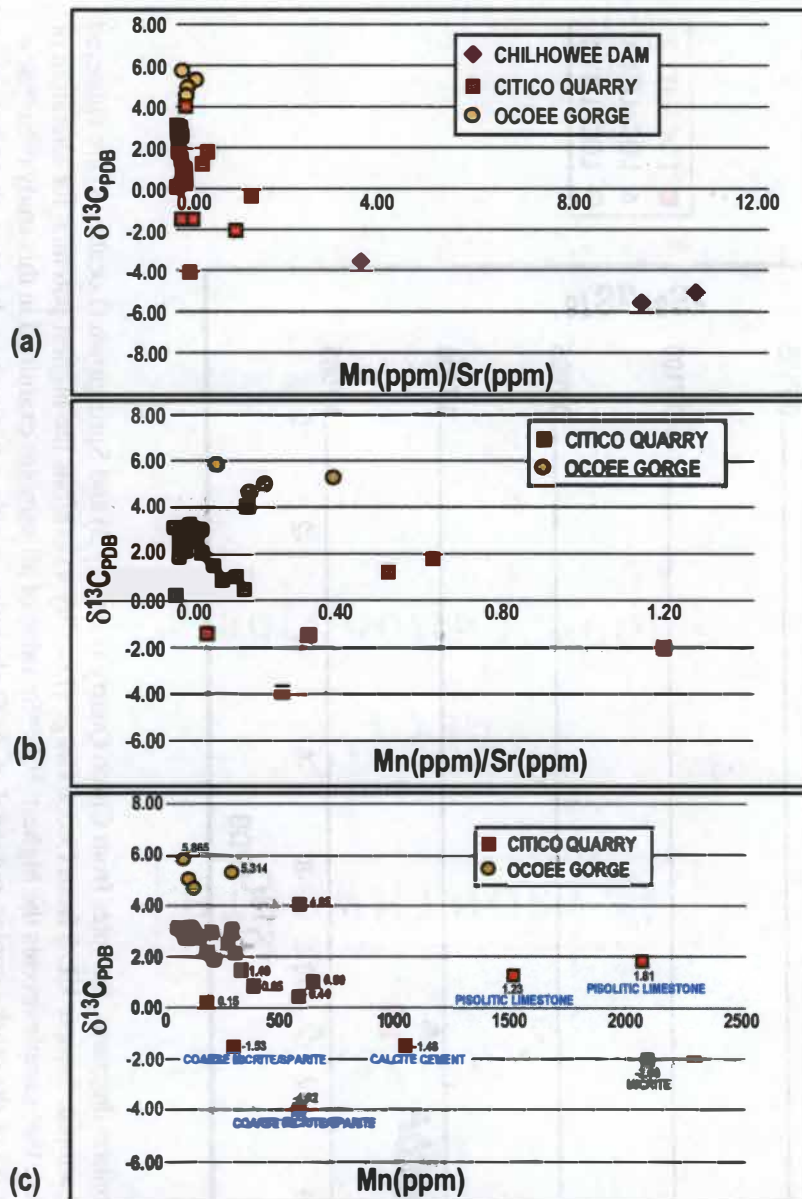


Figure 4-13. $\delta^{13}\text{C}$ vs. Mn/Sr and $\delta^{13}\text{C}$ vs. Mn (ppm) covariation diagrams. During diagenetic alteration, ^{13}C and Sr tend to become depleted, whereas Mn tends to become enriched in carbonate rocks. (a) Plot for samples from Chilhowee Dam (Locality 1), Citico Quarry (Locality 2), and Ocoee Gorge (Locality 4). Samples from Chilhowee Dam show a potential for alteration many orders higher than samples from Citico Quarry or Ocoee Gorge. (b) Plot for samples from Citico Quarry and Ocoee Gorge. Low Mn/Sr and a limited range of $\delta^{13}\text{C}$ values suggests little potential for alteration. (c) Higher levels of total Mn in a sample may be a more useful indicator for determining diagenetic effects because it does not depend on the original Sr content of the carbonate. Note highest alteration potential confined mostly to coarse-grained sparry or pisolitic lithologies and sparry cement phases. Only one micritic sample appears to have a relatively high alteration potential.

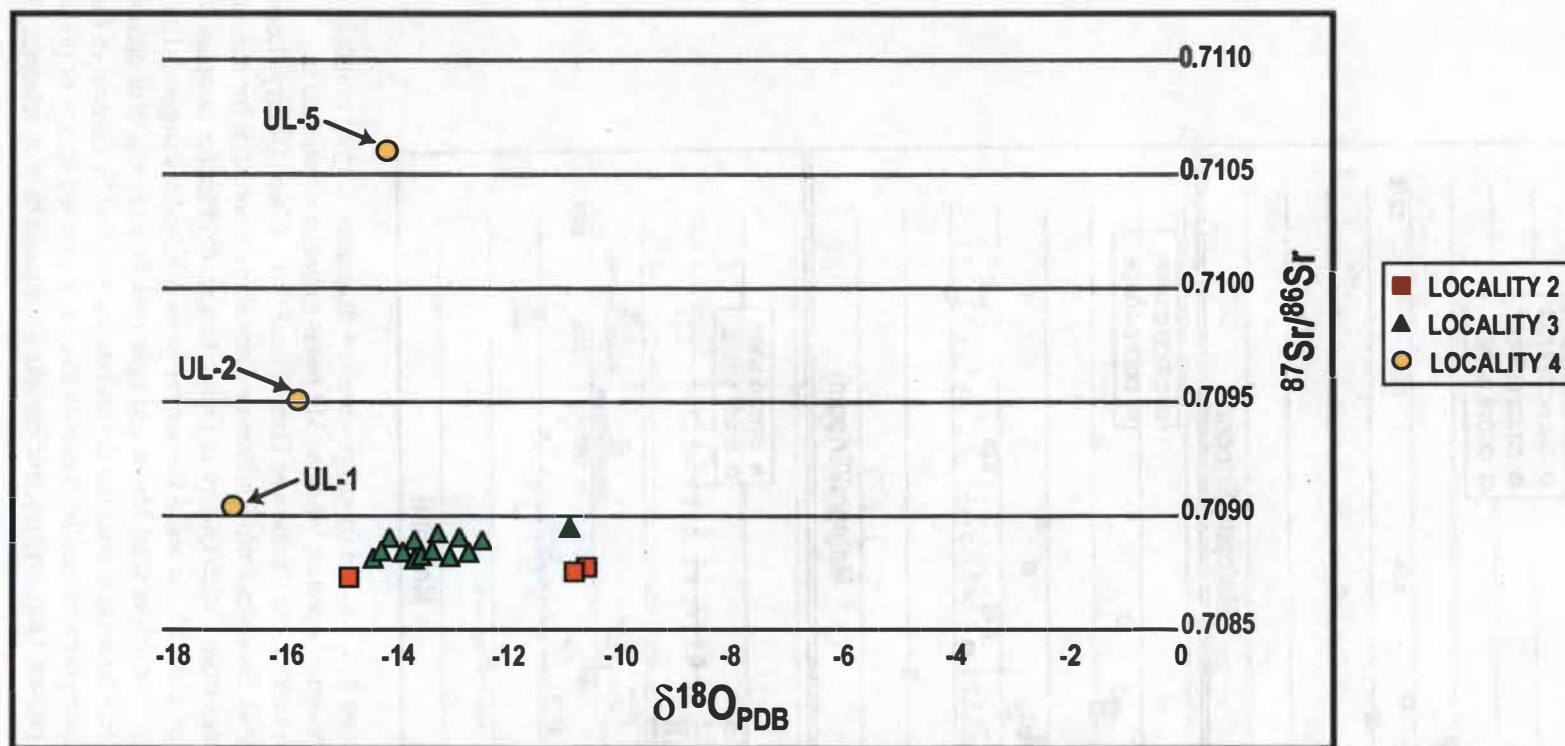


Figure 4-14. $^{87}\text{Sr}/^{86}\text{Sr}$ vs. $\delta^{18}\text{O}$ covariation diagrams. Samples from Citico Quarry (Locality 2) and Springtown (Locality 3) are clustered, and show the least potential for being altered. Sample UL-5 from Ocoee Gorge (Locality 4) exhibits the highest potential for alteration of $^{87}\text{Sr}/^{86}\text{Sr}$, which is worth noting because that sample reveals the highest $^{87}\text{Sr}/^{86}\text{Sr}$ value of all samples examined in this study ($^{87}\text{Sr}/^{86}\text{Sr} = 0.710601$). Because of clustering of most of the other samples, potential of $\delta^{18}\text{O}$ alteration is either minimal or alteration that has occurred is fairly uniform across the range of samples.

carbonate recrystallization at water:rock ratios that are three orders of magnitude lower than that necessary for re-equilibration of $\delta^{13}\text{C}$ by the same fluid (Banner and Hanson, 1990). Thus, the rate of decrease of $\delta^{18}\text{O}$ typically is much greater than that of $\delta^{13}\text{C}$. $\delta^{18}\text{O}$ - $\delta^{13}\text{C}$ covariation diagrams reveal that Localities 1 and 3 show a much higher alteration potential with respect to C and O isotopic values than Locality 4 and most samples from Locality 2 (Fig. 4-15). Locality 2 produced a trend very similar to that observed in fluid interaction models (Fig. 4-15; Banner and Hanson, 1990; Derry et al., 1992). Samples from Locality 4 with the least likely altered C isotope values (Fig. 4-15) are notably different from those indicated in Figure 4-12, which may suggest that although Sr isotopic values have a high alteration potential at Locality 4, the extent of diagenetic alteration may have been insufficient to significantly alter $\delta^{13}\text{C}$ values of those samples. Low Mn/Sr ratios (0.10769-0.38950) and Mn/Sr- $\delta^{13}\text{C}$ covariation diagram trends of samples from Locality 4 further support interpretations of limited diagenetic alteration of $\delta^{13}\text{C}$ values from those samples. $^{87}\text{Sr}/^{86}\text{Sr}$ values from Locality 4, however, should be considered suspect. A covariation plot of Mn(ppm)- $\delta^{13}\text{C}$ was also constructed since a high degree of internal variability in total Sr (1,759-1,6349 ppm) with respect to the Locality 2 suite and external variability with respect to the other three sample localities may create inconsistency for interpretation of Mn/Sr values. For example, sample CQ-11.8 from Locality 2 has a Mn/Sr value of 0.17773, with a total Mn(ppm) of 577. Sample UL-7 from Locality 4 has a similar Mn/Sr value of 0.18750, yet the Mn(ppm) = 125. Thus, significant differences in Mn(ppm) possibly related to diagenetic alteration cannot always be deduced from Mn/Sr values. Instead, the similar Mn/Sr value is related to the notable differences in primary Sr(ppm) values of each respective limestone (CQ-11.8 = 3245, UL-7 = 665).

Based on interpretation of covariation diagrams, samples from Localities 4 (Ocoee Gorge) and most samples from Locality 2 (Citico Quarry) reveal the least potential for alteration of $\delta^{13}\text{C}$. Samples from Locality 3 (Springtown) reveal moderate potential for alteration of $\delta^{13}\text{C}$, while those from Locality 1 (Chilhowee Dam) reveal the greatest potential for alteration of $\delta^{13}\text{C}$.

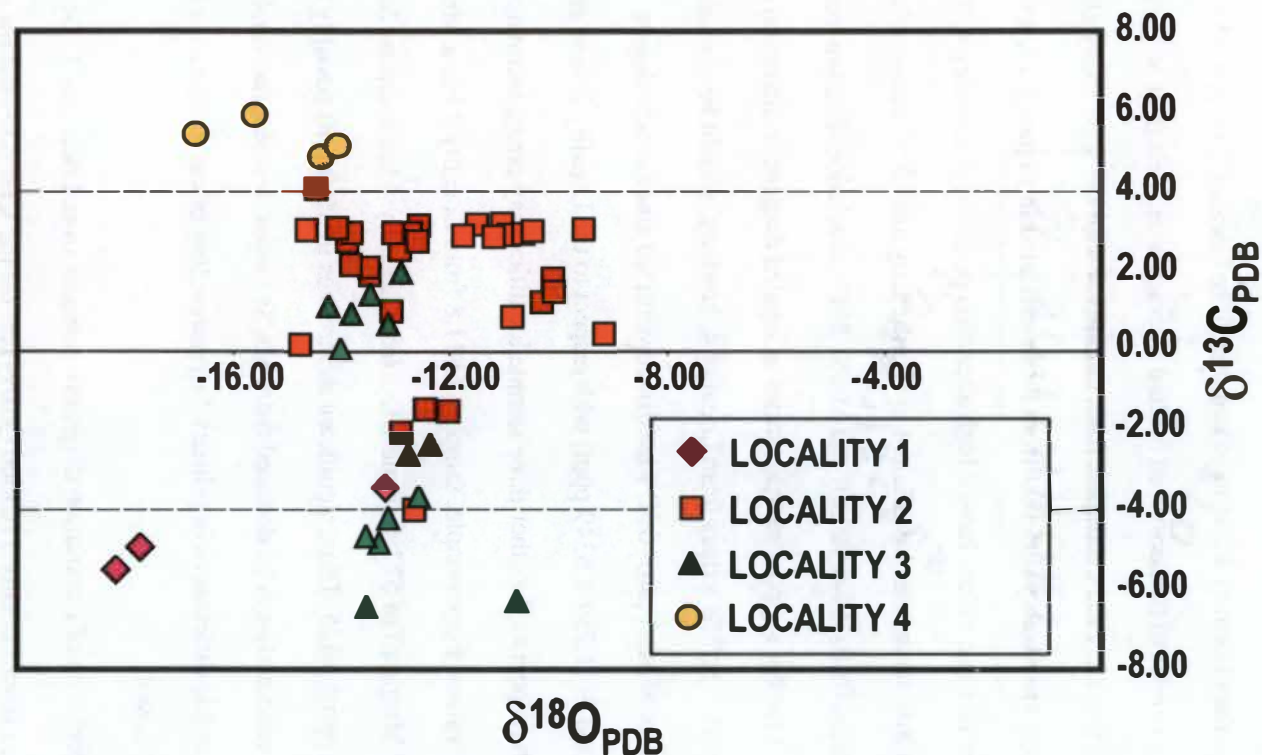


Figure 4-15. $\delta^{13}\text{C}$ vs. $\delta^{18}\text{O}$ covariation diagram. During diagenesis, $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ tend to become more negative. Samples from Citico Quarry (Locality 2) are clustered, and show the least potential for being altered. Samples from Ocoee Gorge (Locality 4; UL-1, UL-2, UL-5) exhibit moderately low potential for alteration of $\delta^{13}\text{C}$, but higher potential for alteration of $\delta^{18}\text{O}$, which is notable since those samples reveal the highest $\delta^{13}\text{C}$ values of all samples examined in this study. Samples from Springtown (Locality 3) seem to present a range of alteration potential, with none being near primary. Chilhowee Dam (Locality 1) samples show the greatest potential for alteration.

With respect to $^{87}\text{Sr}/^{86}\text{Sr}$, samples from Localities 2 and 3 (Citico Quarry, Springtown) present the least potential for alteration, while samples from Locality 4 (Ocoee Gorge), especially the highest $^{87}\text{Sr}/^{86}\text{Sr}$ value recognized in this study (UL-5, $^{87}\text{Sr}/^{86}\text{Sr} = 0.710601$), present moderate to high potential for alteration.

DISCUSSION

Comparison of $\delta^{13}\text{C}$ and $^{87}\text{Sr}/^{86}\text{Sr}$ values with established Neoproterozoic and Phanerozoic C and Sr curves (Fig. 4-16 and 4-17), with special attention afforded to Precambrian-Cambrian boundary and Silurian-Mississippian time intervals, reveals a number of notable observations.

Samples from Locality 1 (Chilhowee Dam) are isotopically (^{13}C) constrained to Neoproterozoic intervals defined by termination of widespread glacial events, such as the Sturtian and Varanger glaciations, as well as a period of extremely low $\delta^{13}\text{C}$ at about 540 Ma (near Precambrian-Cambrian boundary). No preserved values as low as those exhibited by samples from Locality 1 are recognized in the Phanerozoic. Samples from Locality 3 (Springtown) exhibit $\delta^{13}\text{C}$ values recognized during Neoproterozoic glaciations and near the Precambrian-Cambrian boundary. In the Phanerozoic, values consistent with those of Locality 3 are recognized from the earliest Cambrian to the latest Ordovician, and from the earliest Devonian to the latest Devonian. $^{87}\text{Sr}/^{86}\text{Sr}$ values at Locality 3 are similar to values recognized from the Precambrian-Cambrian boundary until the end of the Silurian. According to Unrug et al. (2000), microfaunal suites from Locality 3 suggest a Silurian-Devonian age based on an ostracode and phosphatic brachiopod valves. Samples from Localities 1 and 3, however, show convincing evidence of isotopic alteration during diagenesis, and are thus considered inconclusive for age differentiation.

Samples from Locality 2 represent several contrasting lithologies with varying degrees of diagenetic overprinting. Major element and isotopic analyses further suggest that significant geochemical differences exist between the many components of this stratigraphic section. Petrographic examination allowed subdivision of two groups of carbonate phases. Those

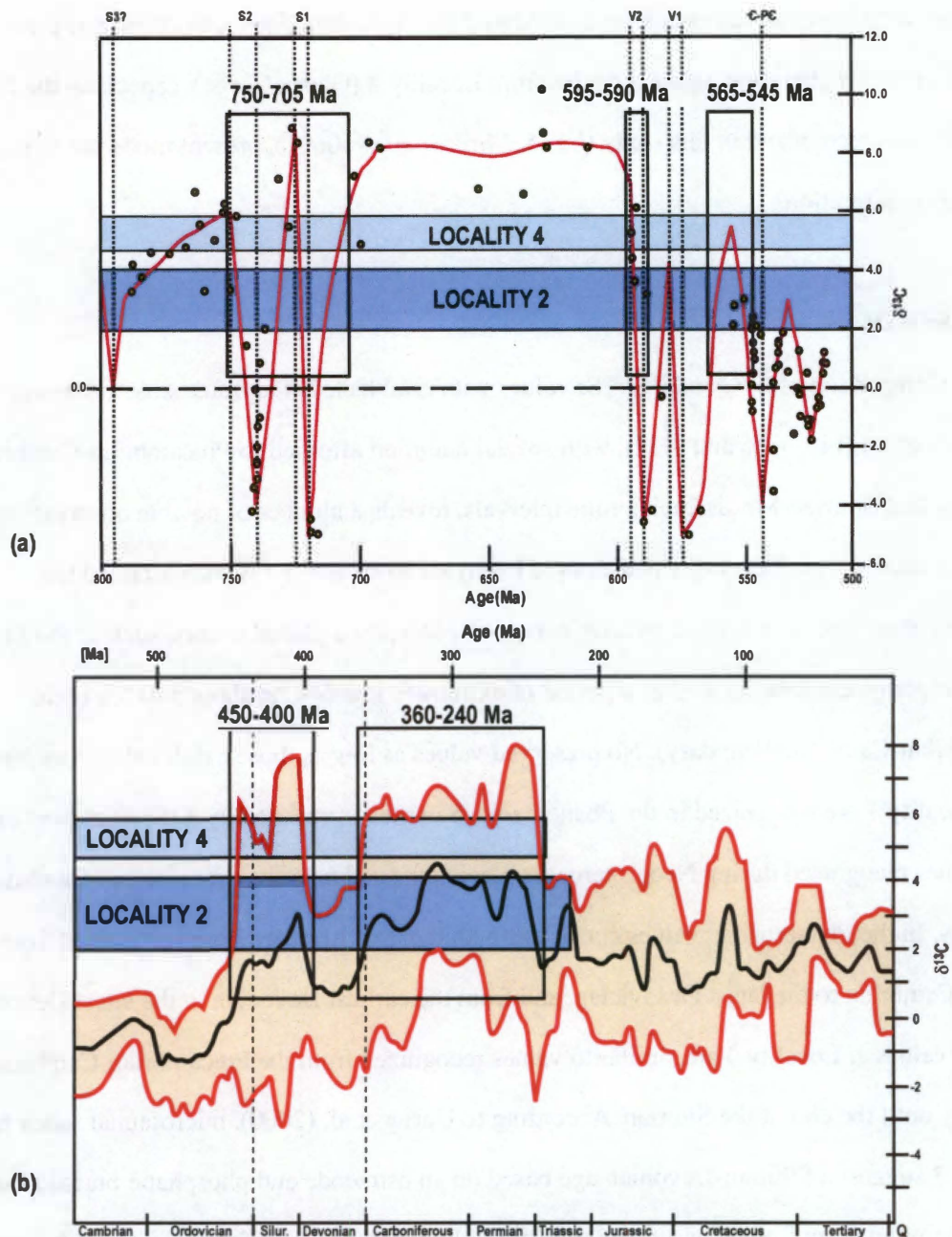


Figure 4-16. Temporal variation of $\delta^{13}\text{C}$ from Early Neoproterozoic-Recent. Blue-shaded boxes indicate range of values obtained at Locality 2 and Locality 4 of this study. (a) Established $\delta^{13}\text{C}$ isotope curve for the Neoproterozoic to Early Cambrian. Extreme positive and negative excursions interpreted to result from periods of extensive glaciation. S3 - possible Sturtian glaciation. S2, S3 - upper and lower Sturtian glaciations. V1, V2 - upper and lower Vendian glaciations. C-PC - Cambrian-Precambrian boundary. Red line based on data from Kaufman and Knoll (1995). Modified from Jacobsen and Kaufman (1999). (b) Phanerozoic $\delta^{13}\text{C}$ trend for LMC (low-magnesium calcite) shells. Black line is running mean. Shaded area around the running mean includes 95% of all data. Modified from Veizer et al. (1999).

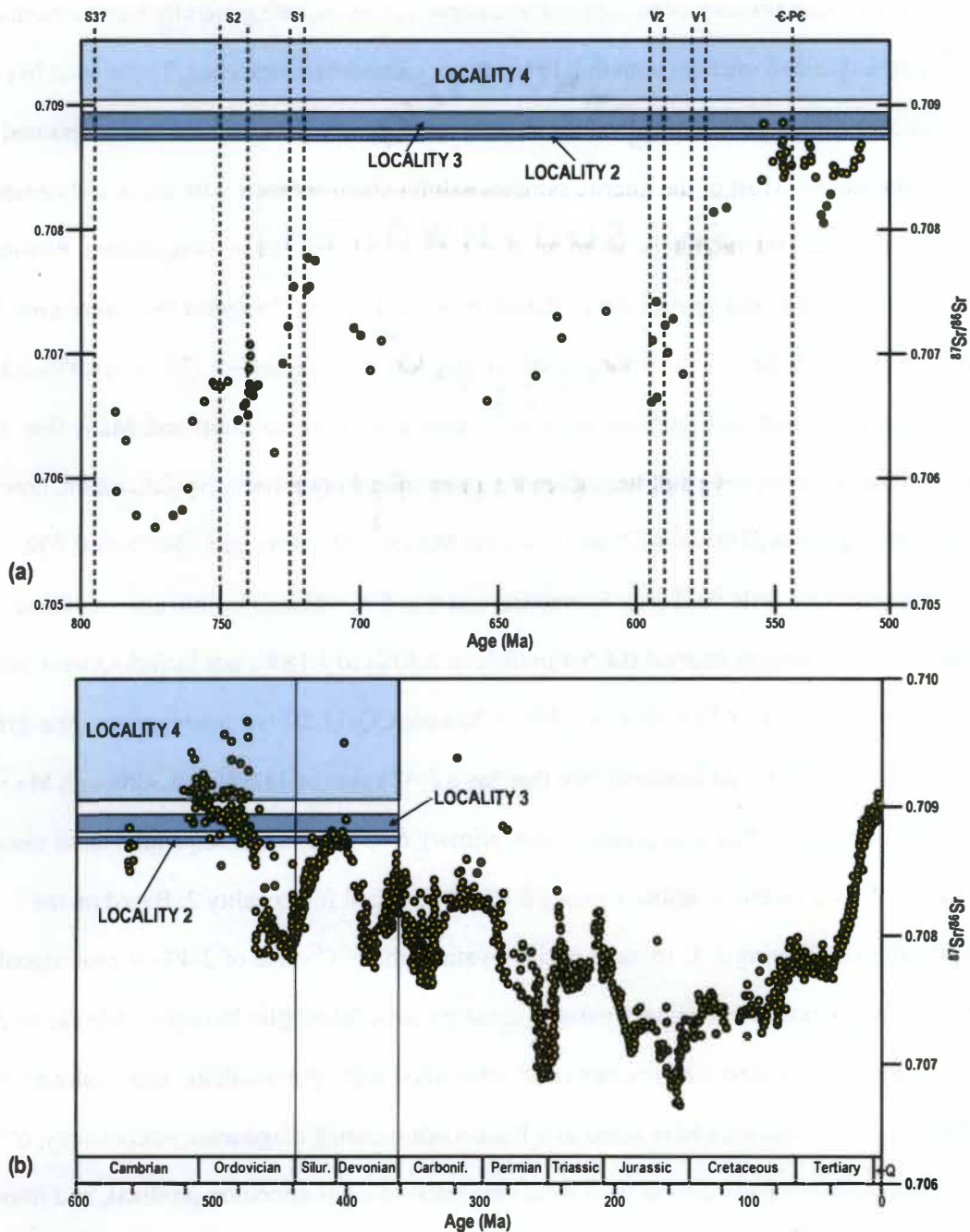


Figure 4-17. Temporal variation of $^{87}\text{Sr}/^{86}\text{Sr}$ from early Neoproterozoic–Recent. Shaded blue boxes represent range of $^{87}\text{Sr}/^{86}\text{Sr}$ values obtained at three sample localities of this study. (a) Established $^{87}\text{Sr}/^{86}\text{Sr}$ isotope curve for the Neoproterozoic to Early Cambrian. Secular variation likely related to Sr flux to the oceans from weathering of continental crust (high $^{87}\text{Sr}/^{86}\text{Sr}$), and input from submarine hydrothermal systems (low $^{87}\text{Sr}/^{86}\text{Sr}$). Symbols S3?, S2, S1, V2, V1, C-PC, same as Fig. 4-3. Modified from Jacobsen and Kaufman (1999). (b) Phanerozoic $^{87}\text{Sr}/^{86}\text{Sr}$ trend based on 4055 brachiopod shells, belemnites, conodonts, and 9 samples of micrite. Sources of data may be seen in Veizer et al. (1999; pg. 66). Modified from Veizer et al. (1999).

more likely to retain primary or near primary isotopic values include generally homogenous, fine- to coarse-grained micrites with dull to moderate cathodoluminescence. Those least likely to retain near primary geochemical values include veins, sparry cements, and coarse-grained pisolitic limestones. Most of the micrite samples exhibit sharp contacts with veins and cements, suggesting that fluid interaction between micritic matrix and later phases was limited. Evaluation of geochemical trends and petrographic characteristics at Locality 2 suggest that every sample has experienced some degree of alteration, based on very low $\delta^{18}\text{O}$ values (-9.17‰ to 14.48‰) and evidence for very minor to significant recrystallization in all samples examined. Many fine- to coarse-grained micrites have dull luminescence and minimal observed recrystallization, however, have low Mn/Sr ratios (0.009-0.072) and low total Mn (52-286 ppm), and $^{87}\text{Sr}/^{86}\text{Sr} < 0.709$, suggesting relatively little fluid rock interaction and that $\delta^{13}\text{C}$ values are little altered. These samples represent section interval 0.4-5.4 m ($\delta^{13}\text{C} = 2.53\text{‰}$ to 3.18‰ ; not including vein sample CQ-1.0B) and sample CQ-10.4 ($\delta^{13}\text{C} = 2.15\text{‰}$). Sample CQ-11.2B is a homogenous, fine-grained micritic limestone with dull luminescence that has a $\delta^{13}\text{C}$ value of 4.05‰ and, although Mn = 578 ppm for that sample, it may also preserve near primary $\delta^{13}\text{C}$ values. Consequently, these samples (0.4-5.6, 10.4, 11.2) seem to define a strong 2-4‰ $\delta^{13}\text{C}$ signal for Locality 2. Based on the difficult nature of altering $\delta^{13}\text{C}$ to more positive values, the $\delta^{13}\text{C}$ value of 2-4‰ is provisionally interpreted as a depositional value. Coarse-grained pisolitic lithologies have high Mn (up to 2084 ppm), abundant and widespread fractures and veins filled with sparry calcite, and moderate to high luminescence, and may have acted as a fluid conduit during diagenesis. Accordingly, $\delta^{13}\text{C}$ values from these samples (2.09‰ to -4.02‰) are interpreted as alteration products, and must be considered suspect.

Samples from Locality 4 (Ocoee Gorge) possess $\delta^{13}\text{C}$ values similar to those recognized near the 750-720 Ma glaciations (Sturtian 1, 2), the onset of the earliest Varanger glaciation (V2), and just before the Precambrian-Cambrian boundary (~560 Ma). In the Phanerozoic, these values are also observed from the Late Ordovician (~450 Ma) to the Silurian-Devonian boundary

(~400 Ma) and from the latest Devonian (~360 Ma) to the Permian-Triassic boundary (~240 Ma). Significantly elevated $^{87}\text{Sr}/^{86}\text{Sr}$ values from Locality 4, however, are only present from the Late Cambrian to the Ordovician, although petrographic examination and geochemical covariation diagrams suggest that $^{87}\text{Sr}/^{86}\text{Sr}$ values from Locality 4 are likely altered.

$\delta^{13}\text{C}$ values of 2-4‰ are recognized in all five glacial periods of the Neoproterozoic (Sturtian 1, 2, 3; Varanger 1, 2) and on each side of the Precambrian-Cambrian boundary (565-550 Ma, 530-525 Ma). These same values are also recognized from Late Ordovician (~450 Ma) to late Silurian times (400 Ma) and from Late Devonian (~360 Ma) to Triassic (~240 Ma) times. $^{87}\text{Sr}/^{86}\text{Sr}$ values at Locality 2 reveal a range of values recognized from near the Precambrian-Cambrian boundary to latest Silurian-earliest Devonian times. The microfauna of Unrug et al. (2000) constrain the age of rocks at Locality 2 to Silurian or younger, thus indicating that geochemical evidence from this locality is inconclusive with respect to age differentiation. Isotopic evidence does appear to rule out any depositional age between the early Middle Cambrian and Late Ordovician.

CONCLUSIONS

- 1) Samples from localities 2 and 4 that are interpreted to contain the least altered $\delta^{13}\text{C}$ values examined in this study temporally delimit the depositional age of the Sanduck Formation to Neoproterozoic intervals interpreted as the Varanger and Sturtian glaciations, intervals near the Precambrian-Cambrian boundary (~540 Ma), and to Phanerozoic intervals from the Late Ordovician to the Silurian-Devonian boundary (~400 Ma) and from the Late Devonian (~360 Ma) to the Triassic (~240).
- 2) While the results of this study seem to conclusively rule out any depositional age for the Sanduck Formation between the early Middle Cambrian and Late Ordovician,

isotopic data are inconclusive with respect to differentiating Neoproterozoic vs. middle Paleozoic depositional ages.

- 3) The interpreted stratigraphic position of the Sandsuck Formation beneath the Cambrian fossil-bearing Chilhowee Group and Taconic metamorphic age dates of Walden Creek samples support a Neoproterozoic rather than mid-Paleozoic depositional age. Taken together, the stratigraphic, chronological, and geochemical data are all consistent only with a Neoproterozoic depositional age.

CHAPTER V

CONCLUSIONS

- 1) Detailed mapping in the study area indicates that the Anakeesta-Wehutt, Ammons, Dean, and Wilhite Formation form a conformable stratigraphic sequence separated from the Elkmont and Thunderhead Sandstones only by minimal displacement Alleghanian faulting.
- 2) The lithologic and stratigraphic similarities of the Cades Sandstone in the Rabbit Creek thrust sheet and the Dean Formation in the Greenbrier thrust sheet suggest that they are correlative. The Shields Formation shares many lithologic features with the Dean Formation and lies in the same stratigraphic position beneath the Wilhite Formation in the Miller Cove thrust sheet, though the lack of graded beds suggests that the Shields is time transgressive with though depositionally distinct from the Cades and Dean in the study area.
- 3) The Thunderhead Sandstone in the Greenbrier and Hangover Lead thrust sheets represents the lower and upper members of that unit, respectively. The upper member of the Thunderhead is equivalent to the unnamed sandstone in GSMNP and the Copperhill Formation in the core of the Ducktown anticlinorium. The disappearance of the coarser-grained lower member and the increasing prevalence of the upper member to the southwest suggest a dominantly northeastern source of the Elkmont-Thunderhead-Copperhill sequence.
- 4) Like the Thunderhead Sandstone, the Anakeesta Formation in the Greenbrier thrust sheet and Hangover Lead thrust sheets is interpreted as the upper and lower members of that

unit, respectively. The upper member in the Hangover Lead thrust sheet is equivalent to the Wehuttu Formation in the Ducktown anticlinorium and Murphy synclinorium.

- 5) To the north, OSG deposition likely occurred in two separate rift basins divided by a region of basement uplift. To the south, diminution of that uplift allowed deposition in a single basin. The SG is interpreted as a lower boundary proximal onlap of a sequence transgressive toward the southeast and northeast margins of the basin. Ubiquitous graded bedding, lateral variations in average grain size, and a high feldspar content of most GSG units is related to deposition by turbidite flows originating from a relatively proximal, high relief, rapidly eroded source area to the northeast and/or northwest. WCG deposition occurred after a significant reduction in subsidence rates with respect to sedimentation rate and/or after the cratonic highland source areas had become erosionaly subdued. Lateral continuity and intertonguing of OSG units suggests that the SG, GSG, and WCG lithologies experienced at least partially contemporaneous deposition.
- 6) WCG carbonate rocks may have discontinuously fringed the Laurentian margin as patch-like build-ups, which would provide a nearly infinite supply of clastic sediment from the craton to be transported to deeper water through channels between those build-ups.
- 7) Onset of Chilhowee Group deposition above the OSG during the Cambrian marks the rift-to-drift transition along the southeastern Laurentian margin.
- 8) Rocks of the study area are deformed by at least three periods of faulting and folding (F_1 - F_2) and one regional deformational/metamorphic cleavage-forming event (S_2). The only F_1 fold in the study area is transected by slaty cleavage (S_2 ; pressure solution and recrystallization) that is axial-planar to F_2 folds. S_2 , S_{2a} (pressure-solution), and F_2 folds

are related to Taconic (480–430 Ma) Barrovian metamorphism based on $^{40}\text{Ar}/^{39}\text{Ar}$ and $^{40}\text{K}/^{39}\text{Ar}$ metamorphic mineral cooling ages and the axial-planar relationship of S_2 and S_{2a} to F_2 . Crenulation cleavage (S_3) is suborthogonal to and deforms S_2 , indicating it occurred later.

- 9) The GBF and RCF here were initially emplaced prior to Taconic peak metamorphism under dominantly ductile conditions. The GBF was folded (F_2) coveval with peak Taconic metamorphism, which prevented late Paleozoic reactivation of that structure. The brittle HLF likely propagated from the hinge or southeast limb of the Ducktown anticlinorium (first-order F_2) during early Alleghanian orogenesis. The brittle SSMF and possibly coeval Oconaluftee faults cut the folded GBF surface to accommodate Alleghanian thrust displacement, while the RCF was reactivated. During the latest stages of the Alleghanian orogeny, emplacement and bending of the Great Smoky thrust sheet above the Foothills duplex (Valley and Ridge horses) produced second- and higher-order F_3 folds.
- 10) Rocks on the leading edge of the GBF in western and northern GSMNP contain abundant rutilated blue quartz clasts, so it is unlikely that rocks of the Rabbit Creek thrust sheet or those of Webb Mountain-Big Ridge are klippe of the Greenbrier thrust sheet. A foreland fold-thrust belt style of deformation during the Taconic orogeny is difficult to validate, because evidence of Taconic deformation suggests ductile conditions along faults that are not bedding thrusts.
- 11) Reinterpretation by this study of the fault geometry surrounding the Cades Sandstone suggests that the Cades was likely thrust over the Metcalf Phyllite, with timing constrained to the Taconic orogeny due to evidence of ductile conditions along portions of the RCF fault zone. Synmetamorphic (Taconic) folding and coeval ductile imbrication

of the southeast margin of the Rabbit Creek thrust sheet followed emplacement, producing the Coalen Ground and Parson Branch faults.

- 12) Stratigraphic and structural relations imply a sequence of events in southeastern Tennessee initiated by the emplacement of the Rabbit Creek and Greenbrier faults before regional synmetamorphic folding. Later brittle reactivation along the RCF transected and readjusted the synmetamorphic folds into their present configuration. Because the SSMF apparently broke the synclinal trough between the Blue Mountain and Rafter anticlines in the RCF hanging wall to accommodate more displacement, it must have been out-of-sequence to postmetamorphic RCF reactivation.
- 13) Samples from localities 2 and 4 that are interpreted to contain the least altered $\delta^{13}\text{C}$ values examined in this study temporally delimit the depositional age of the Sanduck Formation to Neoproterozoic intervals interpreted as the Varanger and Sturtian glaciations, intervals near the Precambrian-Cambrian boundary (~540 Ma), and to Phanerozoic intervals from the Late Ordovician to the Silurian-Devonian boundary (~400 Ma) and from the Late Devonian (~360 Ma) to the Triassic (~240). While the results of this study seem to conclusively rule out any depositional age for the Sanduck Formation between the early Middle Cambrian and Late Ordovician, isotopic data are inconclusive with respect to differentiating Neoproterozoic vs. middle Paleozoic depositional ages.
- 14) The interpreted stratigraphic position of the Sanduck Formation beneath the Cambrian fossil-bearing Chilhowee Group and Taconic metamorphic age dates of Walden Creek samples support a Neoproterozoic rather than mid-Paleozoic depositional age. Taken together, the stratigraphic, chronological, and geochemical data are all consistent only with a Neoproterozoic depositional age.

REFERENCES CITED

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REFERENCES CITED

- Aleinikoff, J.N., Zartman, R.E., Walter, M., Rankin, D.W., Lyttle, P.T., and Burton, W.C., 1995, U-Pb ages of metarhyolites of the Catoclin and Mount Rogers Formations, central and southern Appalachians: Evidence for two pulses of Iapetan rifting: *American Journal of Science*, v. 295, p. 428-454.
- Aleinikoff, J.N., Southworth, C.S., Yacob, E.Y., and Fanning, C.M., 2004, Isotopic constraints on the time of deposition of the Thunderhead Sandstone, Ocoee Supergroup: U-Pb geochronology of monazite and xenotime overgrowths: *Geological Society of America Abstracts with Programs*, v. 36, p. 98.
- Ausburn, M.P., 1983, Stratigraphy, structure, and petrology of the northern half of the Topton quadrangle, North Carolina [M.S. thesis]: Tallahassee, Florida State University, 174 p.
- Ausburn, M.P., 1998, Geologic map and mineral resources summary of the Topton quadrangle, North Carolina: North Carolina Department of Environmental and Natural Resources, 7 p.
- Aylor, J.G., Jr., 1991, Stratigraphy of the Nantahala and Brasstown Formations, Hiwassee River Group, North Carolina, in Kish, S.A., ed., *Studies in Precambrian and Paleozoic stratigraphy in the western Blue Ridge*: Carolina Geological Society Guidebook, p. 87-96.
- Banner, J.L., and Hanson, G.N., 1990, Calculation of simultaneous isotopic and trace element variations during water-rock interaction with applications to carbonate diagenesis: *Geochemica et Cosmochimica Acta*, v. 54, p. 3123-3137.
- Banner, J.L., Hanson, G.N., and Meyers, W.J., 1988, Water-rock interaction history of regionally-extensive dolomites of the Burlington-Keokuk Formation (Mississippian): Isotopic evidence, in Shukla, V., and Baker, P.A., eds., *Sedimentology and Geochemistry of Dolostones*: Society of Economic Paleontology and Minerals Special Publication, v. 43, p. 97-113.
- Bouma, A.H., *Sedimentology of some flysch deposits*: Amsterdam, Elsevier, 168 p.
- Bream, B.R., Hatcher, R.D., Jr., Miller, C.F., and Fullagar, P.D., 2004, Detrital zircon ages and Nd isotopic data from the southern Appalachian crystalline core, Georgia, South Carolina, North Carolina, and Tennessee; new provenance constraints for part of the Laurentian margin, in Tollo, R.P., Corriveau, L., McClelland, J., and Bartholomew, M.J., eds., *Proterozoic tectonic evolution of the Grenville orogen in North America*: Geological Society of America Memoir, v. 197, p. 459-475.

- Brenchley, P.J., Marshall, J.D., Carden, G.A.F., Robertson, D.B.R., Long D.G.F., Meidla, T., Hints, L., and Anderson, T.F., 1994, Bathymetric and isotopic evidence for short-lived Late Ordovician glaciation in a greenhouse period: *Geology*, v. 22, p. 295-298.
- Broadhead, T.W., Hatcher, R.D., Jr., and Costello, J.O., 1991, Tectonic and stratigraphic implications of mid-Paleozoic (?) fossils from the Later Proterozoic (?) Walden Creek Group rocks in the Foothills belt, eastern Tennessee, *in* Kish, S.A., ed., *Studies of Precambrian and Paleozoic stratigraphy in the western Blue Ridge: Carolina Geological Society Guidebook*, p. 39-44.
- Burdett, J.W., Grotzinger, J.P., and Arthur, M.A., 1990, Did major changes in the stable-isotope composition of Proterozoic seawater occur?: *Geology*, v. 18, p. 227-230.
- Butler, J.R., 1972, Age of regional metamorphism in the Carolinas, Georgia, and Tennessee southern Appalachians: *American Journal of Science*, v. 272, p. 319-333.
- Carroll, D., Neuman, R.B., and Jaffe, H.W., 1957, Heavy minerals in arenaceous beds in parts of the Ocoee series, Great Smoky Mountains, Tennessee: *American Journal of Science*, v. 255, p. 175-193.
- Carter, M.W., 1994, Stratigraphy and structure of a portion of the western Blue Ridge foothills, Polk and Monroe counties, southeast Tennessee [M.S. thesis]: Knoxville, University of Tennessee, 233 p.
- Carter, M.W., and Hatcher, R.D., Jr., 1992, Tectonic reevaluation of the Walden Creek Group (Ocoee Supergroup), Blue Ridge foothills, southeastern Tennessee: *Geological Society of America Abstracts with Programs* v. 24, p. 186.
- Cawood, P.A., McCausland, P.J.A., and Dunning, G. R., 2001, Opening Iapetus; constraints from the Laurentian margin in Newfoundland: *Geological Society of America Bulletin*, v. 113, p. 443-453.
- Connelly, J.B., and Dallmeyer, R.D., 1990, Ordovician (?) or Silurian (?) metamorphism in the western Blue Ridge, Tennessee: Evidence from $^{40}\text{Ar}/^{39}\text{Ar}$ whole-rock phyllite ages: *Geological Society of America Abstracts with Programs*, v. 22, p. 231.
- Connelly, J.B., and Dallmeyer, R.D., 1991, Polymetamorphic evolution of the western Blue Ridge, Tennessee and North Carolina: Evidence from $^{40}\text{Ar}/^{39}\text{Ar}$ ages: *Geological Society of America Abstracts with Programs*, v. 23, p. 18.
- Connelly, J.B., and Woodward, N.B., 1992, Taconian foreland-style thrust system in the Great Smoky Mountains, Tennessee: *Geology*, v. 20, p. 177-180.
- Cook, F.A., and Oliver, J.E., 1981, The Late Precambrian-Early Paleozoic continental edge in the Appalachian orogen: *American Journal of Science*, v. 281, p. 993-1008.

- Cook, F.A., Iverson, W.P., and Smithson, S.B., 1979, Reprocessed COCORP Southern Appalachian reflection data: root zone to coastal plain: Discussion and reply: *Geology*, v. 12, p. 249-251.
- Cook, F.A., Brown, L.D., Kaufman, S., and Oliver, J.E., 1983, The COCORP seismic-reflection traverse across the southern Appalachians: *American Association of Petroleum Geologists Studies in Geology*, v. 14, 61 p.
- Corsetti, F.A., 1993, Is most of the Tommotian missing in the White-Inyo region, eastern California?: *Geological Society of America Abstracts with Programs*, v. 25, p. 23-24.
- Corsetti, F.A., and Kaufman, A.J., 1992, Chemostratigraphy of Neoproterozoic-Cambrian units, White-Inyo region, eastern California; new correlations between China, Siberia, and the Great Basin *in* Dundas, R.G., ed., *California Paleontology conference Abstracts*, p. 1.
- Costain, J.K., Coruh, C., Glover, L., III, Pratt, T.L., Hatcher, R.D., Jr., Williams, R.T., and Phinney, R.A., 1986, Appalachian ultradeep core hole (ADCOH) Project site investigation regional seismic lines and geologic interpretation, *in* Hatcher, R.D., Jr., Viele, G.W., and Thomas, W.A., eds., *The Appalachian-Ouachita orogen in the United States: Boulder, Colorado, Geological Society of America, The Geology of North America*, v. F-2, p. 385-416.
- Costello, J.O., 1993, Studies in Appalachian foreland-to-hinterland transition zone geology, Georgia and Tennessee [Ph.D. thesis]: Columbia, University of South Carolina, 144 p.
- Costello, J.O., and Hatcher, R.D., Jr., 1986, Contact relationships between the Walden Creek Group and the Great Smoky Group in Ocoee Gorge, Tennessee: Implications on the regional extent of the Greenbrier fault: *Geological Society of America Abstracts with Programs*, v. 18, p. 216.
- Costello, J.O., and Hatcher, R.D., Jr., 1991, Problems of stratigraphic correlation between Great Smoky, Snowbird, and Walden Creek Groups between the Great Smoky National Park, central east Tennessee, and Ocoee Gorge, southeastern Tennessee, *in* Kish, S.A., ed., *Studies of Precambrian and Paleozoic stratigraphy in the western Blue Ridge: Carolina Geological Society Guidebook*, p. 13-25.
- Costello, J.O., McConnell, K.I., and Power, W.R., 1982, Geology of late Precambrian and early Paleozoic rocks in and near the Cartersville district, Georgia: *Georgia Geological Society Guidebook*, v. 2, p. 40.
- Dallmeyer, R.D., 1978, $^{40}\text{Ar}/^{39}\text{Ar}$ incremental-release ages of hornblende and biotite across the Georgia Inner Piedmont: Their bearing on Late Paleozoic-Early Mesozoic tectonothermal history: *American Journal of Science*, v. 278, p. 124-149.

- Derry, L.A., Kaufman, A.J., and Jacobsen, S.B., 1992, Sedimentary cycling and environmental change in the late Proterozoic: Evidence from stable and radiogenic isotopes: *Geochemica et Cosmochemica Acta*, v. 56, p. 1317-1329.
- DeWindt, J.T., 1975, Geology of the Great Smoky Mountains, Tennessee and North Carolina, with road log for field excursion, Knoxville-Clingmans Dome-Maryville: *Compass*, v. 52, p. 73-129.
- Donath, F.A., and Parker, R.B., 1964, Folds and folding: *Geological Society of America Bulletin*, v. 75, p. 45-62.
- Einsele, G., 2000, *Sedimentary basins: evolution, facies, and sediment budget*: Springer Verlag, Berlin, 2nd ed., 792 p.
- Espenshade, G.H., 1963, Geology of some copper deposits in North Carolina, Virginia, and Alabama: *U.S. Geological Survey Bulletin* 1142-I, 150 p.
- Fairchild, I.J., and Spiro, B., 1987, Petrological and isotopic implications of some contrasting Late Precambrian carbonates, NE Spitsbergen: *Sedimentology*, v. 34, p. 973-989.
- Fairley, W.M., 1965, The Murphy syncline in the Tate quadrangle, Georgia: *Georgia Geological Survey Bulletin* 75, 71 p.
- Forrest, J.T., 1970, Rocks and structures of the Murphy Marble Belt in the Murphy, North Carolina 7.5 minute quadrangle [M.S. thesis]: Columbia, University of South Carolina.
- Gao, G., 1990, Geochemical and isotopic constraints on the diagenetic history of a massive, stratal, Late Cambrian (Royer) dolomite, Lower Arbuckle Group, Slick Hills, SW Oklahoma, USA: *Geochemica et Cosmochemica Acta*, v. 54, p. 1979-1989.
- Geddes, D.J., 1995, Stratigraphy, structure, and environmental site assessment of a portion of the western Blue Ridge, Monroe County, Tennessee [M.S. thesis]: Knoxville, University of Tennessee, 195 p.
- Grant, S.W.F., 1992, Carbon isotopic vital effect and organic diagenesis, Lower Cambrian Forteau Formation, northwest Newfoundland: implications for $\delta^{13}\text{C}$ chemostratigraphy: *Geology*, v. 20, p. 243-246.
- Hadley, J.B., 1970, Geological mapping by the U.S. Geological Survey in the Great Smoky Mountains National Park: *Geological Society of America Bulletin*, v. 60, Part 2.
- Hadley, J.B., and Goldsmith, R., 1963, Geology of the eastern Great Smoky Mountains, North Carolina and Tennessee: *U.S. Geological Survey Professional Paper* 349-B, 188 p.
- Hale, R.C., 1974, Gold deposits of the Coker Creek district, Monroe County, Tennessee: *Tennessee Division of Geology Bulletin* 72, 93 p.

- Hamilton, W., 1961, Geology of the Richardson and Jones Cove Quadrangles, Tennessee: U.S. Geological Survey Professional Paper 349-A, 55 p.
- Hanselman, D.H., Conolly, J.R., and Horne, J.C., 1974, Carbonate environments in the Wilhite Formation of Central Eastern Tennessee: Geological Society of America Bulletin, v. 85, p. 45-50.
- Hardeman, W.D., 1966, Geologic map of Tennessee: Tennessee Division of Geology, scale 1:250,000.
- Haskin, L.A., 1984, Petrogenetic modeling-use of rare earth elements, *in* Henderson, P., ed., Rare Earth Element Geochemistry: Developments in Geochemistry, Elsevier, p. 115-152.
- Hatcher, R.D., Jr., 1972, Developmental model for the southern Appalachians: Geological Society of America Bulletin, v. 83, p. 2735-2760.
- Hatcher, R.D., Jr., 1978, Tectonics of the western Piedmont and Blue Ridge, southern Appalachians: Review and speculation: American Journal of Science, v. 278, p. 276-304.
- Hatcher, R.D., Jr., 1987, Tectonics of the southern and central Appalachians Internides: Annual Review of Earth and Planetary Sciences, v. 15, p. 337-362.
- Hatcher, R.D., Jr., and Zietz, I., 1978, Thin crystalline thrust sheets in the southern Appalachian Inner Piedmont and Blue Ridge: Interpretation based upon regional aeromagnetic data: Geological Society of America Abstracts with Programs, v. 10, p. 417.
- Hatcher, R.D., Jr., and Zietz, I., 1980, Tectonic implications of regional aeromagnetic and gravity data from the southern Appalachians, *in* Wones, D.R., ed., Proceedings, The Caledonides in the U.S.A.: Blacksburg, Virginia Polytechnic Institute and State University Department of Geological Sciences Memoir 2, p. 235-244.
- Hatcher, R.D., Jr., and Carter, M.W., 1992, Tectonic reevaluation of the Walden Creek Group (Ocoee Supergroup), Blue Ridge foothills, southeastern Tennessee: Geological Society of America Abstracts with Programs, v. 24, p. 186.
- Hatcher, R.D., Jr., Thomas, W.A., Geiser, P.A., Snoke, A.W., Mosher, S., and Wiltschko, D.V., 1989, Alleghanian orogen, *in* Hatcher, R.D., Jr., Thomas, W.A., and Viele, G.W., eds., The Appalachian-Ouchita Orogen in the United States: Boulder, Colorado, Geological Society of America, the Geology of North America, v. F-2.
- Hayes, C.W., 1891, The overthrust faults of the southern Appalachians: Geological Society of America Bulletin, v. 2, p. 141-152.
- Hayes, C.W., 1895, Description of the Cleveland sheet (Tennessee): U.S. Geological Survey Geologic Atlas, Folio 20, 12 p.

- Hemming, N.G., Meyers, W.J., and Grams, J.C., 1989, Cathodeluminescence in diagenetic calcites: the role of Fe and Mn as deduced from electron probe and spectrophotometric measurements: *Journal of Sedimentary Petrology*, v. 59, p. 404-411.
- Heron, R.M., 1968, Geology of the Ducktown, Isabella, and Persimmon Creek quadrangles, Tennessee and North Carolina: U.S. Geological Survey Open-File Report, 71 p.
- Hoffman, P.F., and Schrag, D.P., 2002, The snowball earth hypothesis: Testing the limits of global change: *Terra Nova*, v. 14, p. 129-155.
- Hurst, V.J., 1955, Stratigraphy, structure, and mineral resources of the Mineral Bluff quadrangle, Georgia: *Georgia Geological Survey Bulletin* 63, 137 p.
- Hurst, V.J., and Schlee, J.S., 1962, Ocoee metasediments, north-central Georgia, southeast Tennessee: Southeastern Section, Geological Society of America Guidebook 3, Georgia Department of Mines, Mining, and Geology, 28 p.
- Jacobsen, S.B., and Kaufman, A.J., 1999, The Sr, C, and O isotopic evolution of Neoproterozoic seawater: *Chemical Geology*, v. 161, p. 37-57.
- Kaufman, A.J., and Knoll, A.H., 1995, Neoproterozoic variations in the carbon isotopic composition of seawater: stratigraphic and biogeochemical implications: *Precambrian Research*, v. 73: p. 27-49.
- Kaufman, A.J., Hayes, J.M., and Klein, C., 1990, Primary and diagenetic controls of isotopic compositions of iron-formation carbonates: *Geochimica et Cosmochimica Acta*, v. 54, p. 3461-3473.
- Kaufman, A.J., Hayes, J.M., Knoll, A.H., and Germs, G.J.B., 1991, Isotopic compositions of carbonates and organic carbon from upper Proterozoic successions in Namibia: stratigraphic variation and the effects of diagenesis and metamorphism: *Precambrian Research*, v. 49, p. 301-327.
- Keith, A., 1895, Description of the Knoxville sheet (Tennessee and North Carolina): U.S. Geological Survey Geologic Atlas, Folio 16, 6 p.
- Keith, A., 1896, Description of the Loudon sheet (Tennessee): U.S. Geological Survey Geologic Atlas, Folio 25, 6 p.
- Keith, A., 1903, Description of the Cranberry quadrangle (North Carolina-Tennessee): U.S. Geological Survey Geologic Atlas, Folio 90, 9 p.
- Keith, A., 1904, Description of the Asheville quadrangle (Tennessee and North Carolina): U.S. Geological Survey Geologic Atlas, Folio 116, 10 p.
- Keith, A., 1907a, Description of the Nantahala quadrangle (North Carolina and Tennessee): U.S. Geological Survey Geologic Atlas, Folio 143, 11 p.

- Keith, A., 1907b, Description of the Roan Mountain quadrangle (Tennessee-North Carolina): U.S. Geological Survey Geologic Atlas, Folio 151, 12 p.
- Keller, F.B., 1980, Late Precambrian stratigraphy, depositional history, and structural chronology of part of the Tennessee Blue Ridge [Ph.D. thesis]: New Haven, Connecticut, Yale University, 353 p.
- King, P.B., 1949, The base of the Cambrian in the southern Appalachians: *American Journal of Science*, v. 247, p. 513-530, 622-645.
- King, P.B., 1964, Geology of the central Great Smoky Mountains, Tennessee: U.S. Geological Survey Professional Paper 349-C, 148 p.
- King, P.B., Hadley, J.B., Neuman, R.B., and Hamilton, W.B., 1958, Stratigraphy of the Ocoee Series, Great Smoky Mountains, Tennessee and North Carolina: *Geological Society of America Bulletin*, v. 69, p. 947-966.
- Kish, S.A., 1989, Igneous and metamorphic history of the eastern Blue Ridge, southwestern North Carolina: K-Ar and Rb-Sr studies, *in* Fritz, W.J., Hatcher, R.D., Jr., and Hopson, J.L., eds., *Geology of the eastern Blue Ridge of northeast Georgia and the adjacent Carolinas: Georgia Geological Society Guidebook*, v. 9, p. 41-55.
- Kish, S.A., 1991, Potassium-argon dating in the western Blue Ridge of North Carolina and Tennessee, *in* Kish, S.A., ed., *Studies in Precambrian and Paleozoic stratigraphy in the western Blue Ridge: Carolina Geological Society of America Special Paper 191*, p. 19-30.
- Knoll, A.H., and Keller, F.B., 1979, Late Precambrian microfossils from the Walden Creek Group, Ocoee Supergroup, Tennessee: *Geological Society of America Abstracts with Programs*, v. 11, p. 185.
- Knoll, A.H., Hayes, J.M., Kaufman, A.J., Swett, K., and Lambert, I.B., 1986, Secular variation in carbon isotope ratios from upper Proterozoic successions of Svalbard and East Greenland: *Nature*, v. 321, p. 832-838.
- Lesure, F.G., Force, E.R., Windolph, J.F., and Hill, J.J., 1977, Mineral Resources of the Joyce Kilmer-Slickrock Wilderness, North Carolina-Tennessee: U.S. Geological Survey Bulletin 1416, 41 p.
- Lewis, J.C., 1988, Structural geology and finite strain analysis of the Precambrian Thunderhead Sandstone along the Greenbrier fault and the Roundtop klippe [M.S. thesis]: Knoxville, University of Tennessee, 186 p.
- Lundin, R.F., 1965, A new name for *Leperditia symmetrica* Lundin: *Journal of Paleontology*, v. 39, p. 1221.

- Mack, G.H., 1980, Stratigraphy and depositional environments of the Chilhowee Group (Cambrian) in Georgia and Alabama: *American Journal of Science*, v. 280, p. 497-517.
- Marshall, J.D., and Middleton, P.D., 1990, Changes in marine isotopic composition and Late Ordovician glaciation: *Journal of Geological Society of London*, v. 147, p. 1-4.
- Martin, S.L., 1997, Stratigraphy and structure of part of the western Blue Ridge Foothills near Tellico Plains, southeastern Tennessee [M.S. thesis]: Knoxville, University of Tennessee, 249 p.
- McConnell, K.I., and Costello, J.O., 1984, Relationship between Talladega belt rocks and Ocoee Supergroup rocks near Cartersville, Georgia, *in* Bearce, D.N., Black, W.W., Kish, S.A., and Tull, J.F., eds., *Tectonic studies in the Talladega and Carolina slate belts, southern Appalachian orogen*: Geological Society of America Special Paper 191, p.19-30.
- Merschat, C.E., and Hale, R.C., 1983, Geologic map and mineral resources summary of the Farmer quadrangle, Tennessee and North Carolina: North Carolina Geological Survey map GM 133-NE, scale 1:24,000.
- Merschat, C.E., and Wiener, L.S., 1973, Provisional geologic map of the Ocoee Supergroup, southwestern North Carolina and southeastern Tennessee: *Geological Society of America Abstracts with Programs*, v. 5, p. 420.
- Meyers, W.J., 1989, Trace element and isotope geochemistry of zoned calcite cements, Lake Valley Formation (Mississippian, New Mexico): Insights from water-rock interaction modeling: *Sedimentary Geology*, v. 65, p. 355-370.
- Middleton, G.V., 1973, Johannes Walther's Law of the Correlation of Facies: *Geological Society of America Bulletin*, v. 84, p. 979-987.
- Middleton, G.V., 1993, Sediment deposition from turbidity currents: *Annual Review of Earth and Planetary Sciences*, v. 21, p. 89-114.
- Middleton, P.D., Marshall, J.D., and Brenchley, P.J., 1991, Evidence for isotopic change associated with Late Ordovician glaciation, from brachiopods and marine cement of central Sweden: *Geological Survey of Canada Papers*, v. 90-9, p. 313-321.
- Milton, D.J., 1983, Garnet-biotite geothermometry confirms the premetamorphic age of the Greenbrier fault, Great Smoky Mountains, North Carolina: *Geological Society of America Abstract with Programs*, v. 15, p. 90.
- Moecher, D.P., Samson, S.D., and Miller, C.F., 2004, Precise time and conditions of peak Taconian granulite facies metamorphism in the Southern Appalachian Orogen, U.S.A., with implications for zircon behavior during crustal melting events: *Journal of Geology*, v. 112, p. 289-304.

- Mohr, D.W., 1973, Stratigraphy and structure of part of the Great Smoky and Murphy belt groups, western North Carolina: *American Journal of Science*, v. 273-A, p. 569-590.
- Mohr, D.W., 1975, Geologic map of the Noland Creek quadrangle, North Carolina: North Carolina Geological Survey, GM 158-NE, scale 1:24,000.
- Montanez, I.P., and Read, J.F., 1989, Trace element and isotopic evidence for water-rock interaction during regional dolomitization of lower Ordovician, Upper Knox carbonates: *Geological Society of America Abstracts with Programs*, v. 21, p. 219.
- Montes, C., 1997, The Greenbrier and Hayesville faults in central-western North Carolina [unpublished M.S. thesis]: Knoxville, University of Tennessee, 145 p.
- Montes C., and Hatcher, R.D., Jr., 1999, Documenting late Proterozoic rifting in the Ocoee Basin, western Blue Ridge, North Carolina: *Southeastern Geology*, v. 39, p. 37-50.
- Mount, J.F., Gevirtzman, D.A., and Signor, P.W., 1983, Precambrian-Cambrian transition problem in western North America; Part 1, Tommotian fauna in the southwestern Great Basin and its implications for the base of the Cambrian system: *Geology*, v. 11, p. 224-226.
- Mutti, E., and Ricci-Lucchi, F., 1975, The significance of certain sequential units in turbidite series: *Bulletin de la Societe Geologique de France*, v. 16, p. 577-582.
- Myrow, P.M., 1983, Sedimentology of the Cheshire Formation in west-central Vermont: *Geological Society of America Abstracts with Programs*, v. 15, p. 126.
- Nabelek, P.I., 1987, General equations for modeling fluid-rock interaction using trace elements and isotopes: *Geochemica et Cosmochemica Acta*, v. 51, p. 1765-1769.
- Neuman, R.B., and Nelson, W.H., 1965, Geology of the western part of the Great Smoky Mountains, Tennessee: U.S. Geological Survey Professional Paper 349-D, 81 p.
- Nuttall, B.D., 1951, The Nantahala-Ocoee contact in north Georgia [M.S. thesis]: Cincinnati, University of Cincinnati, 32 p.
- Palmer, M.R., 1985, Rare earth elements in foraminifera tests: *Earth and Planetary Sciences Letter*, v. 73, p. 285-298.
- Phillips, H.E., 1952, The geology of the Starr Mountain area, southeast Tennessee [M.S. thesis]: Knoxville, University of Tennessee, 61 p.
- Poppelreiter, B.S., 1980, A structural analysis of the metasedimentary rocks of the Ocoee Supergroup above the Great Smoky overthrust in southeast Tennessee [M.S. thesis]: Knoxville, University of Tennessee, 115 p.

- Power, W.R., and Forrest, J.T., 1973, Stratigraphy and paleogeography in the Murphy Marble belt, *in* Geology of the Blue Ridge-Ashland-Wedowee belt in the Piedmont: American Journal of Science, v. 273, p. 698-711.
- Rackley, R.I., 1951, Geology of the Bean Mountain area [M.S. thesis]: Knoxville, University of Tennessee, 76 p.
- Rankin, D.W., 1975, The continental margin of eastern North America in the southern Appalachians: The opening and closing of the Proto-Atlantic ocean: American Journal of Science, v. 275-A, p. 298-336.
- Rankin, D.W., Drake, A.A., Jr., Glover, L., III, Goldsmith, R., Hall, L.M., Murray, D.P., Ratcliffe, N.M., Read, J.F., Secor, D.T., Jr., and Stanley, R.S., 1989, Pre-orogenic terranes, *in* Hatcher, R.D., Jr., Thomas, W.A., and Viele, G.W., eds., The Appalachian-Ouachita orogen in the United States: Boulder, Colorado, Geological Society of America, v. F-2, p. 7-100.
- Rast, N., and Kohles, K.M., 1986, The origin of the Ocoee Supergroup: American Journal of Science, v. 286, p. 593-616.
- Ripperdan, R.L., 2001, Stratigraphic Variation in Marine Carbonate Carbon Isotope Ratios, *in* Valley, J.W., and Cole, D.R., eds., Stable Isotope Geochemistry: Mineralogical Society of America Reviews in Mineralogy and Geochemistry, v. 43, p. 637-662.
- Rodgers, J., 1953, Geologic map of east Tennessee with explanatory text: Tennessee Division of Geology Bulletin 58, Part II, 168 p. Rodgers, J., 1991, Evolution of ideas about the Ocoee conglomerates and slates, *in* Kish, S.A., ed., Studies of Precambrian and Paleozoic stratigraphy in the western Blue Ridge: Carolina Geological Society Guidebook, p. 1-12.
- Rupke, N.A., 1977, Growth of an ancient deep-sea fan: Journal of Geology, v. 85, p. 725-744.
- Safford, J.M., 1856, A geological reconnaissance of the State of Tennessee: Nashville State Geologist 1st Bicentennial Report, 164 p.
- Safford, J.M., 1869, Geology of Tennessee: Nashville, Tennessee, 550 p.
- Schultz, A.S., 2000, Geologic map of the Mount Leconte 7.5 minute quadrangle, Great Smoky Mountains National Park, Tennessee and North Carolina: U.S. Geological Survey Open-File Report 00-261, 1:24,000.
- Schwab, F.L., 1971, Geosynclinal compositions and the new global tectonics: Journal of Sedimentary Petrology, v. 41, p. 928-938.

- Shaw, A.B., 1964, Paleontology of northeastern Vermont, Part 10, fossils from the (Cambrian) Skeels Corners Formation: *Journal of Paleontology*, v. 40, p. 269-295.
- Signor, P. W., Mount, J.F., and Onken, B.R., 1987, A pre-trilobite shelly fauna from the White-Inyo region of eastern California and western Nevada: *Journal of Paleontology*, v. 61, p. 425-438.
- Slack, J.F., Force, E.R., Behum, P.T., and Williams, B.B., 1984, Mineral resources of the Citico Creek Wilderness Study Area, Monroe County, Tennessee: U.S. Geological Survey Bulletin 1552, 32 p.
- Southworth, S., Chirico, P., and Putbrese, T., 1999, Geologic map of parts of the Cades Cove and Calderwood quadrangles, Tennessee and North Carolina, Great Smoky Mountains National Park: U.S. Geological Survey, Open-File Report 99-175, 1:24,000.
- Stose, G.W., and Stose, A.J., 1944, The Chilhowee Group and Ocoee Series of the southern Appalachians: *American Journal of Science*, v. 242, p. 367-390, 401-416.
- Stose, G.W., and Stose, A.J., 1949, Ocoee Series of the southern Appalachians: *Geological Society of America Bulletin*, v. 60, p. 267-320.
- Taylor, H.P., Jr., 1977, Water-rock interactions and the origin of H₂O in granitic batholiths: *Journal of the Geological Society of London*, v. 133, p. 509-558.
- Thomas, W.A., 1991, The Appalachian-Ouachita rifted margin of southeastern North America: *Geological Society of America Bulletin*, v. 103, p. 415-431.
- Tucker, M.E., 1985, Calcitized aragonite ooids and cements from the late Precambrian of southern Norway: *Precambrian Research*, v. 43, p. 67-84.
- Tull, J.F., in review, Rift-margin architecture, cover stratigraphy, structure of basement culminations, frontal Appalachian Blue Ridge, Georgia, *in* Hatcher, R.D., Jr., *Geological Society of America Memoir XX*, p. XX-XX.
- Unrug, R., and Unrug, S., 1990, Paleontological evidence of Paleozoic age for the Walden Creek Group, Ocoee Supergroup, Tennessee: *Geology*, v. 18, p. 1041-1045.
- Unrug, R., and Unrug, S., 1991, Paleozoic age for the Walden Creek Group, Southern Blue Ridge Province: Exploring consequences: *Geological Society of America Abstracts with Programs*, v. 23, p. 142.
- Unrug, R., Unrug, S., and Palmes, S.L., 1991, Carbonate rocks of the Walden Creek Group in the Little Tennessee River valley: Modes of occurrence, age, and significance for the basin evolution of the Ocoee Supergroup, *in* Kish, S.A., ed., *Studies of Precambrian and Paleozoic stratigraphy in the western Blue Ridge*: Carolina Geological Society Guidebook, p. 27-36.

- Unrug, R., Ausich, W.I., Jolanta, B., Cuffey, R.J., Mamet, B.L., Palmes, S.L., Unrug, S., 2000, Paleozoic age of the Walden Creek Group, Ocoee Supergroup, in the western Blue Ridge, southern Appalachians: Implications for evolution of the Appalachian margin of Laurentia: Geological Society of America Bulletin, v. 112, p. 982-996.
- Veizer, J., 1983, Chemical diagenesis of carbonates: theory and application, *in* Arthur, M.A., Anderson, T.F., Kaplan, I.R., Veizer, J., and Land, L.S., eds., Stable Isotopes in Sedimentary Geology: S.E.P.M. Short Course, 10: 3-1-3-100.
- Veizer, J., and Compston, W., 1976, $^{87}\text{Sr}/^{86}\text{Sr}$ in Precambrian carbonates as an index of crustal evolution: *Geochimica et Cosmochimica Acta*, v. 40, p. 905-914.
- Walker, R.G., 1978, Deep-water sandstone facies and ancient submarine fans; models for exploration of stratigraphic traps: AAPG Bulletin, v. 62, p. 905-914.
- Walker, J.D., and Driese, S.G., 1991, Constraints on the position of the Precambrian-Cambrian boundary in the southern Appalachians: *American Journal of Science*, v. 291, p. 258-283.
- Walker, J.D., and Rast, N., 1991, The Walden Creek Group: Is it part of the Ocoee Supergroup?, *in* Kish, S.A., ed., Studies of Precambrian and Paleozoic stratigraphy in the western Blue Ridge: Carolina Geological Society Guidebook, p. 45-56.
- Walters, R.R., 1988, Structural geometries, fabrics, and stratigraphic relationships in the Cades Cove region, Great Smoky Mountains National Park [M.S. thesis]: Knoxville, University of Tennessee, 155 p.
- Walther, J., 1894, *Modern lithogenesis*: Jena, Verlag von Gustav Fischer, v. 3.
- Wiener, L.S., and Merschat, C.E., 1978, Summary of geology between the Great Smoky fault at Parksville, Tennessee and basement rocks of the Blue Ridge at Glade Gap, North Carolina, *in* Milici, R.C., ed., Field trips in the southern Appalachians: Tennessee Division of Geology Report of Investigation No. 37, p. 2-29.
- Wiener, L.S., and Merschat, C.E., 1981, Provisional geologic map of southwest North Carolina, southeast Tennessee, and north Georgia: North Carolina Geological Survey Open-File Map, scale 1:250,000.
- Wiener, L.S., and Merschat, C.E., 1992, Geologic map of southwestern North Carolina, including adjoining southeastern Tennessee, and north Georgia: North Carolina Geological Survey, scale 1:250,000.
- Woodward, N.B., Connelly, J.B., Walters, R.R., and Lewis, J.C., 1991, Tectonic evolution of the Great Smoky Mountains, *in* Kish, S.A., ed., Studies of Precambrian and Paleozoic stratigraphy in the western Blue Ridge: Carolina Geological Society Guidebook, p. 57-68.

APPENDIX

Station	Quad	Lithology	Foliation		Bedding		Fold Axis		Joints		Axial Surface		Fold Verg	Intersection Lin.	
			Strike	Dip	Strike	Dip	Plunge	Trend	Strike	Dip	Strike	Dip		Plunge	Trend
1	WOF	BLACK SLATE	N40E	55SE											
2	WOF	BLACK SULFIDIC SLATE	N39E	35SE											
3	WOF	GWAND SS	N41	27SE											
4	WOF	BLACK SLATE	N49E	26SE											
5	WOF	GRAY SANDSTONE	N55E	27SE											
6	WOF	SM PEB CONG	N41E	42SE											
7	WOF	CONG	N60E	50SE											
8	WOF	CONG	N60E	21SE											
9	WOF	CONG	N58E	41SE											
10	WOF	CONG	N58E	15SE											
11	WOF	BLACK SLATE	FLOAT												
12	WOF	BLACK SLATE	N87E	61SE			2	221			N41E	51SE			
13	WOF	CONG-CS SS	N60E	41SE											
14	WOF	CONG	N59E	51SE	N60E	54NW									
15	WOF	CONG	N59E	51SE											
16	WOF	SM PEB CONG	N43E	49SE											
17	WOF	SM MD PEB CONG	FLOAT												
18	WOF	SM MD PEB CONG	N49E	51SE											
19	WOF	SM MD PEB CONG	FLOAT												
20	WOF	SM MD PEB CONG	FLOAT												
21	WOF	SM MD PEB CONG	FLOAT												
22	WOF	SM MD PEB CONG	N26E	47SE											
23	WOF	SLATE			N40E	20NW									
24	WOF	CONG	N42E	68SE					N75E	VERT					
25	WOF	SLATE	FLOAT												
26	WOF	CONG-SS	N30E	82SE											
27	WOF	CONG	N47E	40SE											
28	WOF	CONG	N61E	74SE											
29	WOF	CONG	N64E	36SE											
30	WOF	CONG	N50E	44SE											
31	WOF	DK GRAY SLATE	N46E	56SE											
32	WOF	DK GRAY SLATE	N44E	56SE											
33	WOF	DK GRAY SLATE	N54E	31SE											
34	WOF	DK GRAY SLATE	N50E	20SE											
35	WOF	DK GRAY SLATE	N53E	61SE											
36	WOF	GRAY SL-SLT	HORIZ												
37	WOF	GRAY SL-SLT	N50E	54SE											
38	WOF	GRAY SL-SLT	N24E	VERT											
39	WOF	GRAY SL-SLT	N15E	19SE											
40	WOF	GRAY SL-SLT	N40E	51SE											
41	WOF	GRAY SL-SLT	N56E	33SE											
42	WOF	SL - CS SS	N81E	57SE											
43	WOF	GRAY SL-SLT	N29E	62SE											
44	WOF	GRAY SL-SLT	N24E	40SE											
45	WOF	SLATE	N29E	27SE											
46	WOF	CS PEB CONG	N46E	44SE											
47	WOF	CS PEB CONG	FLOAT												
48	WOF	SLATE	FLOAT												
49	WOF	CONG-CS SS	FLOAT												
50	WOF	CONG-CS SS	N43E	64SE											
51	WOF	SLATE	N36E	50SE											
52	WOF	SLATE	N64E	25SE											
53	WOF	CONG	N24E	22SE											
54	WOF	CONG			N78W	28SW									
55	WOF	CS SS	N39E	18SE							N27E	25SE	NW		
56	WOF	CONG	FLOAT												
57	WOF	SM PEB CONG	N54E	30SE											
58	WOF	CONG - GW	N31E	41SE					N34E	VERT					
59	WOF	CONG - GW	N46E	32SE											
60	WOF	GW	N33E	13SE											
61	WOF	SLATE	N46E	36SE											
62	WOF	DK GRAY BND SL	N51E	32SE											
63	WOF	DK GRAY BND SL	N39E	27SE											
64	WOF	DK GRAY BND SL	N38E	33SE											
65	WOF	BLACK SLATE	N35E	62SE	N54E	85NW			N55W	VERT					
66	WOF	BLACK SLATE	N85E	39SE											
67	WOF	BLACK SLATE	N51E	35SE											
68	WOF	BLACK SLATE	N40E	57SE											
69	WOF	BLACK SLATE	N47E	33SE					N86W	75SW					
70	WOF	SL - SLT	N58E	31SE	N19E	63SE									
71	WOF	CS PEB CONG	FLOAT												
72	WOF	CS PEB CONG	N18E	32SE											
73	WOF	GW	N76E	22SE											
74	WOF	CS PEB CONG	N36E	44SE											
75	WOF	BND SULF SLATE	N46E	36SE											

Station	Quad	Lithology	Foliation		Bedding		Fold Axis		Joints		Axial Surface		Fold Verg.	Intersection Lin.	
			Strike	Dip	Strike	Dip	Plunge	Trend	Strike	Dip	Strike	Dip		Plunge	Trend
76	WOF	BND SULF SLATE	N51E	15SE											
77	WOF	BND SULF SLATE	N40E	36SE											
78	WOF	BND SULF SLATE	N71E	23SE											
79	WOF	BL SULF SLATE	N34E	31SE			2	90			N31E	23SE			
80	WOF	BL SULF SLATE	N38E	40SE											
81	WOF	BL SULF SLATE	N26E	26SE	N26E	46NW									
82	WOF	SM-MD PEB CONG			N44E	64NW									
83	WOF	CONG - GW	N72E	49SE											
84	WOF	CONG - GW			N5W	14SW									
85	WOF	GW			N2W	32SW									
86	WOF	SM-MD PEB CONG	N51E	34SE											
87	WOF	DK GRAY SULF SLT AND SL	N54E	63SE	N25E	34NW									
88	WOF	DK GRAY SULF SLT AND SL	N49E	79SE	N9E	52NW									
89	WOF	MD PEB CONG	N57E	50SE											
90	WOF	MD-CS SS	N10E	82SE	N64W	69NE									
91	WOF	DK GRAY BND SL	N46E	50SE											
92	WOF	SM PEB CONG	N61E	39SE											
93	WOF	SM PEB CONG	N36E	53SE											
94	WOF	SM PEB CONG + GW	N34E	35SE											
95	WOF	SM PEB CONG + GW	N34E	51SE											
96	WOF	SM-MD PEB CONG	N52E	21SE											
97	WOF	SM-MD PEB CONG	N66E	42SE											
98	WOF	SM-MD PEB CONG	N60E	28SE											
99	WOF	SM-MD PEB CONG	N78E	21SE											
100	WOF	SM-MD PEB CONG + GW	N72E	49SE											
101	WOF	DK GRAY BND SL + SL	N67E	36SE											
102	WOF	DK GRAY BND SL	N12E	46SE											
103	WOF	DK GRAY SULF SLT AND SL	N8E	27SE	N85W	21NE									
104	WOF	DK GRAY BND SL	N2E	27SE											
105	WOF	GREEN WILHITE SL	N10E	31SE											
106	WOF	DK GRAY BND SL	N27E	15SE											
107	WOF	DK GRAY BND SL	N28E	38SE											
108	WOF	CONTACT-102-SM PEB CONG	N17E	39SE											
109	WOF	SM-MD PEB CONG + GW	N38E	21SE											
110	WOF	DK GRAY SULF SLT AND SL	N62E	60SE											
111	WOF	DK GRAY SULF SLT AND SL	N36E	37SE											
112	WOF	CON-SL + CONG	N56E	39SE	N28E	41NW									
113	WOF	CONG - GW	N56E	23SE											
114	WOF	DK GRAY SULF SLT AND SL	N43E	54SE											
115	WOF	DK GRAY SULF SLT AND SL	N26E	36SE											
116	WOF	SL + VEIN QTZ	N30E	55SE											
117	WOF	SL + VEIN QTZ	N41E	20SE											
118	WOF	SL + VEIN QTZ	N43E	33SE											
119	WOF	SM-MD PEB CONG	N46W	49SW											
120	WOF	SM-MD PEB CONG	N61E	29SE											
121	WOF	LT. GRAY SLATE	N46E	54SE											
122	WOF	CON + SLATE	N52E	45SE											
123	WOF	LT. GRAY SLATE	N39E	41SE											
124	WOF	LT. GRAY SLATE	N61E	39SE											
125	WOF	LT. GRAY SLATE	N54E	16SE											
126	WOF	LT. GRAY SLATE	N18E	39SE											
127	WOF	LT. GRAY SLATE	N61E	69SE											
128	WOF	LT. GRAY SLATE	N51E	52SE											
129	WOF	LT. GRAY SLATE	N81E	50SE											
130	WOF	LT. GRAY SLATE	N19E	61SE											
131	WOF	LT. GRAY SLATE	N19E	79SE											
132	WOF	LT. GRAY SLATE	N50E	46SE											
133	WOF	LT. GRAY SLATE	N67E	39SE											
134	WOF	LT. GRAY SLATE	N80E	34SE											
135	WOF	LT. GRAY SLATE +CS SS	N59E	56SE											
136	WOF	LT. GRAY-GREEN SL	N11W	25NE											
137	WOF	LT. GRAY-GREEN SL	N39E	38SE											
138	WOF	SM-MD PEB CONG + GW	N25E	4SE											
139	WOF	DK GRAY SULF SLT AND SL	N16E	37SE	N48E	29SE									
140	WOF	LT. GRAY SLATE	N20E	42SE											
141	WOF	DK GRAY SULF SLT AND SL	N37E	25SE	N61E	71NW									
142	WOF	DK GRAY BND SL	N56E	24NW	N64W	33NE			N33E	37SE					
143	WOF	DK GRAY BND SL	N58E	41SE											
144	WOF	DK GRAY BND SL	N60E	56SE											
145	WOF	GREEN WILHITE SL	N70E	46SE											
146	WOF	SAME AS 142 +145	N64E	29SE											
147	WOF	GREEN WILHITE SL	N75E	65SE	N39E	28NW									
148	WOF	GREEN WILHITE SL	N49E	81SE											
149	WOF	GREEN WILHITE SL	N72E	62SE											
150	WOF	GREEN WILHITE SL	N64E	35SE											

Station	Quad	Lithology	Foliation		Bedding		Fold Axis		Joints		Axial Surface		Fold	Intersection Lin.	
			Strike	Dip	Strike	Dip	Plunge	Trend	Strike	Dip	Strike	Dip	Verg.	Plunge	Trend
151	WOF	GREEN WILHITE SL	N84E	24SE											
152	WOF	GREEN WILHITE SL			N12E	11NW									
153	WOF	GREEN WILHITE SL	N56E	45SE											
154	WOF	GREEN WILHITE SL	N84E	71SE			5	79			N85E	33SE			
155	WOF	GREEN WILHITE SL			N65E	34NW									
156	WOF	GREEN WILHITE SL	N30E	42SE											
157	WOF	GREEN WILHITE SL	N20E	50SE											
158	WOF	GREEN WILHITE SL	N55E	56SE											
159	WOF	GREEN WILHITE SL	N52E	44SE											
160	WOF	GREEN WILHITE SL	N52E	34SE											
161	WOF	GREEN WILHITE SL	N54E	36SE											
162	WOF	GREEN WILHITE SL	N55E	56SE											
163	WOF	GREEN WILHITE SL	N70E	31SE											
164	WOF	GREEN WILHITE SL	N56E	31SE											
165	WOF	GREEN WILHITE SL	N34E	59SE											
166	WOF	GREEN WILHITE SL	N45W	34SW											
167	WOF	GREEN WILHITE SL	N51E	22NW											
168	WOF	GREEN WILHITE SL	N39E	48SE			11	217			N52E	49SE			
169	WOF	GREEN WILHITE SL			N54E	8NW									
170	WOF	GREEN WILHITE SL			N80W	27NE									
171	WOF	GRAPHITIC SL - FAULT	N21E	40SE	N56W	70NE									
172	WOF	GREEN WILHITE SL	N24E	20SE											
173	WOF	GREEN WILHITE SL	N36E	46SE											
174	WOF	DK GRAY SULF SLT AND SL	N29E	22SE											
175	WOF	CON + SLATE	N39E	34SE											
176	WOF	SM PEB CONG	N70W	61SW											
177	WOF	DK GRAY SULF SLT AND SL	N17E	26SE											
178	WOF	GREEN WILHITE SL	N57E	46SE											
179	WOF	GREEN WILHITE SL	N62E	24SE											
180	WOF	GREEN WILHITE SL			N56W	13NE									
181	WOF	GREEN WILHITE SL	N42E	15SE			10	208			N32E	39SE			
182	WOF	SM-MD PEB CONG	N59E	60SE											
183	WOF	SM-MD PEB CONG	N74E	64SE											
184	WOF	GREEN WILHITE SL	N51E	54SE	HOR										
185	WOF	GREEN WILHITE SL	N46E	70SE											
186	WOF	GREEN WILHITE SL	N48E	45SE											
187	WOF	GREEN WILHITE SL	N56E	34SE											
188	WOF	GREEN WILHITE SL	N62E	41SE											
189	WOF	GREEN WILHITE SL	N67E	42SE											
190	WOF	GREEN WILHITE SL	N52E	58SE											
191	WOF	GREEN WILHITE SL	N64E	55SE											
192	WOF	GREEN WILHITE SL	N48E	42SE											
193	WOF	GREEN WILHITE SL	N65E	41SE											
194	WOF	GREEN WILHITE SL			N26W	31SW									
195	WOF	GREEN WILHITE SL	N58E	49SE											
196	WOF	GREEN WILHITE SL	N42E	51SE											
197	WOF	GREEN WILHITE SL	N75E	23SE											
198	WOF	GREEN WILHITE SL	N70E	21SE											
199	WOF	GREEN WILHITE SL	N64E	25SE											
200	WOF	GREEN WILHITE SL	N79E	58SE											
201	WOF	GREEN WILHITE SL	N75E	62SE											
202	WOF	GREEN WILHITE SL	N62E	36SE											
203	WOF	GREEN WILHITE SL	N42E	67SE											
204	WOF	GREEN WILHITE SL	N31E	28SE											
205	WOF	DK GRAY SULF SLT AND SL	N34E	47SE					N66W	17SW					
206	WOF	DK GRAY SULF SLT AND SL	N37E	60SE	N31W	15SW								13	209
207	WOF	DK GRAY SULF SLT AND SL	N39E	49SE											
208	WOF	DK GRAY SU-GR SLT + SL	N46E	55SE	N64E	17NW								5	50
209	WOF	DK GRAY SULF SLT AND SL	N40E	55SE											
210	WOF	DK GRAY SULF SLT AND SL	N40E	53SE											
211	WOF	DK GRAY SULF SLT AND SL	N42E	42SE											
212	WOF	DK GRAY SULF SLT AND SL	N51E	47SE											
213	WOF	DK GRAY SULF SLT AND SL	N45E	49SE											
214	WOF	DK GRAY SULF SLT AND SL	N53E	48SE	N36E	26NW								47	140
215	WOF	DK GRAY SULF SLT AND SL	N23E	54SE			17	41			N35E	69SE			
216	WOF	GWAND CS SS	FLOAT												
217	WOF	DK GRAY SULF SLT AND SL	N29E	44SE											
218	WOF	DK GRAY SULF SLT AND SL	FLOAT												
219	WOF	DK GRAY SULF SLT AND SL	N31E	70SE											
220	WOF	DK GRAY SULF SLT AND SL	N64E	51SE											
221	WOF	DK GRAY SILTSTONE	N81E	45SE					N27E	VERT					
222	WOF	DK GRAY SULF SLT AND SL	N80E	27SE											
223	WOF	DK GRAY SULF SLT AND SL	N74E	41SE											
224	WOF	DK GRAY SULF SLT AND SL	N45E	68SE											
225	WOF	DK GRAY SULF SLT AND SL	N30E	55SE											

Station	Quad	Lithology	Foliation		Bedding		Fold Axis		Joints		Axial Surface		Fold Verg.	Intersection Lin.	
			Strike	Dip	Strike	Dip	Plunge	Trend	Strike	Dip	Strike	Dip		Plunge	Trend
251	WOF	DK GRAY SULF SLT AND SL	N47E	55SE											
252	WOF	DK GRAY SULF SLT AND SL	N36E	45SE											
253	WOF	DK GRAY SULF SLT AND SL	N55E	29SE											
254	WOF	SS+CONG	N71E	58SE											
255	WOF	DK GRAY SULF SLT AND SL	N35E	36SE											
256	WOF	S-M CONG + GW	N60E	66SE					N84W	69NE					
257	WOF	S-M CONG + GW	N36E	68SE					N86W	65NE					
258	WOF	CS SS + SL + GW	N60E	63SE											
259	WOF	DK GRAY SULF SLT AND SL	N35E	39SE	N36E	21NW								11	215
260	WOF	CS SS + SL + SS	N38E	29SE			19	36			N39E	72SE			
261	WOF	GREEN WLHTE SL	N50E	32SE	N40W	32NE								24	95
262	WOF	GREEN WLHTE SL	N36E	13SE											
263	WOF	GREEN SL + CS SS/GW	N52E	27SE					N43E	77SW					
264	WOF	CS SS + SL + GW + CONG	N44E	42SE											
265	WOF	SL + CONG	N56E	60SE			9	214			N27E	68SE			
266	WOF	SL + CONG	N49E	37SE			11	214							
267	WOF	DK GRAY SILTSTONE	N52E	56SE	N61E	20NW								3	54
268	WOF	SL + CS SS/GW	N58E	55SE	N21E	14SE								10	66
269	WOF	GREEN WLHTE SL	N66E	71NW			8	211			N31E	40SE			
270	WOF	CONG + GW	N39E	51SE											
271	WOF	SULFIDIC SLATE	HOR		N48E	79SE									
272	WOF	CONG + SL	N50E	40SE					N80W	81SE					
273	WOF	CONG + GW	N47E	61SE					N47E	86SE					
274	WOF	CONG + CS SS	N49E	61SE	N47E	79NW								3	227
275	WOF	DK GRAY SULF SL + VN QTZ	N41E	22SE	N50E	64NW								3	49
276	WOF	DK GRAY SLATE	N31E	64SE											
277	WOF	DK GRAY SULF SLT AND SL	N40E	53SE											
278	WOF	DK GRAY SULF SLT AND SL	N21E	47SE											
279	WOF	CONG	N44E	49SE											
280	WOF	CONG	N51E	49SE											
281	WOF	CONG	N47E	50SE			2	214			N44E	66SE			
282	WOF	CONG	N50E	54SE											
283	WOF	SM PEB CONG	N68E	36SE											
284	WOF	CONTACT-SL+CONG	N82E	33SE											
285	WOF	MD-DK GRAY PYR SILT	N67E	16SE											
286	WOF	SM PEB SULF CONG	N2E	10SE											
287	WOF	MD PEB CONG	N23E	67SE			10	209			N20E	75SE			
288	WOF	DK GRAY SULF SLT AND SL	N40E	84SE											
289	WOF	SM-MD PEB CONG	N44E	26SE	N42E	54NW			N71W	86NE				1	223
290	WOF	SM PEB CG+GRN-GRY GW	N52E	29SE					N59W	84NE					
291	WOF	GW + CONG	N49E	45SE					N2W	VERT					
292	WOF	GRN-GRY GW	N20E	56SE	N75W	55SW								47	153
293	WOF	CS SS+SL INT	N46E	34SE	N44E	31SE			N71W	42NE				10	62
294	WOF	SM-MD PEB CONG	N27E	51SE					N82E	79SE					
295	WOF	MD GRAY BANDED SL	N75E	16SE					N72E	25NW					
296	WOF	MD GRAY SL	N56E	53SE											
297	WOF	CS SS+CONG FLOAT	N39E	41SE	N31E	4NW								1	218
298	WOF	LT-MD GRAY SL	N49E	33SE	N31E	44NW								7	218
299	WOF	LT-MD GRAY SL	N36E	49SE											
300	WOF	LT-MD GRAY SL	N39E	31SE											
301	WOF	LT-MD GRAY SL	N51E	40SE					N7E	55SE					
302	WOF	LT-MD GRAY SL	N55E	51SE	N75W	11SW			N2W	50NE				9	227
303	WOF	LT-MD GRAY SL	N58E	59SE	N56E	10NW								1	238
304	WOF	LT-MD GRAY SL	N84E	56SE	N65W	8SW								7	240
305	WOF	LT-MD GRAY SL	N75E	29SE	N35W	18SW			N39W	79NE				18	231
306	WOF	LT-MD GRAY SL	N35E	26SE	N25E	4SE			N89W	79NE				1	36
307	WOF	LT-MD GRAY SL	N46E	39SE	N14E	14SE								10	58
308	WOF	MD GRAY SL	N37E	47SE											
309	WOF	MD GRAY SULF SL	N59E	28SE	N15W	11SW								9	221
310	WOF	CS SS+GW	N48E	60SE	N20E	47SE								43	80
311	WOF	CONG + CS SS + GW	N80E	35SE					N57E	82NW					
312	WOF	SULF LG PEB CONG	N39E	32SE					N45W	81NE					
313	WOF	MD - LG PEB CONG	N62E	50SE											
314	WOF	MD GRAY SULF SL			N44W	17SW									
315	WOF	MD - LG PEB CONG + SL	N40E	50SE											
316	WOF	MD. GRAY BANDED SL	N65E	31SE	N45W	42SWO									
317	WOF	MD GRAY SL	N66E	44SE											
318	WOF	MD GRAY SULF SL			N80W	31SW									
319	WOF	MD GRAY CS SS	N82E	41SE											
320	WOF	SM PEB CONG	N71E	42SE	N87W	11SW			N71W	VERT				5	245
321	WOF	MD - DK GRAY SL	N56E	54SE	N89E	21SE								15	225
322	WOF	SM PEB CONG	N66E	5SE	N36E	49SE			N22E	79NW				7	214
323	WOF	LT-MD GRAY BANDED SL	N42E	56SE	N42E	10SE								0	222
324	WOF	SULFIDIC SLATE	N49E	40SE											
325	WOF	SULFIDIC SLATE	N67E	17SE	N81W	30SW									

Station	Quad	Lithology	Foliation		Bedding		Fold Axis		Joints		Axial Surface		Fold Verg.	Intersection Lin.	
			Strike	Dip	Strike	Dip	Plunge	Trend	Strike	Dip	Strike	Dip		Plunge	Trend
326	WOF	SM-MD PEB CONG	N23E	37SE											
327	WOF	SM-MD PEB CONG	N89E	14SE					N81E	79SE					
328	WOF	SM-MD PEB CONG	N52E	40NE	N8E	24NW								23	263
329	WOF	SM-MD PEB CONG	N36E	49SE	N28E	8NW								1	215
330	WOF	SM-MD PEB CONG+SL INT	N44E	77SE	N89W	21SW								17	220
331	WOF	SM-MD PEB CONG+SL INT	N24E	44SE	N1W	8NE								4	28
332	WOF	SM PEB CONG	N25E	32SE	N25W	15SW								9	191
333	WOF	CS SS	N20E	55SE											
334	WOF	SM PEB CONG+SL (CON)	N22E	50SE	N29W	24SW			N85W	VERT				15	189
335	WOF	MD GRAY SULF SL	N43E	41SE	N89E	22SE								21	197
336	WOF	MD GRAY SULF SL	N85E	66SE	N3E	49SE								49	96
337	WOF	MD GRAY SULF SL	N50E	30SE	N79W	8SW								7	217
338	WOF	MD GRAY SULF SL	N70E	72SE	N60W	4SW								3	249
339	WOF	MD GRAY SULF SL	N64E	35SE	N79E	25SE								17	218
340	WOF	MD GRAY SULF SL	N61E	50SE	N62W	14NE								11	70
341	WOF	MD - LG PEB CONG	N65E	67SE											
342	WOF	MD GRAY SULF SL	N28E	49SE	N48E	5SE								2	207
343	WOF	MD GRAY SULF SL	N52E	50SE	N50E	16SE								1	53
344	WOF	MD GRAY SULF SL	N35E	32SE	N85E	23SE								23	172
345	WOF	MD GRAY SULF SL	N21E	44SE	N42E	27SE								19	181
346	WOF	MD GRAY SULF SL	N31E	59SE	N22W	24NW								22	45
347	WOF	MD GRAY BANDED SL	N16E	45SE	N39W	15SW			N14W	58NE					
348	WOF	MD GRAY BANDED SL	N51E	39SE	N30W	25SW									
349	WOF	MD GRAY BANDED SL	N56E	26SE	N67W	22SW									
350	WOF	MD GRAY SULF SL	N52E	48SE	N9E	3NW									
351	WOF	MD GRAY SL	N68E	34SE											
352	WOF	SM-LG PEB CONG													
353	WOF	CONG + CS SS + GW	N39E	65SE			4	219			N31E	77SE			
354	WOF	CONG + CS SS + GW	N38E	55SE	N72E	22SE									
355	WOF	MD - DK GRAY SULF SL			N74E	16SE									
356	WOF	PYR/SULF SL + SILT			N88E	26SE									
357	WOF	PYR/SULF SL + SILT	N30E	56SE	N89E	21SE									
358	WOF	MD - DK GRAY SL			N48E	51SE									
359	WOF	MD - DK GRAY SL			N74E	46SE									
360	WOF	MD - DK GRAY SL	N64E	45SE	N5E	17SE			N14E	74SE					
361	WOF	MD GRAY CS SS	N58E	38SE											
362	WOF	GRAY VN MD PEB CONG	N42E	36SE	N89W	32SW									
363	WOF	CONG + CS SS + GW	N56E	42SE											
364	WOF	CS SS			N25W	26SW			N56E	VERT					
365	WOF	MD GRAY SULF SL	N46E	47SE	N21E	8SE									
366	WOF	MD GRAY SULF SL	N56E	30SE											
367	WOF	MD GRAY SULF SL	N62E	24SE											
368	WOF	MD GRAY SULF SL	N30E	66SE	N77E	24SE	17	200			N22E	72SE			
369	WOF	MD GRAY SULF SL	N65E	36SE											
370	WOF	MD - LG PEB SULF CONG													
371	WOF	MD GRAY SULF SL	N65E	33SE											
372	WOF	SM-MD PEB CONG	N52E	46SE											
373	WOF	MD GRAY SULF SL	N82E	42SE											
374	WOF	MD GRAY SULF SL	N22E	61SE											
375	WOF	SM-MD PEB CONG	N27E	47NE											
376	WOF	SM PEB CONG	N27E	21SE											
377	WOF	CS SS	N46E	51SE	N63E	21SE									
378	WOF	CS SS			N78E	14SE									
379	WOF	CS SS	N71W	13SW											
380	WOF	MD GRAY SULF SL FLOAT													
381	WOF	MD GRAY SULF SL	N72E	21SE											
382	WOF	SULF GW + BL QTZ CL	N65E	74SE	N1E	27NW			N4W	70NE					
383	WOF	LT GRAY SLATE + CS SS	N63E	28SE	N84E	46NW									
384	WOF	CONG + CS SS INT	N72E	51SE	N29E	11NW									
385	WOF	CS SS + INT SULF SL	N29E	43SE	N86E	13SE									
386	WOF	CS SS	N69E	64SE	N63E	16SE									
387	WOF	CS SS	N36E	54SE	N34W	13SW									
388	WOF	CS SS + INT SULF SL	N42E	43SE			20	219			N43E	57SE			
389	WOF	CS SS	N52E	55SE	N79W	46SW									
390	WOF	MD-DKGRAY SILT + FN SS	N53E	43SE											
391	WOF	MD - DK GRAY SILT + SL			N87W	19SW									
392	WOF	CG + GW W/ BL QTZ	N11E	43SE					N85E	87NW					
393	WOF	CG + GW W/ BL QTZ	N44E	55SE	N25W	35SW									
394	WOF	CS SS			N25W	38SW			N32E	VERT					
395	WOF	CG + GW W/ BL QTZ			N18E	72NW			N35E	89NW					
396	WOF	CG + GW W/ BL QTZ	N71E	39SE	N12W	57SW			N38E	84SE					
397	WOF	CS SS	N77E	18SE					N50W	VERT					
398	WOF	CS SS	N23E	39SE											
399	WOF	CS SS CONTACT SULF SL	N71E	83SE	N53E	30NW			N82W	84SW					
400	WOF	BO SULF SL	N10E	55SE	N10E	27NW									

Station	Quad	Lithology	Foliation		Bedding		Fold Axis		Joints		Axial Surface		Fold Verg.	Intersection Lin.	
			Strike	Dip	Strike	Dip	Plunge	Trend	Strike	Dip	Strike	Dip		Plunge	Trend
401	WOF	MD - DK GRAY SL	N18E	52SE	N7W	18SW					N25W	81NE			
402	WOF	MD - DK GRAY SL	N40E	28SE	N5W	15SW									
403	WOF	BD SULF SL	N60E	34SE	N6W	24SW									
404	WOF	DK GRAY SULF SLT AND SL	N29E	52SE						N65W	66NE				
405	WOF	DK GRAY SULF SLT AND SL	N35E	35SE	N42W	12SW									
406	WOF	BD SULF SL	N80E	40SE	N40W	4SW									
407	WOF	BD SULF SL			N65W	11SW									
408	WOF	BD SULF SL	N50E	44SE	N48E	26SE									
409	WOF	BD SULF SL	N75E	35SE	N80W	9SW									
410	WOF	BD SULF SL	N25E	23SE	N70W	10SW									
411	WOF	BD SULF SL	N38E	22SE											
412	WOF	BD SULF SL	N35E	32SE											
413	WOF	CG FLOAT													
414	WOF	CG FLOAT													
415	WOF	DK GRAY SULF SLT AND SL	N30E	35SE											
416	WOF	DK GRAY SL + INT CONG			N36W	72NE									
417	WOF	BD SULF SL	N65E	48SE	N12W	28NE				N80E	55NW				
418	WOF	BD SULF SL	N75E	48SE	N85W	22SW									
419	WOF	BD SULF SL	N49E	64SE	N58E	38SE									
420	WOF	BD SULF SL	N59E	38SE											
421	WOF	BD SULF SL	N45E	64SE											
422	WOF	BD SULF SL	N68E	30SE	N45E	2NW									
423	WOF	BD SULF SL	N61E	43SE	N85W	29SW									
424	WOF	BD SULF SL	N60E	82SE											
425	WOF	BD SULF SL FLOAT													
426	WOF	BD SULF SL FLOAT													
427	WOF	BD SULF SL	N35E	65SE											
428	WOF	DK GRAY SL	N38E	83SE											
429	WOF	MD GRAY SULF SL			N5W	30NE				N5W	45SE				
430	WOF	MD GRAY SULF SL	N45E	58SE											
431	WOF	DK GRAY SULF SL	N60E	77SE											
432	WOF	DK GRAY SULF SL	N45E	79SE	N32E	78NW									
433	WOF	SM PEB CONG + INT CS SS	N42E	35SE	N36E	67NW	C								
434	WOF	SM PEB CONG + INT CS SS	N49E	34SE	N3W	15NE									
435	TAP	BLK SILT + INT CONG	N45E	72SE	N10E	25SE									
436	TAP	FN-MD SS + INT SL	N62E	36SE											
437	TAP	SM-MD PEB CONG	N25E	20SE											
438	TAP	MD GRAY CS SS + GW	N45E	40SE			2	29			N42E	46SE			
439	TAP	SM PEB CONG + GW	N85E	28SE											
440	TAP	SM-MD PEB SULF CONG	N30E	66SE	N30E	30SE									
441	TAP	SM-MD PEB SULF CONG	N53E	54SE	N20E	35SE									
442	TAP	SM-MD PEB CONG + SL			N25E	53SE									
443	TAP	CONG + CS SS	N32E	72SE	N50E	65SE									
444	TAP	SM PEB CONG + SL	N66E	59SE											
445	TAP	SM PEB CONG + SL	N7E	58SE	N89W	21SW									
446	TAP	SM PEB CONG + SL	N29E	84SE	N56W	30SW									
447	TAP	DK GRAY SL	N10E	60SE	N60E	30SE									
448	TAP	DK GRAY SL	N3E	54SE	N55E	25SE									
449	TAP	DK GRAY SL	N30E	60SE			2	49			N36E	56SE			
450	TAP	LT GRAY SLATE + CONG	N11E	37SE	N42E	14SE									
451	TAP	SM-MD PEB CONG			N30E	23SE									
452	TAP	SM-MD PEB CONG	N44E	33SE						N1E	80NW				
453	TAP	LT GRAY GW	N50E	42SE	N66E	22SE				N15W	VERT				
454	TAP	DK SL + FLDSP GRNS	N15E	42SE	N80E	20SE									
455	TAP	SM PEB BL QTZ CONG	N55E	70SE											
456	TAP	SM PEB BL QTZ CONG	N8E	43SE											
457	TAP	MD GRAY SULF SL			N65E	48SE									
458	TAP	SM-MD PEB CONG	N20E	30SE						N50W	72NE				
459	TAP	MD GRAY SULF SL	N45E	49SE											
460	TAP	SM-MD PEB CONG	N70E	45SE											
461	TAP	SM-MD PEB CONG + SL	N44E	60SE			10	238			N52E	69SE			
462	TAP	SM-MD PEB CONG + SL	N70E	20SE											
463	TAP	SM-MD PEB CONG + SL	N12E	53SE											
464	TAP	SM-MD PEB CONG + SL	N64E	54SE											
465	WOF	DK-MD GRAY SL			N45W	25NE									
466	WOF	MD GRAY FELD GW	N80E	49NW											
467	WOF	SM PEB CG + LG PEB CG			N45W	72NE									
468	WOF	MD GRAY SULF SL	N89E	68NW											
469	WOF	SM PEB CONG			N34E	VERT									
470	WOF	MD-DK GRAY BD SL + SILT	N65E	30NW	N15W	28SW									
471	WOF	MD - DK GRAY SL	N38E												
472	WOF	MD - DK GRAY SL	N28E	30NW	N20W	34SW	C								
473	WOF	MD - DK GRAY SL			N27E	30NW									
474	WOF	MD - DK GRAY SL	N50W	48SW	N25E	33NW				N13W	48NE				
475	WOF	SULF GW	N10E	26NW											

Station	Quad	Lithology	Foliation		Bedding		Fold Axis		Joints		Axial Surface		Fold Verg.	Intersection Lin.	
			Strike	Dip	Strike	Dip	Plunge	Trend	Strike	Dip	Strike	Dip		Plunge	Trend
476	WOF	SM PEB CONG + INT SL	N63E	48SE											
477	WOF	DK GRAY SL + SILT	N10E	29SE											
478	WOF	SM PEB CONG			N47E	20SW									
479	WOF	CS SS + GW	N70E	46SE											
480	WOF	SM PEB CONG + INT SL	N75E	26SE											
481	WOF	LT-MD GRAY SULF SL	N20W	25SW											
482	WOF	LT GRAY CS SS	N30E	47SE											
483	WOF	LT GRAY CS SS	N57E	45SE			6	230			N62E	57SE			
484	WOF	MD-LG PEB CONG	N15E	42SE											
485	WOF	FELDSPATHIC GW	N55E	65SE											
486	WOF	MD-LG PEB CONG	N80E	48SE											
487	WOF	LT-DK GRAY SULF SL	N39E	31SE	N25W	28SW									
488	WOF	SM PEB CONG + GW	N71E	20SE											
489	WOF	LG PEB CONG	N40E	4SE											
490	WOF	FELDSPATHIC GW	N75E	50SE											
491	WOF	LT-DK GRAY SULF SL + SILT			N43W	41SW									
492	WOF	LT GRAY SULF SL			N52W	42SW									
493	WOF	SL + SILT	N33E	39SE											
494	WOF	SL + SILT	N73E	54SE	N28E	42SE									
495	WOF	MD PEB CONG	N30E	44SE	N25W	52SW									
496	WOF	CS SS + FELD GW	N76E	53NW											
497	WOF	SL + SILT	N70E	45NW											
498		SM PEB CONG + GW							N35W	VERT					
499		CS SS + GW	N88E	39SE	N55W	30SW									
500		DK GRAY-GRN SILT FLOAT													
501		DK GRAY SILT	N50E	55SE	N35E	52NW									
502	WOF	LT-MD GRAY SULF SL	N80E	33SE	N87E	20SE									
503	WOF	SM PEB CONG + GW	N25E	30SE	N80W	15SW									
504	WOF	DK GRAY-BLCK SL + SILT	N72E	63SE											
505	WOF	DK GRAY-BLCK SL + SILT	N22E	63SE	N84W	14SW									
506	WOF	LT GRAY SM PEB CONG	N5E	25SE											
507	WOF	DK GRAY-BLCK SL + SILT	N23E	25SE					N10W	58NE					
508	WOF	SM PEB CONG	N11E	55SE											
509	WOF	LG PEB CONG	N2E	26SE											
510	WOF	SM-LG PEB CONG	N50E	56SE	N60E	26SE									
511	WOF	DK GRAY-BLCK SL + SILT			N30E	25SE									
512	WOF	SM PEB CONG	N30E	16NW	N85W	8NE									
513	WOF	BND MD GRAY SULF SL	N75E	30SE	N15W	27NE									
514	WOF	BND MD GRAY SULF SL													
515	WOF	SM PEB CONG													
516	WOF	MD GRAY SM PEB CONG	N65E	55SE											
517	WOF	MD GRAY SM PEB CONG													
518	WOF	MD GRAY SM PEB CONG													
519	WOF	MD-LG PEB CONG													
520	WOF	DK GRAY-BLCK SL + SILT	N60E	35SE											
521		MD GRAY MD-CS SS	N42E	56SE	N45W	10NE									
522		DK GRAY SULF SLT AND SL	N20E	26SE	N80W	29SWC									
523		SULF SM PEB CONG			N50W	40SW									
524		SULF SM PEB CONG	N77E	20SE											
525		DK GRAY-BLCK SL + SILT			N60E	47NW									
526		MD GRAY CS SS	N77E	24SE											
527		GRAY-GRN SL + CS SS	N80E	47SE											
528		DK GRAY-BLCK SL + SILT			N20E	35SE									
529		DK GRAY-BLCK SL + SILT	N40E	53SE	N55W	41NE									
530		DK GRAY-BLCK SL + SILT	N15E	48SE	N68E	41SE									
531		DK GRAY-BLCK SL + SILT	N45E	63SE											
532		DK GRAY-BLCK SL + SILT	N50E	43SE	N5E	26SE									
533		DK GRAY-BLCK SL + SILT	N60E	64SE	N84E	16SE									
534		DK GRAY-BLCK SL + SILT	N61E	71SE	N62E	41SE									
535		SM PEB CONG			N78E	24SE									
536		BL QTZ CONG			N89E	23SE									
537		BL QTZ CONG			N49E	53NW									
538		SM-LG PEB CONG	O	O	N75E	58SE									
539		WLHTE SLATE	N59E	82SE	N38E	39NW									
540		WLHTE SLATE			N43E	34NW									
541		WLHTE SLATE			N55E	55NW									
542		WLHTE SLATE			N71E	42NW									
543		WLHTE SLATE	N60E	38SE	N70W	12NE									
544		WLHTE SLATE			N89E	31NW									
545		WLHTE SLATE	N61E	20SE	N85E	13NW									
546	WOF	MD-DK GRAY BND SILT	N80W	26SW	N25E	63NW									
547	WOF	SM-LG PEB CONG W/ BL Q	N55E	36SE	N30E	32NW									
548	WOF	SM PEB CONG	N42E	55SE	N29E	21SE									
549	WOF	SM PEB CONG	N55E	28SE	N43E	70SE	O								
550	WOF	SM-MD PEB CONG	N24E	40SE											

Station	Quad	Lithology	Foliation		Bedding		Fold Axis		Joints		Axial Surface		Fold Verg.	Intersection Un.	
			Strike	Dip	Strike	Dip	Plunge	Trend	Strike	Dip	Strike	Dip		Plunge	Trend
551	WOF	SM-MD PEB CONG	N20E	25SE											
552	WOF	SM-MD PEB CONG	N30E	47SE	N5E	75SE O									
553	WOF	BND MD GRAY SULF SL			N25E	32SE									
554	WOF	BND MD GRAY SULF SL	N28E	34SE											
555	WOF	SM-LG PEB CONG	N15E	67SE											
556	WOF	SM-LG PEB CONG	N30W	66NE	N45E	18SE									
557	WOF	SM-LG PEB CONG			N55E	12SE									
558	WOF	SM-MD PEB CONG	N53E	38SE	N1E	10SE									
559	WOF	SULFIDIC GW			N80W	15SW									
560	WOF	SULFIDIC FELD SS			N25E	23SE									
561	WOF	SULFIDIC CS SS	N38E	44SE											
562	WOF	SULF. FE. FELD SS	N71E	67SE	0	0									
563	WOF	SM PEB CONG			N20W	15NE									
564	WOF	CS FELD SS	N55E	52SE	N22E	10SE									
565	WOF	MED-CS FELD SS	N69E	40SE	N82E	11SE									
566	WOF	CS SS	N15E	76SE	N89E	11SE									
567	WOF	CS SS (EVEN-GRAINED)			N22E	27SE									
568	WOF	CS SS	N31E	70SE	N38E	25SE									
569	WOF	CS SS + GW			N89E	19NW									
570	WOF	CS SS + GW			N52E	31SE									
571	WOF	CS SS			N24E	30SE									
572	WOF	CS SS			N40E	26SE									
573	WOF	CS SS			N70W	32SW									
574	WOF	CS SS + INT SL	N50E	50SE	N1E	80SE O									
575	WOF	BLCK SL + SILT FLOAT													
576	WOF	BLCK SL + SILT FLOAT													
577	WOF	BLCK SL + SILT FLOAT													
578	WOF	BLCK SL + SILT	N32E	46SE	N46E	24SE									
579	WOF	CONTACT - BL SL + CS SS			N8E	16SE			N68E	VERT					
580	WOF	SM-MD PEB CONG			N32E	20SE									
581	WOF	CONG + SL INT	N15E	44SE	N73E	9SE									
582	WOF	BLCK SL + SILT			N45E	30SE									
583	WOF	BLCK SL + SILT			N74E	10SE									
584	WOF	BLCK SL + SILT			N51E	23SE									
585	WOF	FINE-GRAINED SS			N26E	20SE									
586	WOF	CONTACT - BL SL + CS SS			N32E	66NW									
587	WOF	CS SS			N80E	50SE									
588	WOF	BLCK SL + SILT			N74E	14SE									
589	WOF	BLCK SL + SILT			N5E	14NW									
590	WOF	MD PEB CONG			N10W	12SW									
591	WOF	BND SL + SILT	N74E	57SE	N25W	13SW									
592	WOF	SL + LG PEB CONG			N78E	15NW									
593	WOF	BLCK SL + SILT			N72E	8SE									
594	WOF	BLCK SL + SILT			N78E	6SE									
595	WOF	BLCK SL + SILT			N62E	9SE									
596	WOF	BLCK SL + SILT FLOAT													
597	WOF	MD PEB CONG			N40E	26SE									
598	WOF	BLCK SL + SILT			0	0									
599	WOF	CONG + CS SS			N39E	29E									
600	WOF	CONG + CS SS			N47E	38SE									
601	WOF	BND SULF SL + SILT			N65E	29SE									
602	TAP	CS FELD SS/CONG/INT SL			N23E	42SE									
603	TAP	CS FELD SS/CONG/INT SL			N29E	43SE									
604	WOF	CS SS + GW			N38E	21SE									
605	WOF	DK GRAY SL			N75W	24SW									
606	WOF	BLCK-DK GRAY SULF SL			N50E	24SE									
607	WOF	BLCK-DK GRAY SULF SL			N36W	15SW									
608	WOF	BL QTZ CONG FLOAT													
609	WOF	CS SS/GW/FINE PEB FLOAT													
610	WOF	CS SS/GW/FINE PEB FLOAT													
611	WOF	CS SS/GW/FINE PEB			N30E	38NW									
612	WOF	BLCK SILT + INT FN SS			N5E	50NW									
613	WOF	SULF BND SILT			N85E	44NW									
614	WOF	CS SS W/ BL QTZ			N28W	8SW									
615	WOF	DK GRAY-BLCK SULF SL			N55E	48SE									
616	WOF	DK GRAY-BLCK SILT	N30E	35SE	N85E	19SE									
617	WOF	FINE PEB CONG	N32E	54SE	N85E	8SE									
618	WOF	SM-MED PEB CONG	N45E	60SE	N40E	20SE									
619	WOF	LT GRY-GREEN SILT			N35E	16SE									
620	WOF	MD-LG PEB CONG			N44E	27SE									
621	WOF	MD-LG PEB CONG			N20E	41SE									
622	WOF	MD-LG PEB CONG + CS SS			N30E	26SE									
623	WOF	MD-LG PEB CONG + CS SS			N85E	22SE									
624	WOF	MD-LG PEB CONG + CS SS			N40W	25SW									
625	WOF	MD-LG PEB CONG + CS SS			N40E	15SE									

Station	Quad	Lithology	Foliation		Bedding		Fold Axis		Joints		Axial Surface		Fold Verp.	Intersection Un.	
			Strike	Dip	Strike	Dip	Plunge	Trend	Strike	Dip	Strike	Dip		Plunge	Trend
626	WOF	MD-LG PEB CONG + CS SS			N41E	34SE									
627	WOF	BND DK GRAY SILT	N38E	54SE	N60W	35SW									
628	WOF	LG PEB CONG + CS SS			N88E	21SE									
629	WOF	LG PEB CONG + CS SS			N40E	26SE									
630	WOF	LG PEB CONG + CS SS			N79E	26SE									
631	WOF	LG PEB CONG + CS SS			N62E	19SE									
632	WOF	LT GRY-GREEN BND SILT			N60E	28SE									
633	WOF	LG PEB CONG + CS SS			N55E	26SE									
634	WOF	LT GRY-GREEN BND SILT			N50E	9SE									
635	WOF	MD EVEN GRAINED SS			N58E	24SE									
636	WOF	CS SS + GW			N31E	24SE									
637	WOF	CS SS + GW	N57E	55SE											
638	WOF	SM-LG PEB CONG			N52E	22SE									
639	WOF	MD GRY-GREEN SULF SS			N50E	34SE									
640	WOF	MD GRY-GREEN SULF SS			N5E	41SE									
641	WOF	CS SS/GW/FINE PEB FLOAT													
642	WOF	CS SS/GW/FINE PEB FLOAT													
643	WOF	CS SS/GW/FINE PEB FLOAT													
644	WOF	CS SS/GW/FINE PEB FLOAT													
645		SM-LG PEB CONG			N2E	37SE									
646		MD-LG PEB CONG			N40E	28SE									
647	WOF	GRN WLHTE SLATE	N82W	55SW	N71E	44NW									
648	WOF	QTZ-FELD CONG													
649	WOF	GRN WLHTE SLATE			N68E	VERT									
650	WOF	SM PEB CONG			N64E	25NW									
651	WOF	SM PEB CONG			N50E	29SE									
652	WOF	SM PEB CONG			N50E	34SE									
653	WOF	DK GRAY-BLCK SILT			N55E	83SE O									
654	WOF	DK GRAY-BLCK SILT			N43E	VERT									
655	WOF	MD GRAY BND SL/SILT	N60E	76NW	N19E	52NW									
656	WOF	MED-LG PEB CONG			N48E	51NW									
657	WOF	MD GRAY BND SL/SILT			N70E	35NW									
658	WOF	MD GRAY BND SL/SILT	N62E	61NW	N50E	32NW									
659	WOF	MD GRAY BND SL/SILT			N41E	58SE									
660	WOF	MD GRAY BND SL/SILT FL													
661	WOF	BND SULF SL			N75E	29SE									
662	WOF	MD-LG PEB CONG			N43W	25SW									
663	WOF	SM-MD PEB CONG			N45W	51NE									
664	WOF	MD-LG PEB CONG			N35W	35NE									
665	WOF	CON - CS SS/CONG + SF SL			N14E	15SE									
666	WOF	FN-MD SULF SS + SM CG			N40W	18SW									
667	WOF	MD GRAY BND SL/SILT			0	0									
668	WOF	CONG + SL/SILT INT			N45E	32SE									
669	WOF	MD-LG PEB CONG			N12E	22SE									
670	WOF	DK GRAY-BLCK SILT			N85E	15NW									
671	WOF	MD-LG PEB CONG			N86W	32NE									
672	WOF	MD-LG PEB CONG			N84W	19SW									
673	WOF	MD-LG PEB CONG			N40E	35NW									
674	WOF	MD-LG PEB CONG			N51E	22NW									
675	WOF	WLHTE SILTSTONE			N12E	38NW									
676	WOF	WLHTE SILTSTONE	N60E	25SE	N14W	24NE									
677	WOF	WLHTE SILTSTONE			N55E	15NW									
678	WOF	WLHTE SILTSTONE			N22E	39NW									
679	WOF	WLHTE SILTSTONE			N70E	25NW									
680	WOF	WLHTE SILTSTONE			N74E	31NW									
681	WOF	WLHTE SILTSTONE			N45E	36NW									
682	WOF	MD GRY-BLCK SULF SILT	N5E	37SE	N37W	17SW									
683	WOF	MD GRY-BLCK SULF SILT			N60E	31SE									
684	WOF	MD GRY-BLCK SULF SILT			N62W	21NW									
685	WOF	SULF BLCK-GRN SL	N28E	65SE	N38E	32SE									
686	WOF	BND SULF SILT			N65E	27SE									
687	WOF	BND SULF SILT			N50E	15SE									
688	WOF	BND SULF SILT			N20E	21SE									
689	WOF	DK + LT GRY BND SILT			N4E	32SE									
690	WOF	DK + LT GRY BND SILT			N15W	34SE									
691	WOF	LT-GRY SULF SILT	N14E	79SE	N38E	37NE									
692	WOF	CS SS + CONG			N77W	36SW									
693	WOF	MD-LG PEB CONG			N45E	20NW									
694	WOF	LG PEB CONG			N45E	31SE									
695	WOF	LG PEB CONG													
696	WOF	LG PEB CONG			N35E	VERT									
697	WOF	MD GRY SS + CONG			N30E	49SE									
698	WOF	MLT COLORED SILT			N50E	16NW									
699	TAP	EVEN-GRAINED SS			N20E	52SE									
700	TAP	EVEN-GRAINED SS			N11E	21SE									

Station	Quad	Lithology	Foliation		Bedding		Fold Axis		Joints		Axial Surface		Fold Verg.	Intersection Un.	
			Strike	Dip	Strike	Dip	Plunge	Trend	Strike	Dip	Strike	Dip		Plunge	Trend
701	TAP	SILT + INT SS	N22E	55SE	N71E	47SE									
702	TAP	SILT + INT SS			N60E	27SE									
703	TAP	EVEN-GRAINED SS			N79E	40SE									
704	TAP	EVEN-GRAINED SS			N56E	34SE									
705	TAP	FINE-GRAINED SS			N70E	41SE									
706	TAP	SM PEB CONG - GRANITE C			N80E	24SE									
707	TAP	CS SS + CONG			N47E	29SE									
708	TAP	CS SS + CONG			N41E	41SE									
709	TAP	CS SS + CONG			N42E	29SE									
710	TAP	EVEN-GRAINED SS			N39E	47SE									
711	TAP	EVEN-GRAINED SS			N54E	30SE									
712	TAP	EVEN-GRAINED SS			N64E	43SE									
713	TAP	EVEN-GRAINED SS			N54E	36SE									
714	TAP	EVEN-GRAINED SS	N50E	50SE	N45E	15SE									
715	TAP	CS SS + CONG			N25E	29NW									
716	TAP	EVEN-GRAINED SS			N25E	29SE									
717	TAP	CS SILT/FINE SS			N52E	24SE									
718	TAP	CS SS + SM PEB CONG			N64E	24SE									
719	TAP	EVEN-GRAINED SS			N55E	39SE									
720	TAP	EVEN-GRAINED SS	N35E	58SE											
721	TAP	EVEN-GRAINED SS	N42E	58SE											
722	TAP	CS SS + SM PEB CONG			N68E	39SE									
723	TAP	CS SS + SM PEB CONG			N68E	34SE									
724	TAP	EVEN-GRAINED SS			N82E	19SE									
725	TAP	CS SS + SM PEB CONG			N70E	29SE									
726	TAP	FELDSPATHIC GW			N24E	39SE									
727	TAP	SM PEB CONG			N30E	30SE									
728	TAP	SM PEB CONG + INT SL			N39E	42SE									
729	TAP	SM PEB CONG			N75E	24SE									
730	TAP	QUATERNARY ALLUVIUM													
731	TAP	EVEN-GRAINED SS			N18E	31SE									
732	TAP	EVEN-GRAINED SS			N18E	10SE									
733	TAP	CS SILT AND MD GRY SL			N20E	5SE									
734	TAP	CS SILT AND MD GRY SL	N58E	36SE	N14W	20SW									
735	TAP	CS SILT AND MD GRY SL			N45E	15SE									
736	TAP	BL QTZ CONG													
737	TAP	MD GRY MD GRAINED SS			N2W	51SW									
738	TAP	MD GRY MD GRAINED SS			N6W	30SW									
739	TAP	SM-MD PEB CONG			N20W	19SW									
740	TAP	MD GRY CS SS			N75W	22SW									
741	TAP	MD GRY CS SS	N10E	55SE	N40W	2SW									
742	TAP	DK GRY SULF SL			N30E	15SE									
743	TAP	DK GRY SM PEB CONG			N6E	30SE									
744	TAP	MD GRY MD/CS SS			N35E	34SE									
745	TAP	DK GRY SM PEB CONG			N49E	26SE									
746	TAP	DK GRY MD/LG PEB CONG			N30E	32SE									
747	WOF	LT GRY BND SULF SL			N56E	20SE									
748	WOF	LT GRY BND SULF SL			N38E	15SE									
749	WOF	DK GRY SULF SILT			N54E	55SE									
750	WOF	BLCK GRPH/SULF SL			N65E	56SE									
751	WOF	BLCKGRPH/SULF SL			N42E	50SE									
752	WOF	CS SS W BL QTZ			N42E	21SE									
753	WOF	GRN-GRY SILT			N10W	39NE									
754	WOF	DK GRY SULF SL/SILT			N32E	21SE									
755	WOF	DK GRY SULF SL/SILT			N60E	48SE									
756	WOF	DK GRY SULF SL/SILT			N43E	19SE									
757	TAP	CS DK GRY SS			N87E	29SE									
758	TAP	FELD SM PEB CONG			N28E	42SE									
759	TAP	FELD SM PEB CONG			N28E	34SE									
760	TAP	SM PEB CONG + INT SILT	N54E	51SE	N21E	41SE									
761	TAP	CS FELD SS			N34E	32SE									
762	TAP	CS FELD SS	N54E	38SE	N42E	66SE 0									
763	TAP	CS FELD SS			N58E	36SE									
764	TAP	CS FELD SS + GRANULE C	N13E	64SE	N70E	VERT									
765	TAP	CS FELD SS			N15E	58SE	22	229			N2E	51SE	NW		
766	TAP	GRANULE CONG					63	222					NW		
767	TAP	CS SS + GW					39	221					NW		
768	TAP	CS SS + GW			N44E	33SE									
769	TAP	FELDSPATHIC GW			N45E	28SE									
770	TAP	GRANULE CONG			N57E	41SE									
771	TAP	GRANULE CONG			N36E	28SE									
772	TAP	GRANULE CONG			N38E	25SE									
773	TAP	GRANULE CONG													
774	TAP	GRANULE CONG			N45E	16SE									
775	TAP	CS SS + GW			N58E	29SE									

Station	Quad	Lithology	Foliation		Bedding		Fold Axis		Joints		Axial Surface		Fold	Intersection Lin.	
			Strike	Dip	Strike	Dip	Plunge	Trend	Strike	Dip	Strike	Dip	Verg.	Plunge	Trend
778	TAP	FN-MD GRAINED SS			N40E	23SE									
777	TAP	GW + GRANULE CONG			N54E	44SE									
778	TAP	FELDSPATHIC GW			N54E	37SE									
779	TAP	FELDSPATHIC GW	N44E	46SE											
780	TAP	FELDSPATHIC GW	N41E	57SE	N42E	22SE									
781	TAP	DK/LT GRY BND SL	N74E	77SE	N17E	39SE									
782	TAP	CS SS + GWW/ BL QTZ	N39E	59SE	N49E	36SE									
783	TAP	SULF/GRAPH BDN SILT	N60E	44SE	N53E	81SE O	9	231					NW		
784	TAP	CS SS + GW + CONG			N48E	43SE									
785	TAP	MULTIPLE LITHOLOGIES			N50E	40SE	5	233			N53E	31SE	NW		
786	TAP	MD-CS SS					8	237					NW		
787	TAP	MD PEB CONG													
788	TAP	FN-MD GRAINED GW			N30E	26SE									
789	TAP	FN-MD GRAINED GW			N69E	45SE									
790	TAP	SULF/GRAPH BDN SILT			N65E	53SE									
791	TAP	LG PEB CONG			N30E	24SE									
792	TAP	GW + SM PEB CONG			N65E	68SE									
793	TAP	GW + SM PEB CONG			N68E	65SE									
794	TAP	SULF/GRAPH BDN SILT			N68E	56SE									
795		CS SS + GW			N69E	68SE									
796		GW + CS SS + INT SL			N70E	VERT									
797		DK GRY SULF BND SL	N52E	49SE											
798		LT. GRY SULF SL/SILT	N52E	27SE											
799		LT. GRY SULF SL/SILT	N31E	34SE											
800	WOF	DK GRY SULF/GRAPH SL	N37E	41SE											
801	WOF	LT GRY-GRN SILT	N26E	41SE											
802	WOF	DK.GRY SULF SL/SILT			N40E	41NW									
803	WOF	DK GRY SULF SL/SILT	N36E	39SE											
804	WOF	DK GRY SULF SL/SILT	N51E	35SE											
805	WOF	DK GRY SULF SL/SILT	N43E	37SE											
806	WOF	DK GRY SULF SL/SILT	N54E	50SE											
807	WOF	DK GRY SULF SL/SILT	N52E	63SE											
808	WOF	DK GRY SL + INT CS SS			N31E	63NW									
809	WOF	DK GRY SL + INT CS SS	N42E	76SE											
810	WOF	LT/DK GRY BND SL/SILT	N39E	37SE											
811	WOF	GW + SM PEB CONG			N62E	64SE									
812	WOF	MD/DK GRY SULF SL/SILT	N74E	34SE											
813	TAP	FELDSPATHIC SANDSTONE			N65E	13SE									
814	TAP	EVEN-GRAINED SS			N76E	15SE									
815	TAP	COARSE SANDSTONE			N85E	41SE									
816	TAP	COARSE SANDSTONE			N43E	25SE									
817	TAP	SM PEB CONG			N80W	31SW									
818	TAP	SM PEB CONG			N88E	32SE									
819	TAP	SM PEB CONG + CS SS			N57E	47SE									
820	TAP	SM PEB CONG + CS SS			N19E	32SE									
821	TAP	SM PEB CONG + CS SS			N71E	46SE									
822	TAP	SM PEB CONG + CS SS			N69E	14SE									
823	TAP	CS SS + SLATE			N44E	27SE									
824	TAP	COARSE SANDSTONE			N67E	31SE									
825	TAP	COARSE SANDSTONE			N61E	21SE									
826	TAP	COARSE SANDSTONE			N35E	33SE									
827	TAP	COARSE SANDSTONE			N6E	27SE									
828	TAP	COARSE SANDSTONE			N15E	31SE									
829	TAP	EVEN-GRAINED SS			N48E	27SE									
830	TAP	EVEN-GRAINED SS			N67E	22SE									
831	TAP	SM PEB CONG + CS SS			N75E	35SE									
832	TAP	SM PEB CONG + CS SS			N69E	26SE									
833	TAP	EVEN-GRAINED SS			N85E	17SE									
834	TAP	EVEN-GRAINED SS			N75E	35SE									
835	TAP	EVEN-GRAINED SS			N28E	53SE									
836	TAP	CS SS + GW			N80E	24SE									
837	TAP	CS SS + GW			N73W	32SW									
838	TAP	CS SS + GW			N54E	19SE									
839	TAP	CS SS + GW			N68E	23SE									
840	TAP	CS SS + GW			N42E	26SE									
841	TAP	COARSE SANDSTONE			N79E	22SE									
842	TAP	COARSE SANDSTONE			N25E	31SE									
843	TAP	SULFIDIC GW			N86E	27SE									
844	TAP	SULFIDIC GW			N85W	13SW									
845	TAP	SULFIDIC GW			N55E	23SE									
846	TAP	COARSE SANDSTONE			FLOAT										
847	TAP	COARSE SANDSTONE			FLOAT										
848	TAP	COARSE SANDSTONE			FLOAT										
849	TAP	COARSE SANDSTONE			FLOAT										
850	TAP	COARSE SANDSTONE			N89E	17SE									

Station	Quad	Lithology	Foliation		Bedding		Fold Axis		Joints		Axial Surface		Fold Verg.	Intersection Lin.	
			Strike	Dip	Strike	Dip	Plunge	Trend	Strike	Dip	Strike	Dip		Plunge	Trend
851	TAP	COARSE SANDSTONE			N80W	15SW									
852	WOF	QUARTZ SANDSTONE			N24E	51SE									
853	WOF	QUARTZ SANDSTONE			N35E	29SE									
854	WOF	COARSE SANDSTONE			N86W	27SW									
855	WOF	COARSE SANDSTONE			N36E	34SE									
856	WOF	SM PEB CONG + GW			N52E	29SE									
857	WOF	COARSE SANDSTONE			N71W	35SW									
858	WOF	EVEN-GRAINED SS			N39E	31SE									
859	WOF	COARSE SANDSTONE			N42E	55SE									
860	WOF	SM PEB CONG			N56E	5SE									
861	WOF	SM PEB CONG			N70E	13SE									
862	WOF	SM PEB CONG			N53E	12SE									
863	WOF	SM PEB CONG			N64E	25SE									
864	WOF	GREEN WLHTE SL			N89E	31SE									
865	WOF	GREEN WLHTE SL			N48E	42SE									
866	WOF	GREEN WLHTE SL			N75E	51SE									
867	WOF	CS SS + GW			N18E	70SE									
868	WOF	CS SS + GW			N51E	25SE									
869	WOF	SM PEB CONG			N67E	30SE									
870	WOF	SM-LG PEB CONG			N70E	20SE									
871	WOF	SM PEB CONG			N68E	20SE									
872	WOF	COARSE SANDSTONE			N66E	20SE									
873	WOF	SM PEB CONG			N90E	10S									
874	WOF	SM PEB CONG			N68E	10SE									
875	WOF	BLACK SULF SLATE			N21E	55NW									
876	WOF	BLACK SULF SLATE			N21E	55NW									
877	WOF	GREEN WLHTE SL	N60E	77SE											
878	WOF	GREEN WLHTE SL			N34E	45SE									
879	WOF	GREEN WLHTE SL	N52E	19SE											
880	WOF	GREEN WLHTE SL	N47E	25SE											
881	WOF	GREEN WLHTE SL			N66E	76SE									
882	WOF	GREEN WLHTE SL			N72E	75SE									
883	WOF	GREEN WLHTE SL	N62E	35SE											
884	WOF	COARSE SANDSTONE			N20E	35SE									
885	WOF	GRAPHITIC SLATE			N44E	50SEO									
886	WOF	GRAPHITIC SLATE			N18E	40SE									
887	WOF	GRAPHITIC SLATE			N2E	30SE									
888	TAP	GRAPHITIC SL + GW			N88E	70SEO									
889	TAP	GRAPHITIC SL + SS	N51E	32SE											
890	TAP	GRAPHITIC SL + SS	N32E	41SE											
891	TAP	GRAPHITIC SL + SS			N52E	25SE									
892	TAP	GRAPHITIC SL + SS			N44W	30SW									
893	TAP	CS SS + GW			N88W	25SW									
894	TAP	COARSE SANDSTONE			N58E	25SE									
895	TAP	COARSE SANDSTONE			N66E	22SE									
896	TAP	COARSE SANDSTONE			N52E	42SE									
897	TAP	SM PEB CONG			N56E	32SE									
898	TAP	COARSE SANDSTONE			N59E	28SE									
899	TAP	GRAPHITIC SL + GW			N55E	21SE									
900	TAP	GRAPHITIC SL + GW			N52E	23SE									
901	TAP	GRAPHITIC SL + GW			N23E	11SE									
902	TAP	GRAPHITIC SL + GW			N45E	17SE									
903	TAP	GRAPHITIC SL + GW			N90E	25SE									
904	TAP	GRAPHITIC SLATE			N44E	15SE									
905	TAP	COARSE SANDSTONE			N43E	34SE									
906	TAP	COARSE SANDSTONE			N80E	10SE									
907	TAP	GRAPHITIC SLATE			N68E	22SE									
908	TAP	GRAPHITIC SLATE	N44E	24SE											
909	TAP	GRAPHITIC SLATE			N42E	75SE									
910	TAP	CS SS + GW			N29E	54SE									
911	TAP	CS SS + GW			N42E	42SE									
912	TAP	DARK GRAY SLATE			N47E	54SE									
913	TAP	DARK GRAY SLATE	N40E	55SE											
914	TAP	GW			N35E	29SE									
915	TAP	GRAPHITIC SLATE	N71E	27NW											
916	TAP	GRAPHITIC SLATE			N87E	40SE									
917	TAP	GRAPHITIC SLATE			N58E	20SE									
918	TAP	GW			N81E	33SE									
919	TAP	DARK GRAY SLATE			N43E	15SE									
920	TAP	GRAPHITIC SLATE	N44E	32SE	N60E	25SE									
921	TAP	DARK GRAY SLATE			N75E	15SE									
922	TAP	DARK GRAY SLATE			N80E	35SE									
923	WOF	DARK GRAY SLATE			N60W	30SW									
924	WOF	DARK GRAY SLATE + SILT			N90E	20S									
925	WOF	DARK GRAY SLATE + SILT			N38E	75NW									

Station	Quad	Lithology	Foliation		Bedding		Fold Axis		Joints		Axial Surface		Fold	Intersection Lin	
			Strike	Dip	Strike	Dip	Plunge	Trend	Strike	Dip	Strike	Dip	Verg.	Plunge	Trend
926	WOF	DARK GRAY SLATE			N61E	85SE									
927	TAP	DARK GRAY SLATE			N60E	65SE									
928	TAP	DARK GRAY SLATE	N49E	45SE											
929	TAP	DARK GRAY SLATE			N57E	55SE									
930	TAP	GRAPHITIC SL + GW	N65E	54SE											
931	TAP	GRAPHITIC SL + GW			N42E	40SE									
932	TAP	CS SS + GW			N67E	50SE									
933	TAP	CS SS + GW			N8W	10NE									
934	TAP	GW + INTBEDDED SL			N55E	20NW									
935	TAP	GW + INTBEDDED SL			N62E	30SE									
936	TAP	GW + INTBEDDED SL			N19E	40SE									
937	TAP	GW + INTBEDDED SL			N25E	44SE									
938	TAP	GW + INTBEDDED SL			N18E	37SE									
939	TAP	CS SS + GW			N61E	80SE									
940	TAP	CS SS + GW			N27E	80NW									
941	TAP	CS SS + GW			N59E	31SE									
942	TAP	GW + INTBEDDED SL			N61E	48SE									
943	TAP	GW + INTBEDDED SL			N43E	53SE									
944	TAP	CS SS + GW			N60E	70SE									
945	TAP	CS SS + GW			N25E	80SE									
946	TAP	CS SS + GW			N25E	20NW									
947	TAP	SM PEB CONG	N58E	47SE											
948	TAP	GW			N25E	67SE									
949	TAP	SM PEB CONG			N55E	40SE									
950	TAP	GW	N40E	45SE											
951	TAP	COARSE SANDSTONE			N35E	40SE									
952	TAP	COARSE SANDSTONE			N74E	63SE									
953	TAP	CS SS + GW	N63E	44SE											
954	TAP	CS SS + GW	N41E	72SE											
955	TAP	COARSE SANDSTONE	N80E	53SE											
956	TAP	COARSE SANDSTONE			N5E	70NW									
957	TAP	SM PEB CONG			N50E	41SE									
958	TAP	DARK GRAY SLATE			N41E										
959	TAP	CS SS + GW			N79E	15NW									
960	TAP	CS SS + GW			N45E	45SE									
961	TAP	SM PEB CONG + GW			N85E	15SE									
962	TAP	COARSE SANDSTONE			N35E	35NW									
963	TAP	CS SS + GW	FLOAT												
964	TAP	DARK GRAY SLATE + SILT			N11E	70SE									
965	WOF	SM PEB CONG	N63E	5SE											
966	WOF	SM PEB CONG			N55E										
967	WOF	SM PEB CONG			N8W	24NE									
968	WOF	COARSE SANDSTONE			N7E	18SE									
969	WOF	SM PEB CONG			N54E	42SE									
970	WOF	COARSE SANDSTONE			N68E	17NW									
971	WOF	GW			N22E	39SE									
972	WOF	BANDED SILTSTONE	N41E	56SE											
973	WOF	LIGHT GRAY SLATE			N36E	46SE									
974	WOF	GW			N52E	47SE									
975	WOF	GW			N48E	42SE									
976	WOF	GW	N10W	36SW											
977	WOF	GW + DK GRAY SILT			N43E	49SE									
978	WOF	GW			N85E	37NW									
979	WOF	CS SS + GW	N72E	59SE											
980	WOF	CS SS + GW	FLOAT												
981	TAL	LT. GRAY SLATE			N70E	53SE									
982	TAL	LT. GRAY SLATE + SILT			N80W	47SW									
983	TAL	LT. GRAY SLATE	N0E	20W											
984	TAL	LT. GRAY SLATE			N80E	75NW									
985	WOF	LT. GRAY SLATE			N53E	36NW									
986	WOF	CONG + FELDSPATHIC SS			N1W	40NE									
987	WOF	FELDSPATHIC SS + GW			N10E	48SE									
988	WOF	FELDSPATHIC SS + GW			N41E	42SE									
989	WOF	GREEN WILHITE SL	N47E	19SE											
990	WOF	GREEN WILHITE SL	N53E	56SE											
991	WOF	GREEN WILHITE SL			N13E	15NW									
992	WOF	GREEN WILHITE SL	N48E	59SE											
993	WOF	GREEN WILHITE SL	N46E	49SE											
994	WOF	GREEN WILHITE SL	N37E	47SE											
995	WOF	GREEN WILHITE SL			N26E	37SE									
996	WOF	GREEN WILHITE SL	N22E	54SE											
997	WOF	GREEN WILHITE SL	N30E	55SE											
998	WOF	GREEN WILHITE SL	N42E	85SE											
999	WOF	GREEN WILHITE SL	N58E	75SE											
1000	WOF	GREEN WILHITE SL			N47E	69NW									

Station	Quad	Lithology	Foliation		Bedding		Fold Axis		Joints		Axial Surface		Fold Verg.	Intersection Lin.	
			Strike	Dip	Strike	Dip	Plunge	Trend	Strike	Dip	Strike	Dip		Plunge	Trend
1001	WOF	MICRITIC LIMESTONE			N45E	34NW									
1002	WOF	POLYMIC TIC CONG.			N36E	72NW									
1003	TAL	GREEN WLHTE SL	N63E	40SE											
1004	TAL	GREEN WLHTE SL	N80E	5SE											
1005	TAL	GREEN WLHTE SL	N37E	74SE											
1006	TAL	POLYMIC TIC CONG.			N47E	69NW									
1007	TAL	POLYMIC TIC CONG			N45E	34NW									
1008	TAL	SANDSUCK SLATE			N38E	50SE									
1009	TAL	GREEN WLHTE SL			N24E	25SE									
1010	TAL	GREEN WLHTE SL			N42E	44SE									
1011	TAL	POLYMIC TIC CONG			N75E	38NW									
1012	TAL	POLYMIC TIC CONG.			N31E	54SE									
1013	TAL	SANDSUCK SLATE			N17E	46SE									
1014	TAL	SANDSUCK SLATE			N52E	50SE									
1015	TAL	SANDSUCK SLATE			N37E	40SE									
1016	TAL	SANDSUCK SLATE			N45E	60SE									
1017	TAL	POLYMIC TIC CONG			N51E	75SE									
1018	TAL	POLYMIC TIC CONG			N31E	75SE									
1019	TAL	MICRITIC LIMESTONE			N52E	80SE									
1020	TAL	POLYMIC TIC CONG.			N30E	62SE									
1021	TAL	POLYMIC TIC CONG			N31E	70NW									
1022	TAL	SANDSUCK SLATE			N38E	52NW									
1023	TAL	SANDSUCK SLATE			N24W	23NE									
1024	TAL	POLYMIC TIC CONG			N46E	52SE									
1025	TAL	POLYMIC TIC CONG			N59E	40SE									
1026	TAL	SANDSUCK SLATE			N41E	66SE									
1027	TAL	SANDSUCK SLATE			N54E	74SE									
1028	TAL	SANDSUCK SLATE			N89W	34SW									
1029	TAL	SANDSUCK SLATE			N29E	45SE									
1030	TAL	SANDSUCK SLATE			N41E	40SE									
1031	TAL	POLYMIC TIC CONG			N78E	40NW									
1032	TAL	SANDSUCK SLATE			N25E	35SE									
1033	TAL	POLYMIC TIC CONG			N26E	54SE									
1034	TAL	GREEN WLHTE SL			N27E	53SE									
1035	TAL	SANDSUCK SLATE			N45E	60SE									
1036	TAL	POLYMIC TIC CONG.			N25E	25SE									
1037	TAL	SANDSUCK SANDSTONE			N24E	17SE									
1038	TAL	SANDSUCK SANDSTONE			N38E	34SE									
1039	TAL	SANDSUCK SLATE			N40E	20SE									
1040	TAL	SANDSUCK SANDSTONE			N64E	40SE									
1041	TAL	SANDSUCK SANDSTONE			N4E	44SE									
1042	TAL	SANDSUCK SLATE			N78W	34SW									
1043	TAL	SANDSUCK SLATE			N25W	62NE									
1044	TAL	SANDSUCK SLATE			N80E	30SE									
1045	TAL	SANDSUCK SANDSTONE			N25E	39SE									
1046	TAL	SANDSUCK SLATE			N30E	38SE									
1047	TAL	POLYMIC TIC CONG			N45E	35NW									
1048	TAL	SANDSUCK SLATE			N40E	75NW									
1049	TAL	POLYMIC TIC CONG.			N39E	64SE									
1050	TAL	SANDSUCK SLATE			N28E	43SE									
1051	TAL	POLYMIC TIC CONG			N70W	8SW									
1052	TAL	SANDSUCK SLATE			N27E	29SE									
1053	TAL	POLYMIC TIC CONG			N42E	25SE									
1054	TAL	GREEN WLHTE SL			N14E	55SE									
1055	TAL	SANDSUCK SLATE			N52E	29SE									
1056	TAL	SANDSUCK SLATE			N52E	29SE									
1057	TAL	SANDSUCK SLATE			N39E	22SE									
1058	TAL	SANDSUCK SLATE			N54E	13SE									
1059	TAL	SANDSUCK SLATE			N90E	22SE									
1060	TAL	SANDSUCK SLATE			N46E	32SE									
1061	TAL	POLYMIC TIC CONG			N64E	30SE									
1062	TAL	SANDSUCK SLATE			N70E	26SE									
1063	TAL	SANDSUCK SLATE			N66E	24SE									
1064	TAL	SANDSUCK SLATE			N49E	53SE									
1065	TAL	COCHRAN SANDSTONE			N18E	27SE									
1066	TAL	SANDSUCK SLATE			N42E	59SE									
1067	TAL	SANDSUCK SLATE			N45E	65SE									
1068	TAL	SANDSUCK SLATE			N2E	35SE									
1069	TAL	COCHRAN SANDSTONE			N62E	35SE									
1070	TAL	SANDSUCK SLATE			N74E	48SE									
1071	TAL	POLYMIC TIC CONG			N60E	78SE									
1072	TAL	POLYMIC TIC CONG.			N35E	67NW									
1073	TAL	SANDSUCK SLATE			N48E	51NW									
1074	TAL	POLYMIC TIC CONG.			N24E	35NW									
1075	TAL	SANDSUCK SLATE			N64E	33SE									

Station	Quad	Lithology	Foliation		Bedding		Fold Axis		Joints		Axial Surface		Fold	Intersection Lin.	
			Strike	Dip	Strike	Dip	Plunge	Trend	Strike	Dip	Strike	Dip	Verg.	Plunge	Trend
1076	TAL	SANDSUCK SLATE			N62E	64SE									
1077	TAL	SANDSUCK SLATE			N77W	30SW									
1078	TAL	SANDSUCK SLATE			N33E	42SE									
1079	TAL	POLYMIC TIC CONG			N88E	75NW									
1080	TAL	SANDSUCK SLATE			N67E	52SE									
1081	TAL	SANDSUCK SLATE			N78E	63SE									
1082	TAL	GREEN WLHTE SL			N78E	53SE									
1083	TAL	GREEN WLHTE SL			N18E	48SE									
1084	TAL	GREEN WLHTE SL	N58E	35SE											
1085	TAL	GREEN WLHTE SL	N57E	31SE											
1086	TAL	GREEN WLHTE SL			N49E	20NW									
1087	TAL	GREEN WLHTE SL	N61E	43SE											
1088	TAL	GREEN WLHTE SL			N83E	80NW									
1089	TAL	GREEN WLHTE SL	N72E	37SE											
1090	TAL	GREEN WLHTE SL	FLOAT												
1091	TAL	GREEN WLHTE SL	N66E	44SE											
1092	TAL	GREEN WLHTE SL	N62E	47SE											
1093	TAL	GREEN WLHTE SL	N65E	34SE											
1094	TAL	GREEN WLHTE SL	N60E	57SE											
1095	TAL	GREEN WLHTE SL	N48E	58SE											
1096	TAL	GREEN WLHTE SL	N65E	39SE											
1097	TAL	GREEN WLHTE SL	N60E	50SE											
1098	TAL	GREEN WLHTE SL	N75E	49SE											
1099	TAL	GREEN WLHTE SL	N53E	35SE											
1100	TAL	GREEN WLHTE SL	N86E	39SE											
1101	TAL	GREEN WLHTE SL	N81E	37SE											
1102	TAL	GREEN WLHTE SL			N8W	5SW									
1103	TAL	GREEN WLHTE SL	N76E	40SE											
1104	TAL	GREEN WLHTE SL	N78E	40SE											
1105	TAL	GREEN WLHTE SL	N79E	22SE											
1106	TAL	GREEN WLHTE SL	N74E	29SE											
1107	TAL	GREEN WLHTE SL	N70E	26SE											
1108	TAL	GREEN WLHTE SL	N78E	23SE											
1109	TAL	GREEN WLHTE SL	N78E	29SE											
1110	TAL	GREEN WLHTE SL	N66E	35SE											
1111	TAL	GREEN WLHTE SL	N76E	26SE											
1112	TAL	GREEN WLHTE SL	N44E	39SE											
1113	TAL	GREEN WLHTE SL	N80E	36SE											
1114	TAL	GREEN WLHTE SL	N86W	35SW											
1115	TAL	GREEN WLHTE SL			N40E	25SE									
1116	WOF	SHIELDS SLATE			N70E	35NW									
1117	WOF	SHIELDS SLATE	N20E	24NW											
1118	WOF	SHIELDS CONGLOMERATE			N89W	47SW									
1119	WOF	SHIELDS CONGLOMERATE			N20E	38NW									
1120	WOF	SHIELDS SLATE			N15E	47NW									
1121	WOF	SHIELDS SLATE			N58E	10SE									
1122	WOF	GREEN WLHTE SL			N79E	17NE									
1123	WOF	GREEN WLHTE SL			N56W	51NE									
1124	TAL	GREEN WLHTE SL	N70E	32SE											
1125	TAL	GREEN WLHTE SL			N36W	55NE									
1128	TAL	GREEN WLHTE SL	N89E	24SE											
1127	TAL	GREEN WLHTE SL	N35E	40SE											
1128	TAL	GREEN WLHTE SL	N41E	65SE											
1129	TAL	GREEN WLHTE SL	N53E	24SE											
1130	TAL	GREEN WLHTE SL	N52E	31SE											
1131	TAL	GREEN WLHTE SL	N61E	33SE											
1132	TAL	GREEN WLHTE SL	N25E	46SE											
1133	TAL	GREEN WLHTE SL	N52E	52SE											
1134	TAL	GREEN WLHTE SL			N33E	37SE									
1135	TAL	GREEN WLHTE SL	N64E	53SE											
1136	TAL	GREEN WLHTE SL	N45E	44SE											
1137	TAL	GREEN WLHTE SL	N40E	47SE											
1138	TAL	GREEN WLHTE SL	N50E	66SE											
1139	TAL	GREEN WLHTE SL	N36E	35SE											
1140	TAL	GREEN WLHTE SL	N57E	57SE											
1141	TAL	GREEN WLHTE SL			N71E	29NW									
1142	TAL	GREEN WLHTE SL			N85E	20NW									
1143	TAL	GREEN WLHTE SL	N58E	50SE											
1144	TAL	GREEN WLHTE SL	N65E	54SE											
1145	TAL	GREEN WLHTE SL	N35E	52SE											
1146	TAL	GREEN WLHTE SL			N51E	18SE									
1147	TAL	GREEN WLHTE SL	N55E	60SE											
1148	TAL	GREEN WLHTE SL	N62E	45SE											
1149	TAL	GREEN WLHTE SL	N47E	48SE											
1150	TAL	GREEN WLHTE SL	N61E	60SE											

Station	Quad	Lithology	Foliation		Bedding		Fold Axis		Joints		Axial Surface		Fold Verg.	Intersection Ln.	
			Strike	Dip	Strike	Dip	Plunge	Trend	Strike	Dip	Strike	Dip		Plunge	Trend
1151	TAL	GREEN WLHTE SL	N36E	42SE											
1152	TAL	GREEN WLHTE SL	N39E	38SE											
1153	TAL	GREEN WLHTE SL			N28E	27SE									
1154	TAL	GREEN WLHTE SL	N40E	41SE											
1155	TAL	GREEN WLHTE SL	N40E	46SE											
1156	TAL	GREEN WLHTE SL	N45E	55SE											
1157	TAL	GREEN WLHTE SL			N41E	12SE									
1158	TAL	GREEN WLHTE SL	N20E	60SE											
1159	TAL	GREEN WLHTE SL			N3E	5SE									
1160	TAL	GREEN WLHTE SL	N36E	5SE											
1161	TAL	GREEN WLHTE SL	N54E	60SE											
1162	TAL	GREEN WLHTE SL			N54E	76SE									
1163	TAL	SANDSUCK SLATE			N45E	30SE									
1164	WOF	GREEN WLHTE SL	N85E	20SE											
1165	WOF	GREEN WLHTE SL			N76E	52NW									
1166	WOF	GREEN WLHTE SL	N54E	34SE											
1167	TAL	GREEN WLHTE SL			N23E	20NW									
1168	TAL	GREEN WLHTE SL			N55E	59SE									
1169	TAL	GREEN WLHTE SL			N38E	66NW									
1170	TAL	GREEN WLHTE SL			N20E	16SE									
1171	TAL	GREEN WLHTE SL			N52E	52SE									
1172	TAL	GREEN WLHTE SL			N23E	16SE									
1173	TAL	GREEN WLHTE SL			N35E	28SE									
1174	TAL	GREEN WLHTE SL	N54E	70SE											
1175	TAL	GREEN WLHTE SL			N65E	35SE									
1176	TAL	GREEN WLHTE SL			N88E	19SE									
1177	TAL	GREEN WLHTE SL	N32E	41SE											
1178	TAL	GREEN WLHTE SL			N35E	78NW									
1179	TAL	GREEN WLHTE SL			N18E	80SE									
1180	TAL	GREEN WLHTE SL	N60E	75SE											
1181	TAL	GREEN WLHTE SL			N0E	14W									
1182	TAL	GREEN WLHTE SL	N42E	71SE											
1183	TAL	GREEN WLHTE SL			N30E	32SE									
1184	TAL	GREEN WLHTE SL			N10E	32SE									
1185	TAL	GREEN WLHTE SL	N35E	80SE											
1186	TAL	GREEN WLHTE SL			N70E	69SE									
1187	TAL	GREEN WLHTE SL	N26E	56SE											
1188	TAL	GREEN WLHTE SL			N31E	17SE									
1189	TAL	GREEN WLHTE SL	N17E	32SE											
1190	TAL	WLHTE CONGLOMERATE			N16E	30SE									
1191	TAL	GREEN WLHTE SL	N79W	60SW											
1192	TAL	GREEN WLHTE SL	N44E	23SE											
1193	TAL	GREEN WLHTE SL	N6E	22SE											
1194	TAL	GREEN WLHTE SL	N49E	21SE											
1195	TAL	GREEN WLHTE SL	N69E	31SE											
1196	TAL	GREEN WLHTE SL	N20E	15SE											
1197	TAL	GREEN WLHTE SL	N16E	9SE											
1198	TAL	GREEN WLHTE SL	N83E	16SE											
1199	TAL	GREEN WLHTE SL	N59W	21SW											
1200	TAL	GREEN WLHTE SL			N13E	33NW									
1201	TAL	GREEN WLHTE SL	N62W	23SW											
1202	TAL	GREEN WLHTE SL	N83W	14SW											
1203	TAL	GREEN WLHTE SL	N88E	39SE											
1204	TAL	GREEN WLHTE SL	N11W	11SW											
1205	TAL	GREEN WLHTE SL	N82E	34SE											
1206	TAL	GREEN WLHTE SL	N66E	34SE											
1207	TAL	GREEN WLHTE SL	N83E	47SE											
1208	TAL	GREEN WLHTE SL			N82W	13SW									
1209	TAL	GREEN WLHTE SL			N43E	54NW									
1210	TAL	GREEN WLHTE SL			N79E	79SE									
1211	TAL	GREEN WLHTE SL			N77W	43NE									
1212	TAL	GREEN WLHTE SL			N88W	64SW									
1213	TAL	GREEN WLHTE SL	N78E	16SE											
1214	TAL	GREEN WLHTE SL			N78E	67SE									
1215	TAL	GREEN WLHTE SL	N77W	25SW											
1216	TAL	GREEN WLHTE SL	N80W	24SW											
1217	TAL	GREEN WLHTE SL	N84W	30SW											
1218	TAL	GREEN WLHTE SL	N42E	25SE											
1219	TAL	GREEN WLHTE SL	N78E	37NW											
1220	TAL	GREEN WLHTE SL	N28E	36SE											
1221	TAL	GREEN WLHTE SL	N28E	36SE											
1222	TAL	GREEN WLHTE SL			N40E	25SE									
1223	TAL	GREEN WLHTE SL	N36E	35SE											
1224	TAL	GREEN WLHTE SL	N69E	30SE											
1225	TAL	GREEN WLHTE SL	N70W	26SW											

Station	Quad	Lithology	Foliation		Bedding		Fold Axis		Joints		Axial Surface		Fold Verg.	Intersection Lin.	
			Strike	Dip	Strike	Dip	Plunge	Trend	Strike	Dip	Strike	Dip		Plunge	Trend
1226	TAL	GREEN WILHITE SL	N85E	31SE											
1227	TAL	GREEN WILHITE SL			N51E	56NW									
1228	TAL	GREEN WILHITE SL	N80E	27SE											
1229	TAL	GREEN WILHITE SL	N80E	84SE											
1230	TAL	GREEN WILHITE SL	N80W	16SW											
1231	TAL	GREEN WILHITE SL			N52E	72SE									
1232	TAL	GREEN WILHITE SL	N89E	28SE											
1233	TAL	GREEN WILHITE SL			N89E	57NE									
1234	TAL	GREEN WILHITE SL			N59E	73NW									
1235	TAL	GREEN WILHITE SL	N89E	12SE											
1236	TAL	GREEN WILHITE SL	N87W	28SW											
1237	TAL	GREEN WILHITE SL			N50E	39NW									
1238	TAL	GREEN WILHITE SL			N82E	44NW									
1239	TAL	SHIELDS CONGLOMERATE			N83W	52SW									
1240	TAL	SHIELDS CONGLOMERATE			N25E	45NW									
1241	TAL	SHIELDS CONGLOMERATE			N20E	32NW									
1242	TAL	SHIELDS CONGLOMERATE	N40E	39NW											
1243	TAL	SHIELDS CONGLOMERATE			N54E	73SE									
1244	TAL	SHIELDS SLATE			N88W	35SW									
1245	TAL	SHIELDS SLATE			N74W	25SW									
1246	TAL	SHIELDS SLATE	N10W	46SW											
1247	TAL	GREEN WILHITE SL			N9W	60SW									
1248	TAL	GREEN WILHITE SL			N1E	47NW									
1249	TAL	GREEN WILHITE SL			N29W	23SW									
1250	TAL	GREEN WILHITE SL			N45E	34NW									
1251	TAL	GREEN WILHITE SL			N18W	58SW									
1252	TAL	GREEN WILHITE SL			N2W	24SW									
1253	TAL	GREEN WILHITE SL			N30E	25NW									
1254	TAL	GREEN WILHITE SL	N83E	39SE											
1255	TAL	GREEN WILHITE SL			N35W	21SW									
1256	TAL	GREEN WILHITE SL			N3W	24SW									
1257	TAL	GREEN WILHITE SL			N25E	35NW									
1258	TAL	GREEN WILHITE SL	N86W	34SW											
1259	TAL	GREEN WILHITE SL	N62W	30SW											
1260	TAL	GREEN WILHITE SL			N57E	45NW									
1261	TAL	GREEN WILHITE SL			N29E	50SW									
1262	TAL	GREEN WILHITE SL			N35W	30SW									
1263	TAL	GREEN WILHITE SL			N0E	37W									
1264	TAL	GREEN WILHITE SL	N78W	45SW											
1265	TAL	GREEN WILHITE SL			N12E	47NW									
1266	TAL	GREEN WILHITE SL			N90E	34N									
1267	TAL	GREEN WILHITE SL			N5W	28SW									
1268	TAL	GREEN WILHITE SL			N48E	35NW									
1269	TAL	GREEN WILHITE SL	N10E	18NW											
1270	TAL	GREEN WILHITE SL			N38W	70SW									
1271	TAL	GREEN WILHITE SL	N69W	25NE											
1272	TAL	GREEN WILHITE SL	N32E	32NW											
1273	TAL	GREEN WILHITE SL			N44E	45SE									
1274	TAL	KNOX GROUP			N25E	36SE									
1275	TAL	SHIELDS SLATE	N60W	20NE											
1276	TAL	SHIELDS SLATE	N5W	16NE											
1277	WOF	SHIELDS SLATE			N39E	41SE									
1278	WOF	SHIELDS SLATE	N70E	15SE											
1279	WOF	SHIELDS SLATE			N49W	40NE									

VITA

James Ryan Thigpen was born in Camp Lejeune North Carolina on April 19th, 1979. After leaving North Carolina at the age of 2, Ryan's family settled in Franklin, TN, just south of Nashville. Prior to his graduation from Franklin High School in May of 1997, Ryan had begun to explore the outdoors with steadily increasing fervor. His love of camping and backpacking soon turned to weekends of climbing at Foster Falls with his closest friends. His free nights during the week were spent in climbing gyms near Franklin. After graduating high school, he enrolled in the University of Tennessee to pursue a degree in Biochemistry. I did not take long for him to learn that not only was this not for him, but the wild areas surrounding Knoxville were even better than those he had known as a child. Following his sophomore semester, when he learned the wonders of skiing and whitewater paddling, he was dismissed from UT due to a "lackluster" academic performance, to say the least. After a one year sabbatical in Salt Lake City spent running the big hills of the Wasatch, he realized that the mountains, no matter where, were always to be his home. Thus, geology seemed to fit the picture well. A "responsible" pursuit spent in those places he loved to play. Ryan is presently enrolled at Virginia Tech in Blacksburg, Virginia, where he is pursuing his Ph.D. while spending research time in the Himalayas of Tibet and Nepal.