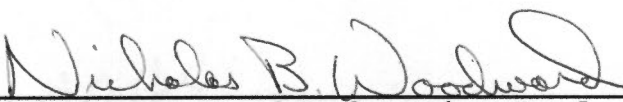
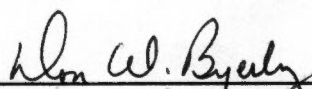
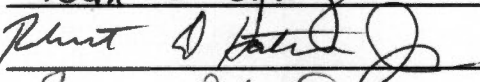
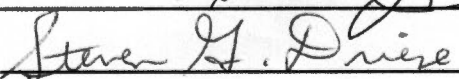


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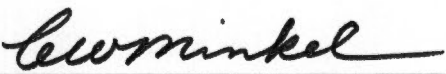
I am submitting herewith a thesis written by Randy R. Walters entitled "Structural Geometries, Fabrics, and Stratigraphic Relationships in the Cades Cove Region, Great Smoky Mountains National Park, Tennessee." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Geology.


Nicholas B. Woodward, Major Professor

We have read this thesis
and recommend its acceptance:

Accepted for the Council:


Vice Provost
and Dean of The Graduate School

STRUCTURAL GEOMETRIES, FABRICS, AND STRATIGRAPHIC
RELATIONSHIPS IN THE CADES COVE REGION,
GREAT SMOKY MOUNTAINS NATIONAL PARK,
TENNESSEE

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

Randy R. Walters

June 1988

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ABSTRACT

The major structure in the Cades Cove area of the western Great Smoky Mountains is best explained as a polydeformed recumbent fold (nappe) within Precambrian Ocoee Series rocks of the Rabbit Creek thrust sheet. The Elkmont Sandstone, southeast of Cades Cove, is upright and gently southeast dipping and represents the hinterland limb of the thrust nappe. The Cades Sandstone, which is lithologically similar to the Elkmont, occurs northwest of the Coalen Ground thrust and is gently southeast dipping and overturned.

Petrographic investigation of thin sections from Cades and Elkmont units reveals very different textures. Cades samples commonly contain large, fractured potassium feldspar grains within a strong ribbon quartz fabric. Pressure-solution features and subgrain development in quartz are also prominent here. In contrast, Elkmont samples generally contain undeformed potassium feldspar, with a general absence of ribbon quartz and subgrain development in quartz. The Cades is much more highly deformed than the Elkmont and represents the overturned forelimb of the thrust nappe.

Strain analysis supports rock fabric data by presence of average tectonic strains (R_s values) in the

XZ plane of 3.0:1 in the Cades Sandstone versus 1.7:1 in the Elkmont Sandstone. High tectonic strains near the Rabbit Creek thrust trace are attributed to Rabbit Creek thrust emplacement. Strain analysis data, in conjunction with rock fabrics, are the principal structural bases for the nappe hypothesis.

The thrust nappe was emplaced along the Rabbit Creek thrust, which is the western most (foreland) expression of an early (Greenbrier?) deformational event in this region. Mylonitic fault zones in the nappe core, formerly interpreted to be stratigraphic contacts, cut through the Rabbit Creek thrust sheet and represent out-of-the-anticline thrusts. The later Great Smoky thrust either re-activated the Rabbit Creek thrust plane or cut up into the Rabbit Creek thrust sheet in the Cades Cove region.

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CHAPTER I

INTRODUCTION

The southern Appalachians and, more specifically, the Great Smoky Mountains National Park region are geologically complex, warranting further detailed investigation of both structure and stratigraphy. The purpose of this study is threefold: 1) to document map geometries and structural (mesofabric and microfabric) data, 2) to clarify stratigraphic relationships, and 3) to interpret the overall structural geometries in the study area.

Since the landmark publications of Hamilton (1961), Hadley and Goldsmith (1963), King (1964), and Neuman and Nelson (1965), little detailed structural work has been done in the Great Smoky Mountains National Park region of the southern Appalachians. This is an attempt to apply modern structural analysis techniques to a part of this area.

AREA OF STUDY

The area chosen for investigation lies in the western Great Smoky Mountains National Park, Tennessee (Fig. 1).

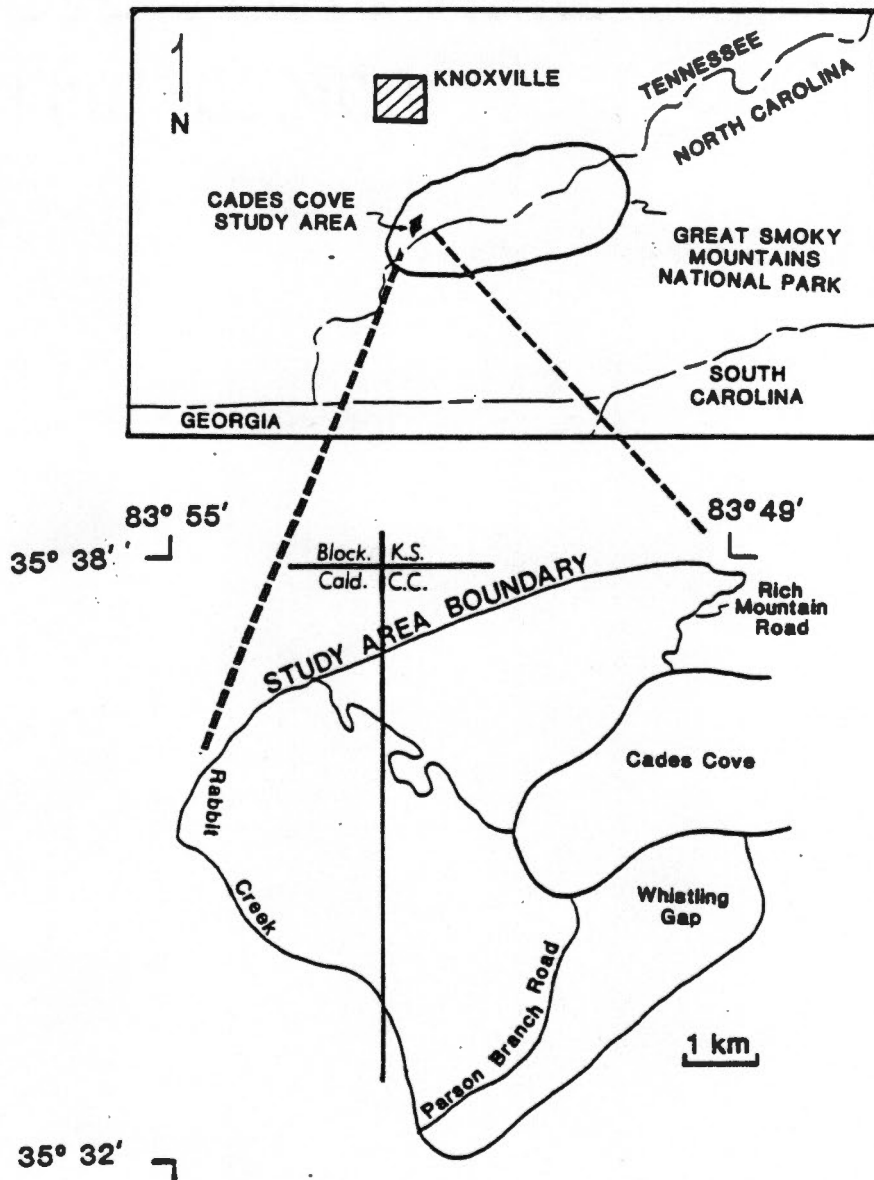


Figure 1 - Location of study area in the Cades Cove region, Great Smoky Mountains National Park, Tennessee. (Block.-Blockhouse quadrangle; K.S.-Kinzel Springs quadrangle; Cald.-Calderwood quadrangle; C.C.-Cades Cove quadrangle).

The primary area of interest is included on portions of the Cades Cove and Calderwood 7.5' quadrangles. This area was chosen for its accessibility as well as the degree of structural complexity. The study area extends northwest-southeast from approximately Rabbit Creek to Parson Branch Road and northeast-southwest from Rich Mountain Road to Rabbit Creek (Fig. 1). Rocks are well exposed along streams, trails and roads. The total area of study is approximately 35 km² (14 mi²). The Ordovician strata in the Cades Cove window have been excluded from the study.

CHAPTER II

PREVIOUS WORK

STRUCTURE

Recent studies in structural geology have resulted in a vast expansion of knowledge, particularly in the area of thrust and nappe tectonics. Of particular relevance to this study is the process of nappe formation and emplacement and fabrics typical of fault rocks (e.g., mylonites).

The presence of nappe structures in orogenic belts has been well-documented, particularly in the Helvetic fold and thrust belt of Switzerland (Heim, 1921; Ramsay, 1983). In that region, nappes are characterized by: 1) a simple shear mechanism of emplacement, 2) tectonic thinning of the overturned limb, and 3) high strains in the overturned limb with lower strains in the upright limb (Ramsay, 1981). Dennis and others (1981) defined a fold nappe as "an allochthonous tectonic unit which exhibits large scale stratigraphic inversion and may have initiated from large recumbent folds. The underlying limbs of these folds may be sheared out into thrust faults." The Cades Cove region contains structural geometries which are consistent with

all of the aforementioned characteristics of nappe structures.

Hatcher (1981) noted nappe structures in the Piedmont and eastern Blue Ridge provinces of the Appalachian orogen, but documentation of these types of structures in the western Blue Ridge is poor. The structural relationships in the western Great Smoky Mountains, located within the western Blue Ridge province, were proposed by Neuman and Nelson (1965). Several of their conclusions as they relate to the Cades Cove study area are: 1) the Elkmont Sandstone is structurally upright, 2) the major portion of the Cades Sandstone adjacent to Cades Cove is structurally overturned, 3) the Rabbit Creek and Greenbrier faults formed early in the tectonic development of the region, 4) the Oconaluftee fault is actually a re-activation of the earlier Greenbrier fault, which emplaces younger Great Smoky Group rocks against older Snowbird Group rocks (King, 1964), and 5) the Great Smoky fault formed late in the tectonic development of the region. No inferences were made, however, as to the overall structural geometries in this region and no structural data are shown on their one-inch-to-the-mile geologic map.

Description of the Geologic Map of Neuman and Nelson (1965)

Neuman and Nelson (1965) mapped the western Great Smoky Mountains (including the study area) at a 1:62,500 scale and interpreted structural geometries based primarily upon stratigraphic relations in the study area. The following discussion will refer to the geologic map (Fig. 2) of the Cades Cove region by Neuman and Nelson (1965).

Oconaluftee-Greenbrier fault block (fault block 1, Fig. 2)

The Elkmont Sandstone is bounded on the northwest by the Oconoluftee-Greenbrier fault. The hanging wall contains Elkmont Sandstone emplaced against Metcalf Phyllite to the east and Cades Sandstone to the west. The majority of beds in the Elkmont dip southeast, and graded bedding in the Elkmont indicates it is mostly upright.

Unnamed fault block (fault block 2, Fig. 2)

A large fault block northwest of the Oconaluftee-Greenbrier fault contains Metcalf Phyllite overlying Cades Sandstone stratigraphically. The contact occurs along the eastern part of Parson Branch Road and

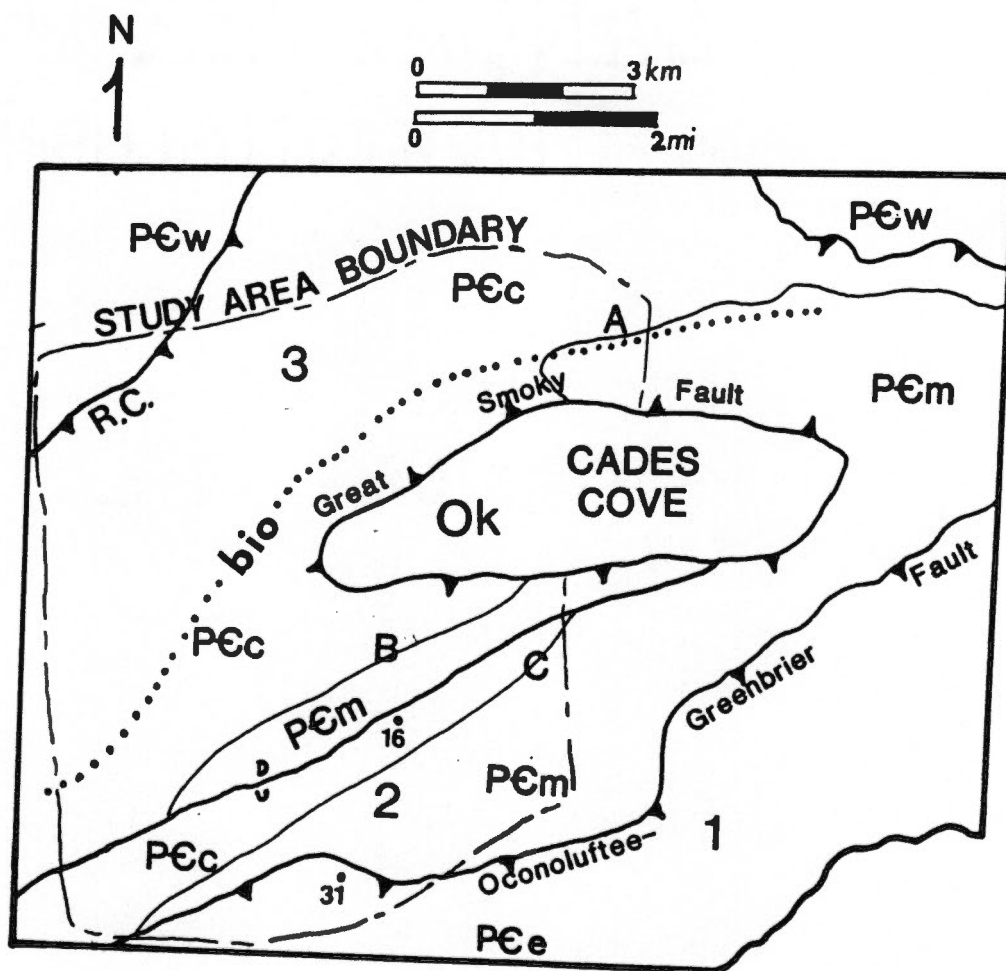


Figure 2 - Geologic map of a part of the western Great Smoky Mountains, which includes the study area of this report (after Neuman and Nelson, 1965). Letters and numbers on the map are specific localities which are referred to in the text. (PCm-Metcalf Phyllite; PCc-Cades Sandstone; PCe-Elkmont Sandstone; PCw-Wilhite Formation; Ok-Knox Group; R.C.-Rabbit Creek thrust fault; bio-biotite isograd).

continues northeastward through Whistling Gap. The Metcalf plunges westward into the subsurface, terminating against the Greenbrier fault in the southwest part of the study area. Fault block 2 is bounded to the northwest by an unnamed fault that terminates against the Great Smoky thrust at the southern boundary of Cades Cove.

Rabbit Creek fault block (fault block 3, Fig. 2)

The Rabbit Creek fault block contains predominantly Cades Sandstone. Small wedges of Metcalf, which were inferred to bound the Cades stratigraphically, occur along the northern boundary of Cades Cove and in the southeastern part of this fault block. The majority of the Cades section in the Rabbit Creek block dips southeast and is apparently overturned, based on graded bedding sequences (fining toward the northwest) and cleavage-bedding relationships (cleavage dipping at a gentler angle than bedding). The Wilhite Formation occurs northwest of the Rabbit Creek fault block.

Metamorphism

The Cades Cove region experienced up to greenschist-facies metamorphism. Neuman and Nelson (1965)

placed the biotite isograd entirely within the Rabbit Creek fault block (Fig. 2).

Radiometric dating of Ocoee Supergroup rocks near Ducktown, Tennessee by Eckelmann and others (1959) revealed ages of 440 Ma (K/Ar in biotite). Other workers (King, 1964; Rodgers, 1970; Kish and Harper, 1973; Dallmeyer, 1974) also determined similar metamorphic age dates. Southwest of the study area, Neuman and Nelson (1965) showed the biotite isograd to be continuous across the Oconaluftee-Greenbrier fault. Northeast of the study area, King (1964) also observed the biotite isograd to be continuous across the Greenbrier thrust (i.e., the isograd was not displaced by the thrust), suggesting that the peak of metamorphism occurred after Greenbrier thrust emplacement.

STRATIGRAPHY

The stratigraphy in the study area consists entirely of the Ocoee Series, which was first described by Safford (1856). The Ocoee Supergroup has been divided into three groups by King and others (1958), all of which are represented in the study area. The Great Smoky Group is here represented by the Elkmont Sandstone, the Walden Creek Group by the Wilhite Formation, and the Snowbird Group by

the Metcalf Phyllite. The Cades Sandstone was left unclassified by King and others (1958) because of its obscure or conflicting relationships to other units in the study area. The following stratigraphic descriptions are from Neuman and Nelson (1965).

Great Smoky Group

Elkmont Sandstone

The Elkmont Sandstone occurs in the southeastern most portion of the study area and is the dominant ridge-former in the area. King (1964) traced the Elkmont continuously into the Thunderhead Sandstone to the east, where both are exposed above the Greenbrier thrust. The Elkmont consists of thick bedded, medium-grained to conglomeratic sandstone with interbedded, finely laminated, black/dark gray argillite and siltstone layers (Neuman and Nelson, 1965). Sandstone beds are generally graded from coarse to fine, and are commonly poorly sorted, with detrital grains set in a micaceous matrix. Subangular grains of quartz and potassium feldspar are the main constituents of the sandstone, with some large blue quartz grains (Neuman and Nelson, 1965).

Cades Sandstone

The unclassified Cades Sandstone is very similar to the Elkmont Sandstone in the western Great Smoky Mountains (Neuman and Nelson, 1965). The Cades appears to be closely related stratigraphically to the Snowbird Group rocks, based on apparent stratigraphic contacts between the Cades and Metcalf units within the study area. The Cades lithology, however, is more similar to the Elkmont and Thunderhead Formations in the Great Smoky Group (Neuman and Nelson, 1965).

The Cades Sandstone consists of medium-bedded, coarse-grained to conglomeratic sandstone interbedded with dark gray argillite and siltstone. Coarse and medium grain sizes dominate in the sandstone, with grains being composed dominantly of quartz (+potassium feldspar). Graded beds are also common in the Cades, with grading typically from granule conglomerate at the base to siltstone or shale at the top.

Composite graded beds with coarser sandstone in contact with finer sandstone, without interbeds of argillite, are much less common in the Cades than in the Elkmont. Most beds in the Cades are thinner than those in the Elkmont. Sandstone beds in the Cades have a wider range in grain size and generally a finer grained matrix than those in the Elkmont. In addition, Cades Sandstone

units contain more fragments of granitic material and dark shaly rocks than the Elkmont. Finally, the Cades Sandstone beds generally contain less blue quartz than the Elkmont (Neuman and Nelson, 1965). Based on these data, Neuman and Nelson (1965) chose to separate the Cades from the Elkmont.

Snowbird Group

Metcalf Phyllite

The Metcalf Phyllite is the sole representative of the Snowbird Group in the western Great Smoky Mountains and in the study area. This unit was been traced into the Pigeon Siltstone to the east (King, 1964).

The Metcalf is composed dominantly of very thinly laminated, greenish-gray phyllite with minor interbedded siltstone and sandstone (Neuman and Nelson, 1965). Petrographic observations by Neuman and Nelson (1965) reveal that about 80% of the phyllite is composed of the micaceous minerals chlorite and sericite, with small amounts of biotite. The overall composition of the Metcalf is consistent throughout the field area, with the major difference from place to place being the amount of deformation present.

Walden Creek Group

Wilhite Formation

The Wilhite Formation occurs in the extreme northwest part of the study area in the footwall of the Rabbit Creek thrust. It is composed dominantly of siltstone, argillite, and fine-grained sandstone, with local interbeds of coarser sandstone, conglomerate, and carbonate rocks (Neuman and Nelson, 1965).

Stratigraphic Relations

The only units in the study area which have been interpreted to be in original stratigraphic contact are the Cades Sandstone and the Metcalf Phyllite. Neuman and Nelson (1965) described several stratigraphic contacts between these units, three of which occur in the study area. Two of these, one on Rich Mountain Road north of Cades Cove (Fig. 2, Locality A) and the other on Mill Creek south of the Cove (Fig. 2, Locality B), contain graded bedding in the Cades that faces away from the Metcalf, indicating the Cades is the younger of the two. Farther to the south in Whistling Gap (Fig. 2, Locality C), however, graded beds in the Cades face southeast towards the Metcalf, indicating the Cades there is older than the

Metcalf. These observations led Neuman and Nelson to conclude that "if the contacts are sedimentary, they suggest that the Cades and Metcalf intertongue in such a manner that either formation might overlies the other from place to place." Figure 3 shows the stratigraphic relations within the Ocoee Supergroup as proposed by Neuman and Nelson (1965).

Age	North of and below Greenbrier fault					South of and above Greenbrier fault							
Cambrian(?) and Cambrian	Chilhowee Group		Cochran Formation and higher units			Rocks of Murphy marble belt		Nantahala Slate and higher units (Early Paleozoic(?))					
Later Precambrian	Ocoee Series	Walden Creek Group	Disconformity?			Ocoee Series	Great Smoky Group	Lithologic break, but probably conformable					
			Sandsuck Formation Withite Formation Shields Formation Licklog Formation					Unnamed sandstone Anakeesta Formation Thunderhead Sandstone					
		Unclassified formations	Fault contact, sequence uncertain		Western part of area			Eastern part of area		Elkmont Sandstone			
			Cades Sandstone	Rocks of Webb Mountain and Big Ridge				Rich Butt Sandstone	Elkmont Sandstone				
Earlier Precambrian	Snowbird Group	Metcalf Phyllite		Pigeon Siltstone Roaring Fork Sandstone Longarm Quartzite Wading Branch Formation		Snowbird Group	Roaring Fork Sandstone Longarm Quartzite Wading Branch Formation						
		Base not exposed		Unconformity			Unconformity						
				Basement complex			Basement complex						

Correlation between these sequences uncertain

Figure 3 - Stratigraphic units in the Ocoee Supergroup of the Great Smoky Mountains, including the study area (from King and others, 1968).

CHAPTER III

GEOLOGIC MAPPING

The lithostratigraphy in the study area was very accurately mapped by Neuman and Nelson (1965), although they did not carry out a systematic examination of deformation fabrics. In this study, I have examined rock fabrics (especially for fault rocks) and, based on these fabrics, I propose major revisions of previous interpretations with regards to structural geometries and relationships. Four major fault blocks are identified here, each of which will be discussed in terms of its internal stratigraphy and nature of bounding faults. Previously unrecognized or unnamed faults have been named (informally) in order to simplify the discussion and fault blocks will be referred to according to the northwest bounding (underlying) fault. Discussion will refer to Plate I, which shows the revised geologic map of Cades Cove. Only bedding-foliation and cleavage attitudes from the map will be presented here. A more detailed discussion of fabrics will be presented in CHAPTER V.

GEOLOGIC MAP OF CADES COVE

Main Greenbrier Fault Block

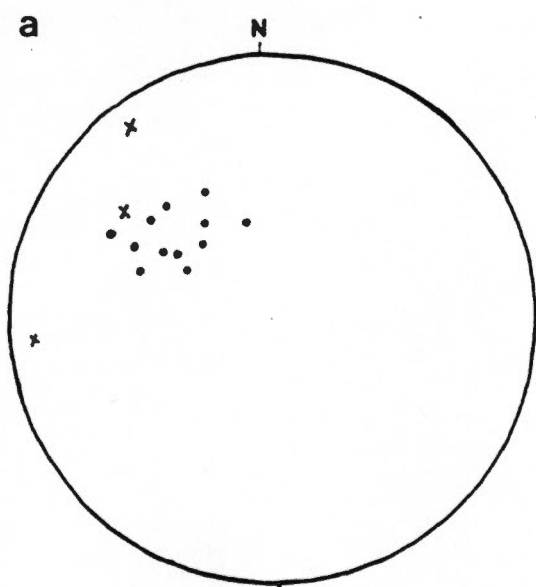
The southern most part of the study area contains Elkmont Sandstone, which is bounded to the northwest by the Greenbrier fault (Plate I, A). Elkmont beds strike N 15°E to N 65°E with dips ranging from 32° to 52° southeast (Fig. 4a). Fining-upward sequences indicate that the Elkmont in this block is stratigraphically upright. Cleavage in the Elkmont, wherever observed, dips more steeply than bedding. Neuman and Nelson (1965) named the northwest bounding fault the Oconaluftee, however, hanging wall-footwall relationships are similar to those of the Greenbrier thrust to the northeast (King, 1964). Thus, what Neuman and Nelson (1965) termed the Oconaluftee fault will be referred to as the Greenbrier thrust in this report.

Parson Branch Fault Block

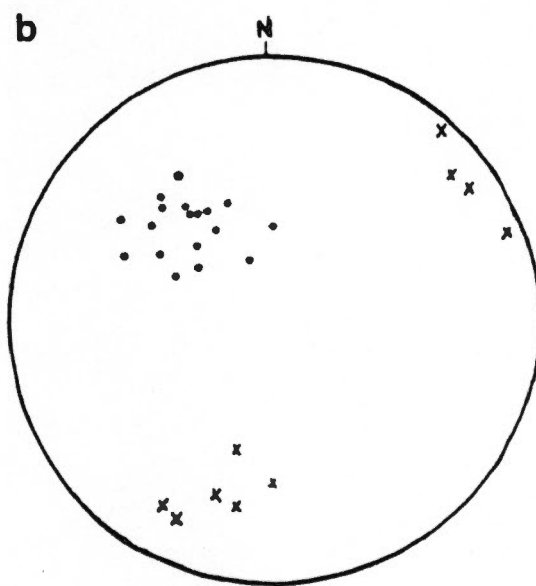
The main Greenbrier fault block is bordered to the northwest by the Parson Branch fault block. This block contains only Metcalf Phyllite (Plate I, B). The Parson Branch thrust was so named because a major segment of the fault occurs along Parson Branch Road. The phyllite in this block is typically highly deformed and may contain

Figure 4 - Equal-area (Schmidt) net stereographic analyses.

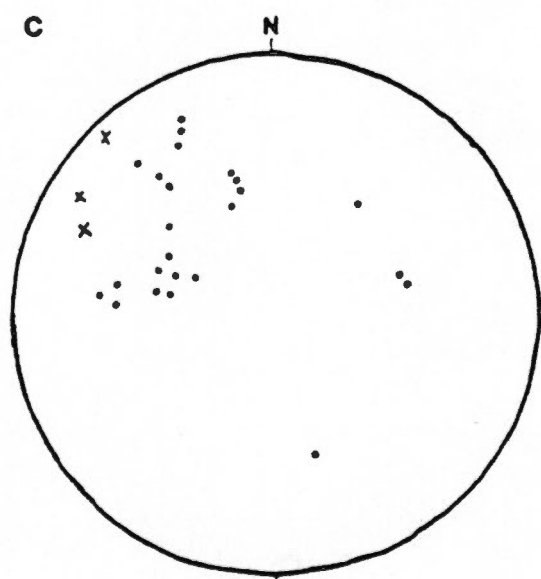
- a. Elkmont Sandstone in the main Greenbrier fault block (Plate I, A).
- b. Metcalf Phyllite in the Parson Branch fault block (Plate I, B).
- c. Cades Sandstone in the Coalen Ground fault block (Plate I, C).
- d. Metcalf Phyllite in the Coalen Ground fault block (Plate I, C).



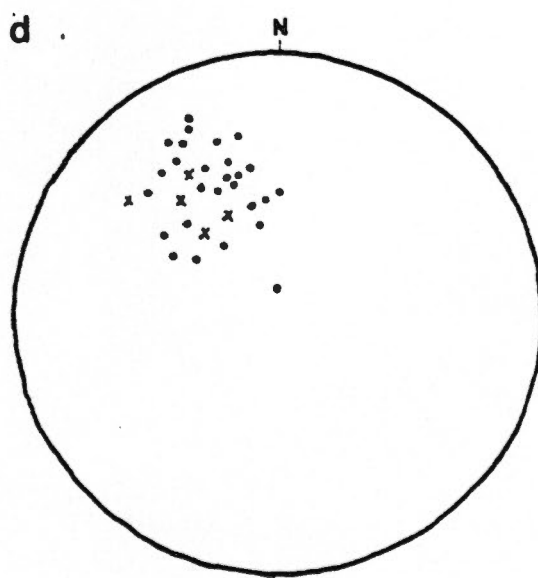
•• Poles to bedding x- Poles to cleavage (S_1)



•• Poles to foliation x- Fold axial trace (S_1)



•• Poles to bedding x- Poles to cleavage (S_1)



•• Poles to foliation (S_1) x- Poles to cleavage (S_2)

shear band cleavage (S_2) and small chevron folds. Attitudes of foliation (S_1) range from N 35°E, 66°SE near Whistling Gap, to E-W, 29°SE along Forge Creek Trail in the footwall of the Greenbrier thrust (Fig. 4b). Mylonitic textures along the contact at the base of the Parson Branch block indicate a thrust contact (Metcalf-over-Cades), as opposed to the original stratigraphic contact proposed by Neuman and Nelson (1965).

Coalen Ground Fault Block

The Coalen Ground fault block contains Metcalf Phyllite underlying Cades Sandstone (Plate I, C). Attitudes of bedding (S_0) in the Cades range from N 6°E, 56°SE to N 75°E, 46°SE (Fig. 4c). Local dip reversals in the Cades occur near the Parson Branch thrust, which probably represent fault drag or minor faulting due to movement on this thrust. Cleavage-bedding relationships, in conjunction with graded beds, indicate that the Cades is structurally upright in the Coalen Ground fault block (Fig. 5) (Shackleton, 1957).

Attitudes of foliation (S_1) in the Metcalf Phyllite are generally similar to attitudes of S_0 in the Cades (Fig. 4d). The contact of the Metcalf with the overlying Cades could not be found, but it is inferred to be the Greenbrier thrust here, based on similar hanging wall-footwall

NW

SE

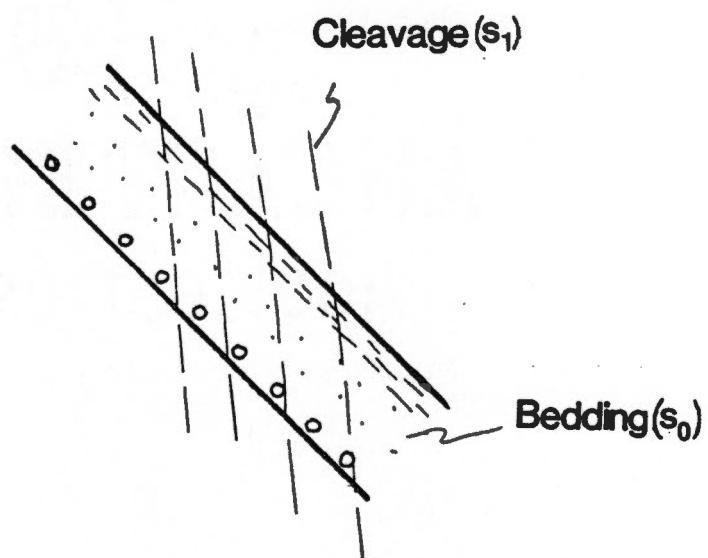


Figure 5 - Cleavage-bedding relationships in the Cades Sandstone in the Coalen Ground thrust block (schematic).

relationships to the Greenbrier thrust northeast of the study area (King, 1964). It is repeated here by the Coalen Ground thrust.

Evidence for the existence of the Coalen Ground thrust, as opposed to the original stratigraphic contact proposed here by Neuman and Nelson (1965), is the occurrence of mylonitic textures in both the hanging wall (Metcalf) and the footwall (Cades) rocks.

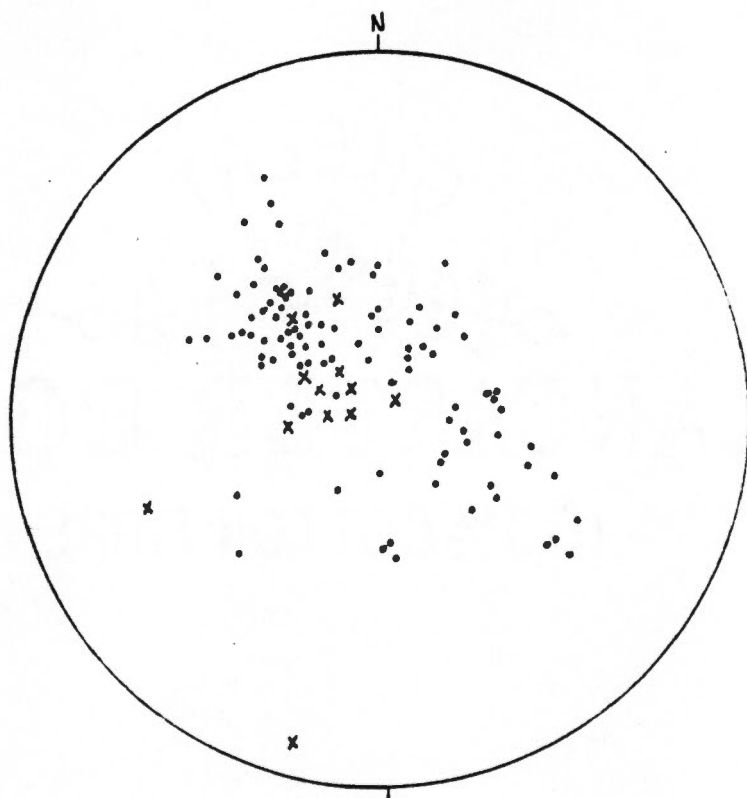
A small fault horse (Plate I, E) occurs in the Coalen Ground thrust zone, just south of the western boundary of Cades Cove. A small body of Cades overlies a small body of Metcalf here. It is interpreted to be a fault slice which was plucked and moved along with the Coalen Ground thrust.

Rabbit Creek Fault Block

The majority of the study area occurs within this fault block, that contains both Cades and Metcalf units (Plate I, D). Both bedding and cleavage generally dip towards the southeast in the Cades (Fig. 6a). Cleavage-bedding relationships and graded beds indicate that much of the Cades section is overturned in this block (Fig. 6b) (Neuman and Nelson, 1965; Shackleton, 1957). Local dip reversals along Abrams Creek reveal minor, moderate wavelength (approx. 20 m), open folds of low amplitude. No evidence of tight isoclinal folding could be

Figure 6 - Fabrics in the Cades Sandstone in the
Rabbit Creek fault block (Plate I, D).

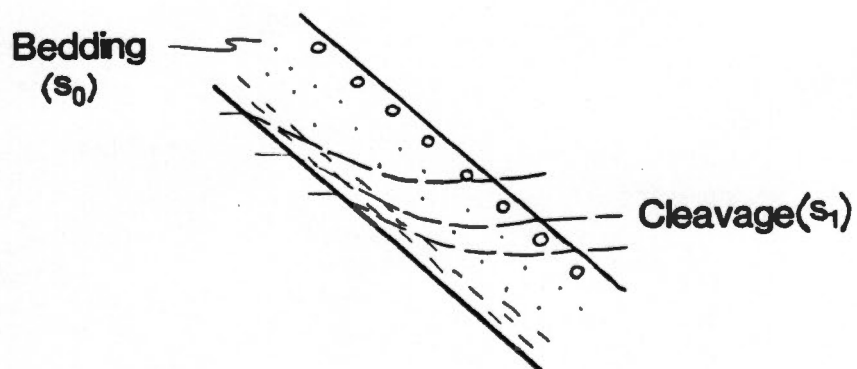
- a. Equal area (Schmidt) net stereographic
analysis.
- b. Cleavage-bedding relationships.



• - Poles to bedding x - Poles to cleavage (S_1)

NW

SE



seen along the Abrams Creek traverse. Some outcrop-scale (contractional?) faults were noted in Abrams Creek, however, they appeared to be minor and they could not be traced laterally.

A thin outcrop band of Metcalf Phyllite occurs in the Rabbit Creek fault block against the Great Smoky thrust, on the north side of Cades Cove. The contact between the Metcalf and Cades here was originally interpreted as a stratigraphic contact by Neuman and Nelson (1965). An outcrop on Tater Branch shows the Cades-over-Metcalf contact, which is oriented N 53°E, 17°NW. Foliation in the Cades (S_1) and foliation in the Metcalf (S_1) appear concordant, but fabrics in the Cades suggest that this contact is a fault (Greenbrier?). Several outcrop-scale faults are present, with displacement on the order of meters.

The Rabbit Creek thrust, in the northwest corner of the study area, emplaces Cades Sandstone against the Wilhite Formation. In this study, several portions of the fault were examined and attempts were made to trace the fault laterally. Cleavage occurs on both sides of the fault in the Cades and Wilhite, but mylonitization (as has been observed along the Parson Branch and Coalen Ground thrusts) was not observed, possibly due to poor exposure of the fault.

Metamorphism

In this study, the location of the biotite isograd on the geologic map differs from that of Neuman and Nelson (1965). Petrographic observations reveal that biotite first occurs in the northwest part of the Rabbit Creek fault block (Plate I). In this region, it is observed (in thin section) as small, brown, pleochroic grains, usually rimmed by chlorite. No biotite was noted in samples from the Wilhite Formation northwest of the Rabbit Creek thrust (Plate I). The biotite isograd should, therefore, be located near the Rabbit Creek thrust trace. A definite chronological relationship between Rabbit Creek thrust emplacement and metamorphism could not be determined here.

The biotite isograd in the Cades Cove region appears to mark a gradual transition from chlorite-bearing rocks (northwest) to biotite-chlorite assemblages (southeast). The various reactions which lead to the first formation of biotite are poorly understood (Ferry, 1984), and speculation upon a given one without more detailed petrologic investigation would be tenuous, at best.

CHAPTER IV

STRATIGRAPHIC COMPARISON OF CADES AND ELKMONT SANDSTONES

In this study, ten samples of Cades Sandstone and four samples of Elkmont Sandstone were collected and examined, both in hand sample and in thin section. One relatively undeformed sample from each Formation was then chosen as representative of the mean composition of each in the study area so that a comparison could be made between them.

The samples chosen for comparison appear relatively undeformed and are approximately equidistant (100 m) from the inferred trace of (different segments of) the Greenbrier thrust (Figs. 2 and 9; Locality 16 - Cades Sandstone, Locality 31 - Elkmont Sandstone).

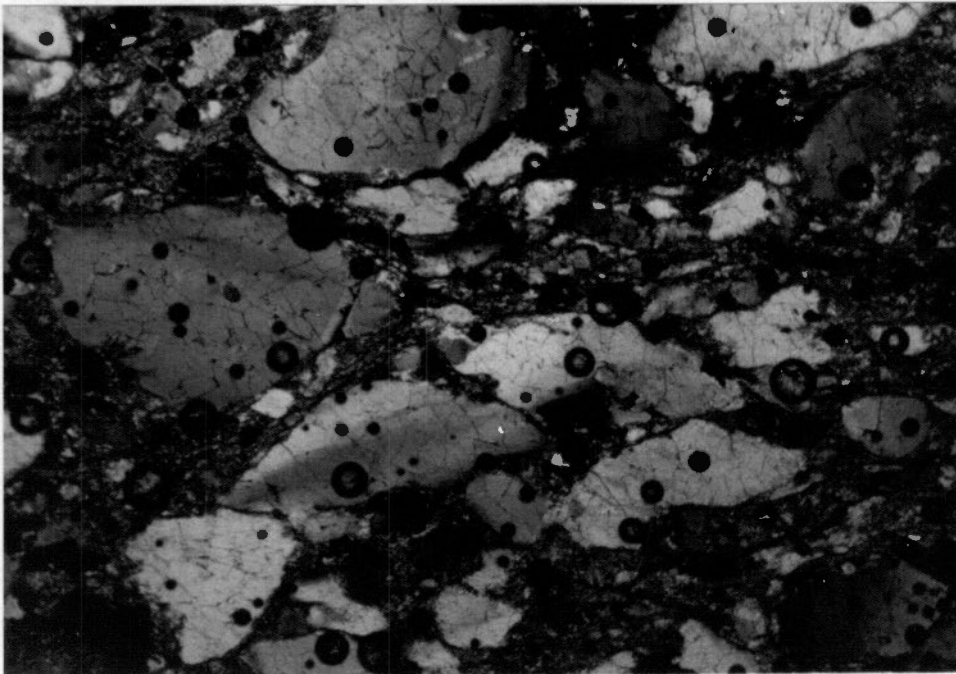
CADES SANDSTONE

The Cades sample is a course-grained to conglomeratic sandstone (Figs. 7a and 7b). Sand grains are typically sub-angular and comprise 70% of the sample. They are composed of quartz (85%) and potassium feldspar (15%) and average 0.6 mm in diameter. The matrix (25%) is composed

Figure 7 - Cades Sandstone (Locality 16, Figs. 2 and 9)

a. Hand sample. Scale bar is in cm.

b. Photomicrograph. Scale bar equals 1 mm.



dominantly of sericite and quartz silt, with a minor amount of opaque minerals. Pressure solution seams are evident in thin section. Undulatory extinction in quartz is almost universal and subgrain development is apparent in 5-10% of quartz grains.

ELKMONT SANDSTONE

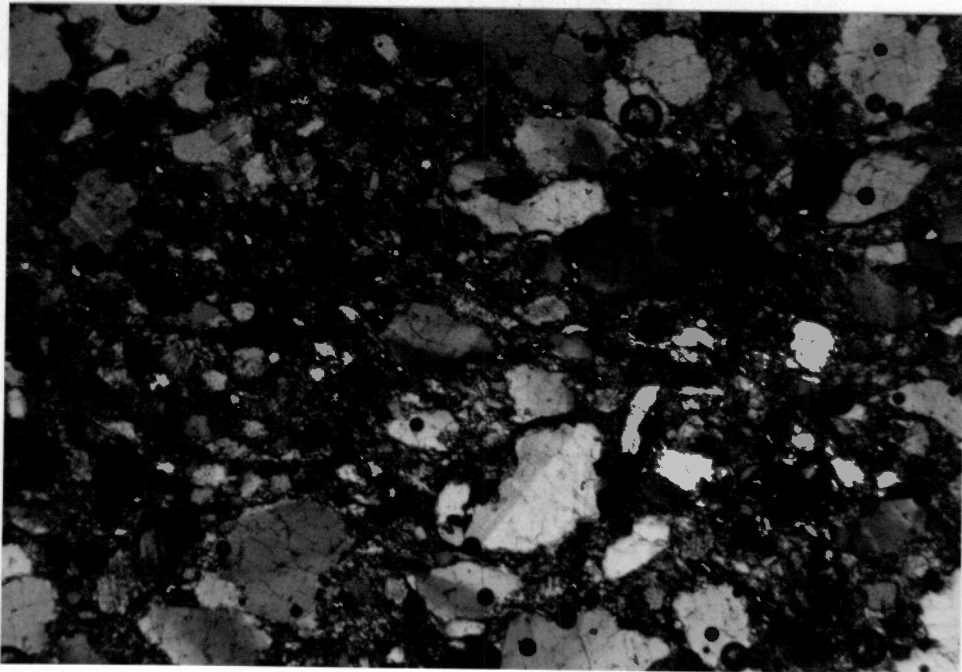
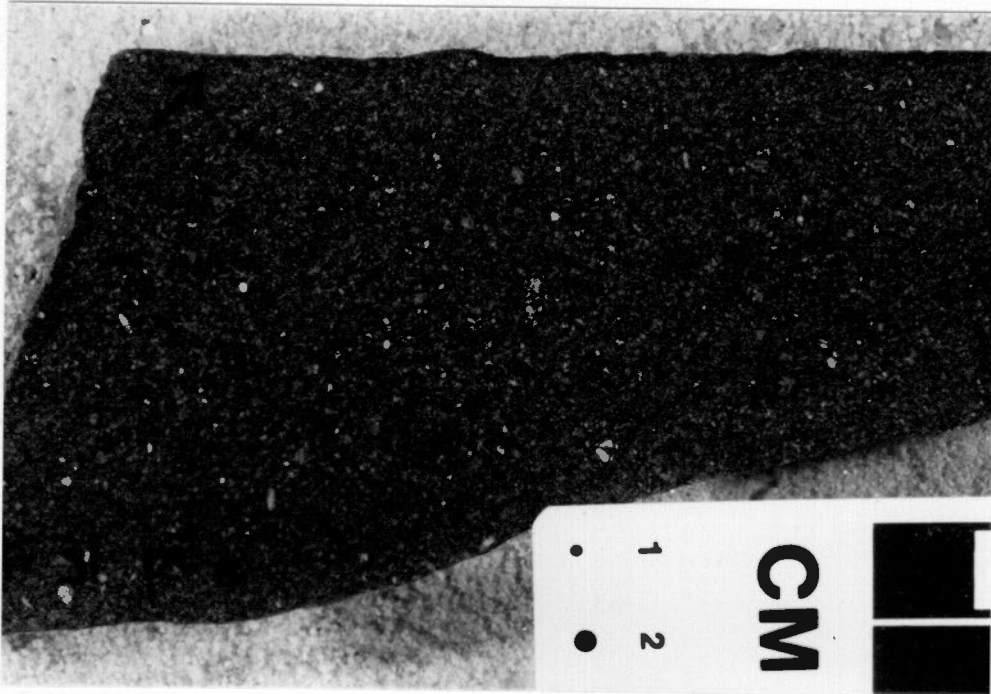
The Elkmont sample is a medium-grained sandstone (Figs. 8a and 8b). Sand grains comprise 65% of the sample and are typically sub-angular to sub-rounded. Grains are composed of quartz (90%) and potassium feldspar (10%) and average 0.4 mm in diameter. The matrix (35%) is dominated by biotite and sericite, with minor amounts of opaque minerals. Pressure solution features are rare, and subgrain development occurs in about 5% of quartz grains. Undulatory extinction also occurs in many grains.

Whereas compositions of each unit vary widely (from conglomerate to shale and slate), the samples described here are the most common compositions of the Cades and Elkmont (respectively) in the study area.

The overall mineralogy of the Cades and Elkmont are similar. Both are characterized by graded sequences which are interpreted to have been deposited by turbidity

Figure 8 - Elkmont Sandstone (Locality 31, Figs. 2 and 9)

- a. Hand sample. Scale bar is in cm.
- b. Photomicrograph. Scale bar equals 1 mm.



currents in a tectonically unstable environment (Pettijohn, 1975). In addition, heavy mineral studies of both the Cades and Elkmont Sandstones by Carroll and others (1957) showed no significant differences between the two units. Slight grain size and bedding variations (Neuman and Nelson, 1965) between the two may be attributed to varying distances from their common source area.

Petrographic examination of undeformed samples therefore supports the idea that the Cades and Elkmont are stratigraphic equivalents. The question remains as to how the stratigraphically equivalent Cades and Elkmont have been juxtaposed to create the present map pattern.

CHAPTER V

ROCK FABRICS

INTRODUCTION

Deformational fabrics are essential for interpreting the overall structural geometries in the study area. The fabrics discussion will be divided geographically across the area: 1) main Greenbrier thrust sheet, 2) zone of faulting of Metcalf and Cades (Parson Branch, Coalen Ground and Greenbrier thrust sheets) and 3) Rabbit Creek thrust sheet (Fig. 9). Pertinent mesofabrics and microfabrics will be discussed from each region and deformation mechanisms will be suggested based on these fabrics.

PREVIOUS WORK

Fabrics and related deformation mechanisms in quartz-rich rocks have been discussed extensively in the literature. Quartz deformation may occur in a number of different ways, the most common of which are: 1) cataclasis, 2) pressure solution, 3) dislocation creep, 4) dislocation glide, 5) grain boundary diffusion (Coble

creep), and 6) volume diffusion (Nabarro-Herring creep) (Rutter, 1976). This study primarily observed evidence for pressure solution and dislocation movement as indicators of the degree of deformation in the quartz-rich rocks (e.g., Cades and Elkmont Sandstones) of the area.

White (1976) stated that crystal-plastic (dislocation) deformation mechanisms are important processes in quartz deformation. Two mechanisms, dynamic recovery and dynamic recrystallization, may lead to steady-state flow, which is necessary if large strains are to be attained (Sibson, 1977). The first observable effect of strain in quartz grains is the development of intracrystalline strain features, such as undulatory extinction and (strained) subgrain development. This is known as dynamic recovery. If recovery cannot keep pace with increases in dislocation density, dynamic recrystallization may occur, resulting in the formation of new, small, strain-free quartz grains.

Pressure solution is also an important deformation mechanism in rocks (Rutter, 1976). Textures characteristic of pressure solution are common in rocks deformed at temperatures generally below 400°C, with crystal-plastic mechanisms dominating at higher temperatures (Ramsay, 1967; Durney, 1972). Pressure solution textures in the area include solution seams (at mesoscopic and microscopic scale), quartz pressure shadows around grains and

precipitation of pressure-dissolved quartz in fractured grains.

FABRICS

Main Greenbrier Thrust Sheet (Elkmont Sandstone)

In general, fabrics in the Elkmont Sandstone indicate a small amount of deformation. Thin-section analysis of the Elkmont reveals that it is a medium- to coarse-grained sandstone. Grains (60%) appear equidimensional and are composed dominantly of quartz with some feldspar. Subgrain development in quartz is minor, and undulatory extinction in most grains indicates only weak crystal-plastic deformation. However, although undulatory extinction is common, some grains are characterized by uniform extinction.

Hand samples 31 (Fig. 8a) and 32 (Fig. 10) are medium-grained sandstone lithologies, which exhibit very little deformation. Grains are composed dominantly of quartz (+feldspar) within a matrix of dominantly mica and fine grained quartz silt.

Outcrops of Elkmont may contain weak southeast dipping cleavage, which appears to be the principal manifestation



Figure 10 - Hand sample photo of Elkmont Sandstone
(Locality 32, Fig. 9). Scale bar is in cm.

of pressure solution in the main Greenbrier sheet (Fig. 11).

Zone of Faulting of Cades and Metcalf

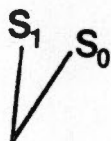
Three major thrust faults occur here which affect fabric development in the region. The Parson Branch and Coalen Ground thrusts emplace Metcalf upon Cades, whereas the Greenbrier thrust emplaces Cades upon Metcalf. Therefore, the fabrics discussion for the zone of faulting will be subdivided into three sections (southeast to northwest): 1) Parson Branch thrust sheet, 2) Greenbrier thrust sheet, and 3) Coalen Ground thrust sheet (Plate I).

Parson Branch thrust sheet

The Parson Branch thrust sheet contains only Metcalf Phyllite, which is moderately to highly deformed. The Metcalf here shows well-developed shear band cleavage (S_2) (White and others, 1980) and small kink folds (S_2), both of which deform the main foliation (S_1).

The shear band cleavage in the hanging wall of the Parson Branch thrust (Fig. 12) is similar to what Platt and Vissers (1980) term extensional crenulation cleavage (ECC) and also to what Lister and Snoke (1984) term an S-C mylonite. These terms here appear to be synonymous for all

SE



NW



Figure 11 - Outcrop photo of cleavage in Elkmont Sandstone in the main Greenbrier thrust sheet (Locality 31, Fig. 9). Water bottle for scale (20 cm.).

SE

NW



Figure 12 - Outcrop photo of shear band cleavage in Metcalf Phyllite in the hanging wall of the Parson Branch thrust, $\frac{1}{2}$ km east of branch point between Parson Branch and Greenbrier thrusts (Fig. 9). Wooden stake for scale (25 cm.).

practical purposes, and the term shear band cleavage will be used throughout the rest of the discussion.

Dennis and Secor (1987) also provided a morphological description of shear band cleavage, describing it in terms of crenulation slip with respect to foliation planes. Applying their conclusions, the texture in the Metcalf in the hanging wall of the Parson Branch thrust is a normal slip crenulation (NSC). This NSC texture marks a zone of heterogeneous simple shear (Dennis and Secor, 1987), with the Parson Branch hanging-wall moving up.

The Metcalf near the Parson Branch thrust is also characterized by small scale conjugate kink-fold development (Fig. 13). The layers of the fold, as viewed in thin section, appear to maintain constant orthogonal thickness throughout, suggesting that they developed primarily due to flexural slip along the phyllitic foliation (Ramsay, 1967). Ramsay (1962) suggested that the kink axial surfaces may originate in response to a primary shear system (Fig. 14). The kink band axes are sub-parallel to the inferred trace of the Parson Branch thrust, suggesting that they formed as a result of movement on this thrust (Fig. 15).

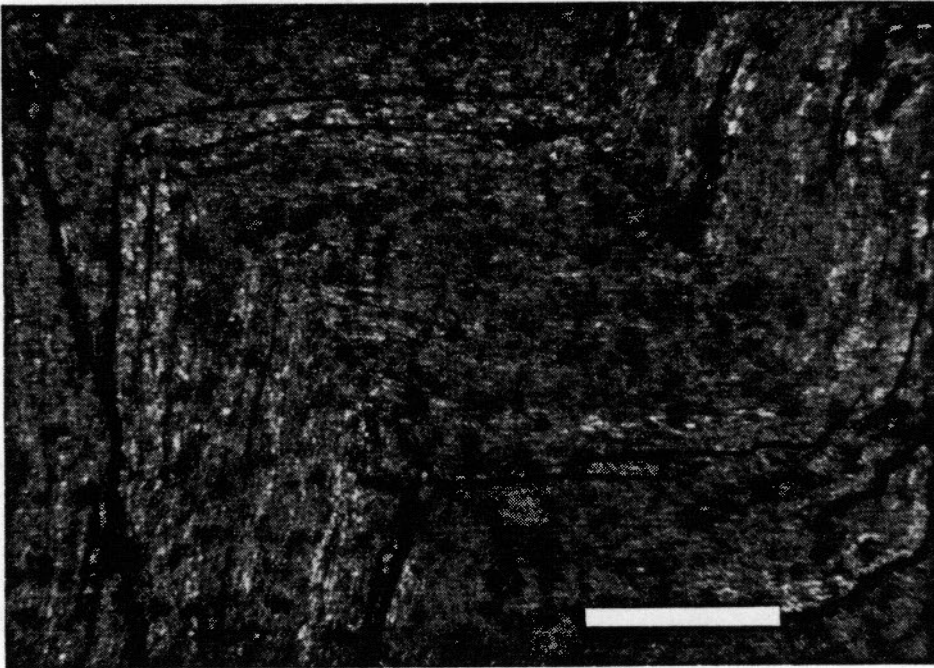
The presence of shear band cleavage here indicates that the Metcalf-over-Cades contact here is tectonic, rather than the stratigraphic as originally proposed by Neuman and Nelson (1965).

Figure 13 - Photomicrograph of kink bands in Metcalf Phyllite from hanging wall of the Parson Branch thrust (Locality 59, Fig. 9). Plane polarized light. Scale bar equals 1 mm.

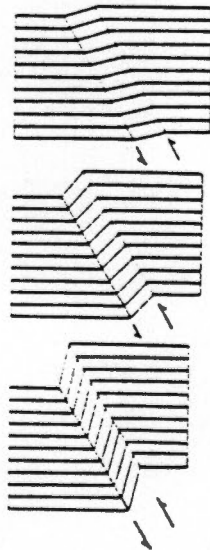
Figure 14 - Simple shear model for progressive development of a kink band (from Ramsay, 1967).

S_2

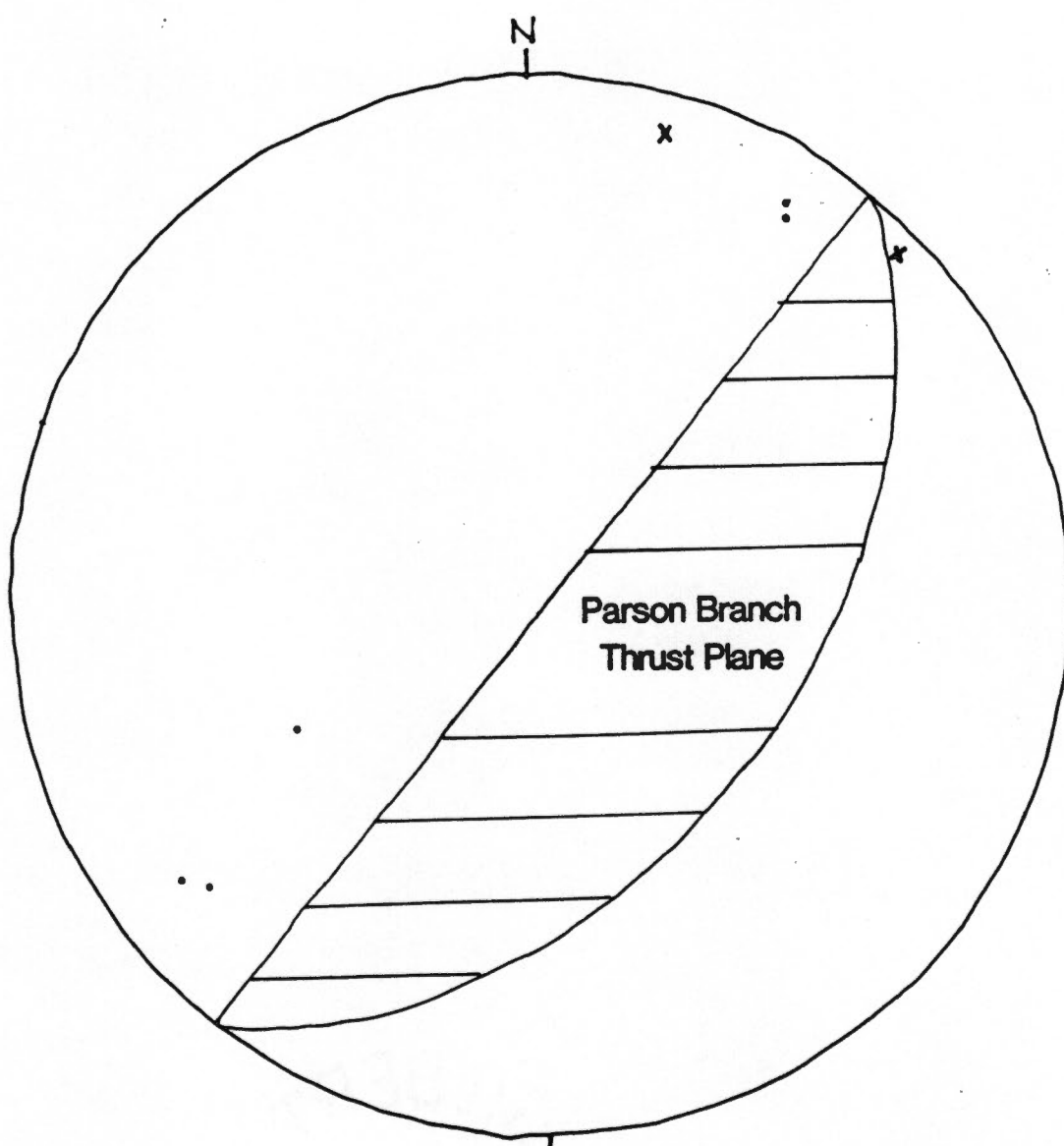
S_1



Model 1



Simple shear zone



- x - Foliation/shear band intersection (lineation)
- - Kink axial trace (lineation)

Figure 15 - Equal-area (Schmidt) net illustrating Parson Branch thrust orientation and kink axes/shear band orientations in Metcalf Phyllite.

Greenbrier thrust sheet

The Greenbrier thrust sheet in the faulted zone contains only Cades Sandstone. Fabrics in the Cades in this sheet here vary with proximity to the bounding thrusts (Greenbrier beneath and Parson Branch above).

Sample 16 (Figs. 7a and 7b) is characteristic of the undeformed texture of the Cades, and is located approximately 100 m above the Greenbrier thrust.

Sample 66 (Fig. 16) is characteristic of the deformed Cades Sandstone from this sheet and is located approximately 100 m beneath the Parson Branch thrust. This sample shows a distinct flattening fabric (S_1), and would be referred to as a proto-mylonite by Sibson (1977). In addition, Sample 66 contains pressure solution features, such as quartz pressure beards adjacent to large feldspar grains (Fig. 17) and quartz re-precipitation within fractured feldspar grains (Fig. 18).

Subgrain development in quartz is also prominent in Sample 66. Figure 19a shows a photomicrograph of a single quartz grain. Figures 19b and 19c show the sub-division of the grain into many distinct subgrains, typical of crystal-plastic deformation.



—S₁

Figure 16 - Photomicrograph of Cades Sandstone in the Coalen Ground thrust block within 100 m of the Parson Branch thrust (Locality 66, Fig. 9). Plane polarized light. Scale bar equals 1 mm.

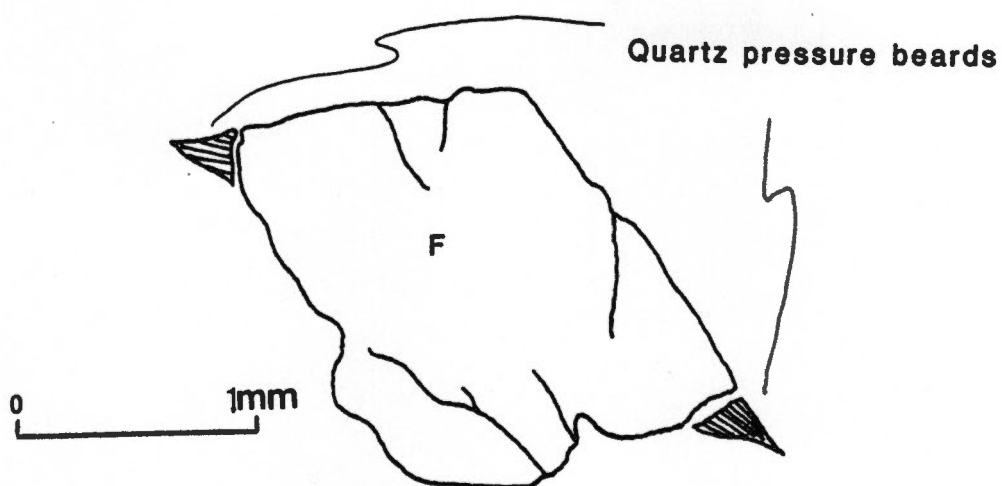


Figure 17 - Sketch of photomicrograph of Cades Sandstone showing quartz pressure solution beards adjacent to large feldspar grain (Locality 66, Fig. 9). Scale is indicated.

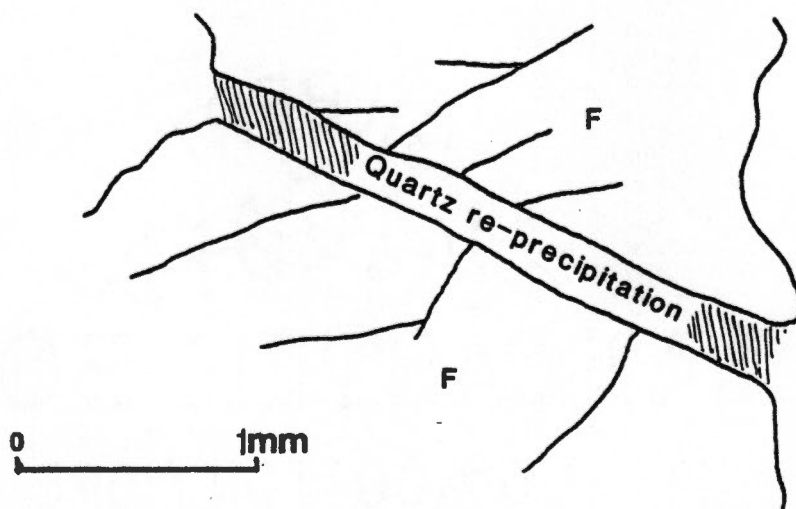
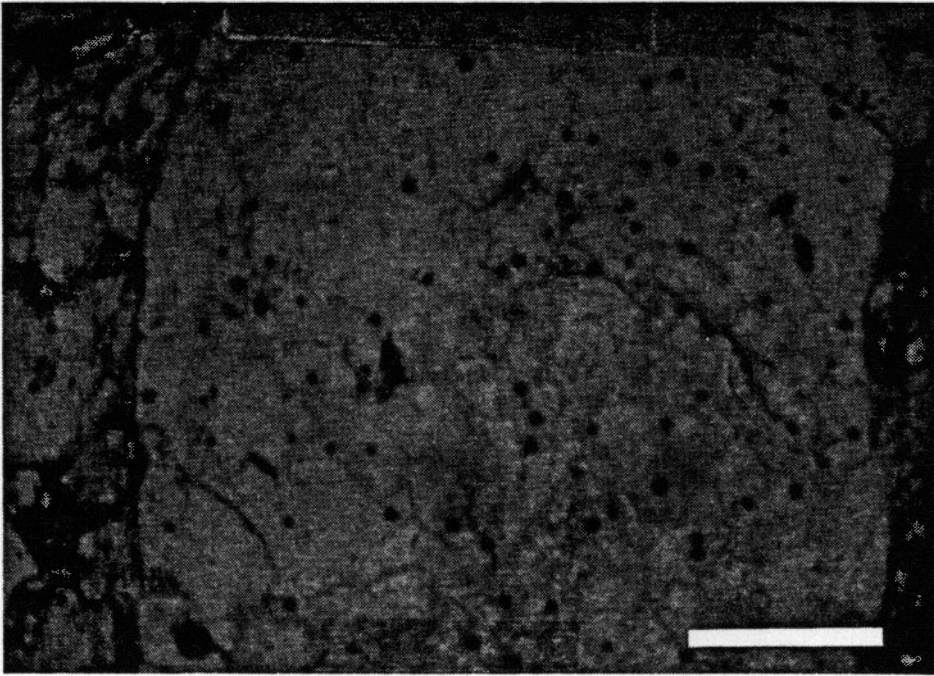


Figure 18 - Sketch of photomicrograph of Cades Sandstone showing large fractured feldspar grain which was infilled by quartz (Locality 66, Fig. 9). Scale is indicated.

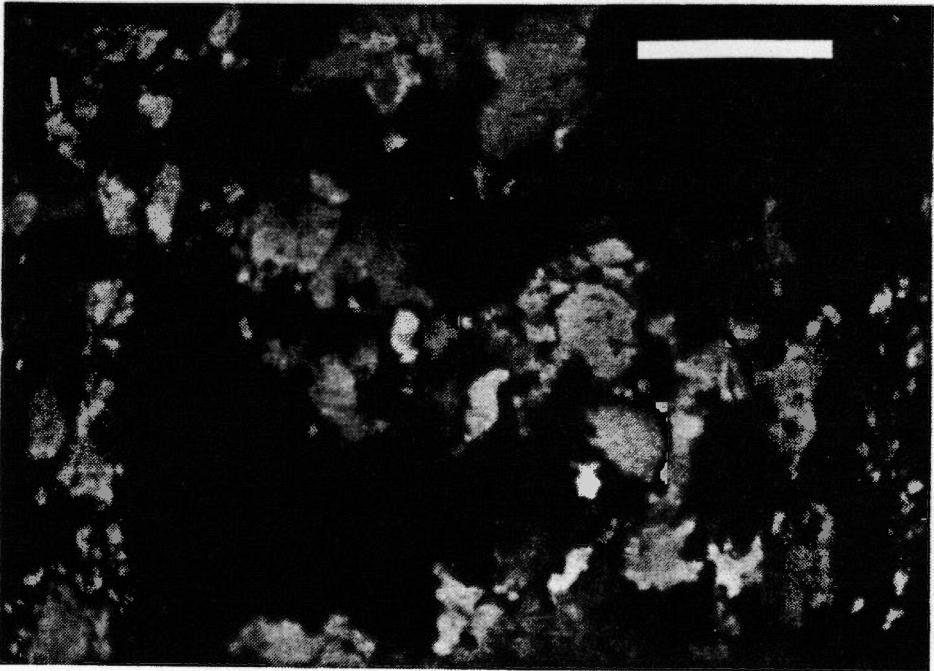
Figure 19 - Photomicrographs of Cades Sandstone
(Locality 66, Fig. 9).

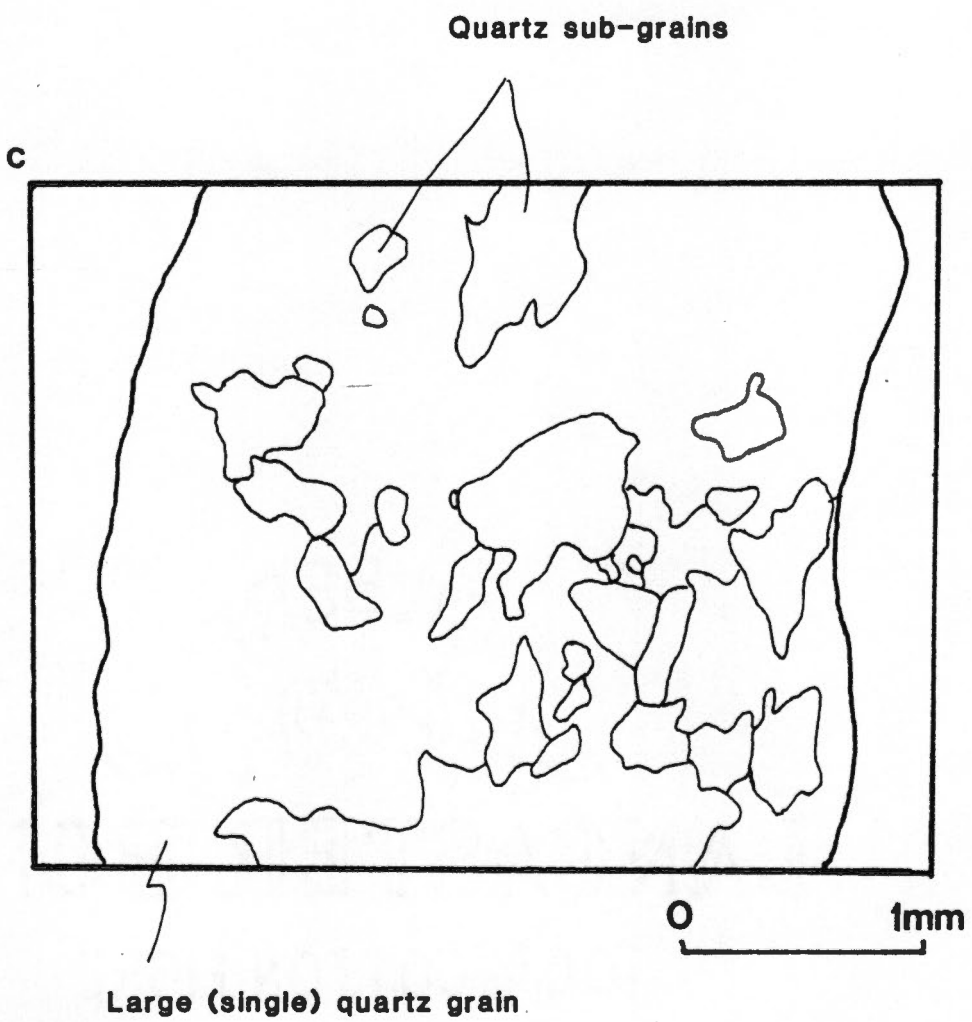
- a. Plane polarized light. Scale bar equals 1 mm.
- b. Crossed polars.
- c. Overlay sketch showing quartz subgrains.

a



b





Coalen Ground thrust sheet

The Coalen Ground sheet, like the Parson Branch sheet, is composed only of Metcalf Phyllite. Fabrics in the Metcalf here vary with proximity to bounding thrusts (Coalen Ground beneath and Greenbrier above).

Sample 17 (Fig. 20) is characteristic of the less-deformed Metcalf and is located approximately 100 m beneath the Greenbrier thrust. This sample exhibits phyllitic foliation (S_1) that is slightly crenulated (S_2). S_2 may represent an incipient shear band cleavage.

In contrast, Sample 19 is highly deformed Metcalf which is located approximately 100 m above the Coalen Ground thrust. It contains a well-developed shear band cleavage (Fig. 21), that probably formed as a result of movement on the Coalen Ground thrust.

Again, the presence of shear-band cleavage here indicates that this Metcalf over Cades contact is tectonic, rather than stratigraphic as originally proposed by Neuman and Nelson (1965).

Rabbit Creek Thrust Sheet (Cades Sandstone)

Fabrics in Cades Sandstone in the Rabbit Creek thrust sheet generally exhibit a greater degree of deformation than those in the main Greenbrier sheet (Elkmont

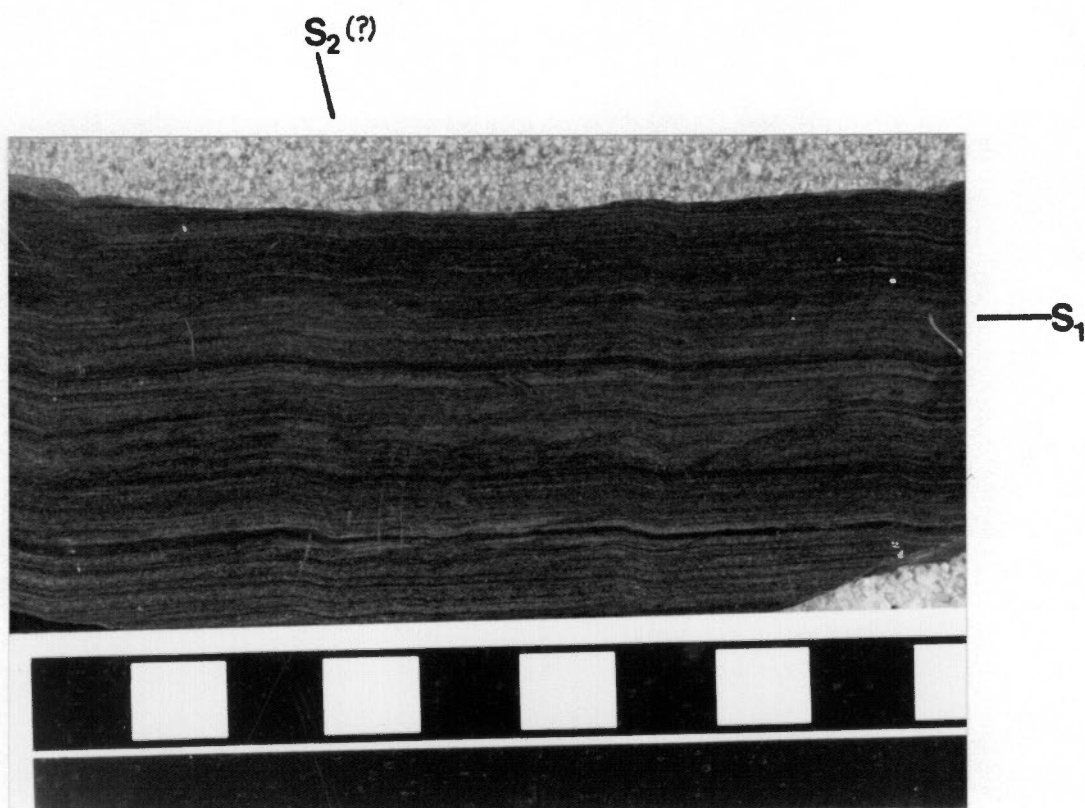


Figure 20 - Hand sample photo of crenulated foliation in Metcalf Phyllite (Locality 17, Fig. 9). Scale bar is in cm.



Figure 21 - Hand sample photo of shear band cleavage in Metcalf Phyllite (Locality 19, Fig. 9). Scale bar is in cm.

Sandstone). Three separate fabric domains are noted here and each will be discussed separately (see Fig. 22 for domain division).

Domain I - Fabrics associated with the Coalen Ground thrust

Samples from the footwall of the Coalen Ground thrust (southeast flank of Boring Ridge) are characterized by extensive mylonitic development. Samples 1 (Fig. 23) and 46 typify this region. Both exhibit well-developed quartz ribbons in the dip sections and quartz flattening (S_1), that defines the cleavage (XY) plane. Sample 46 contains undulatory extinction and subgrain development in quartz, both of which are much more pronounced than in the main Greenbrier sheet. Pressure-solved quartz is also common and was observed as: 1) pressure seams parallel or at low angle to quartz ribbons (Fig. 24), 2) pressure beards adjacent to large feldspar grains, and 3) re-precipitation of quartz in fractured feldspars (Fig. 25).

Domain II

This fabric domain occurs from Boring Ridge northwestward to Spruce Double Hill and is characterized by Samples 27, 35 and 62. The Great Smoky thrust dips

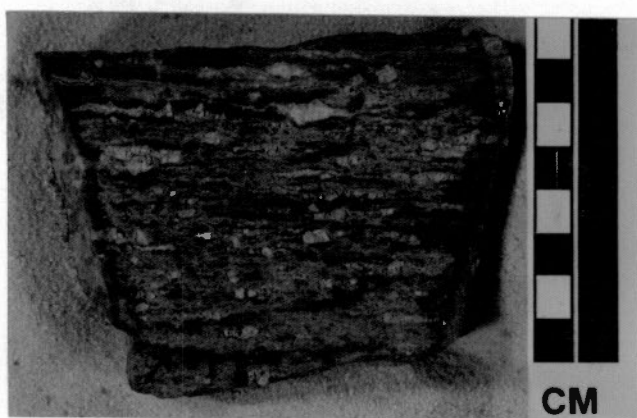
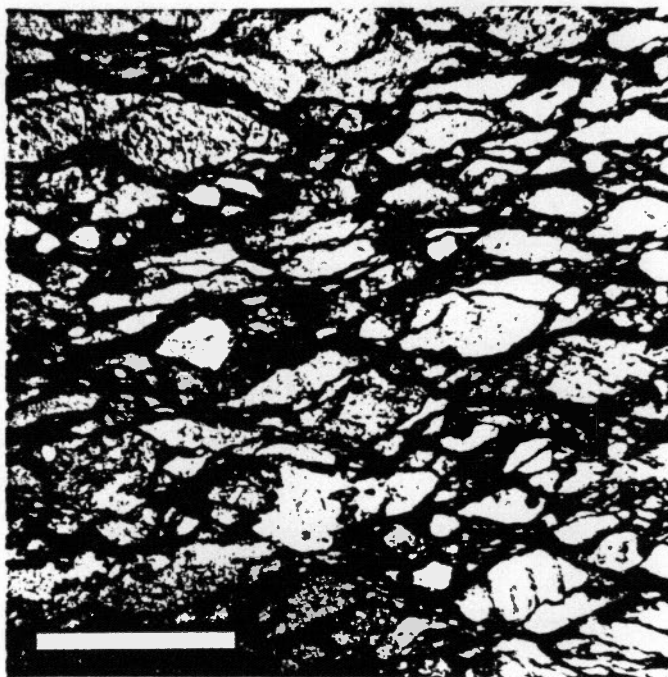


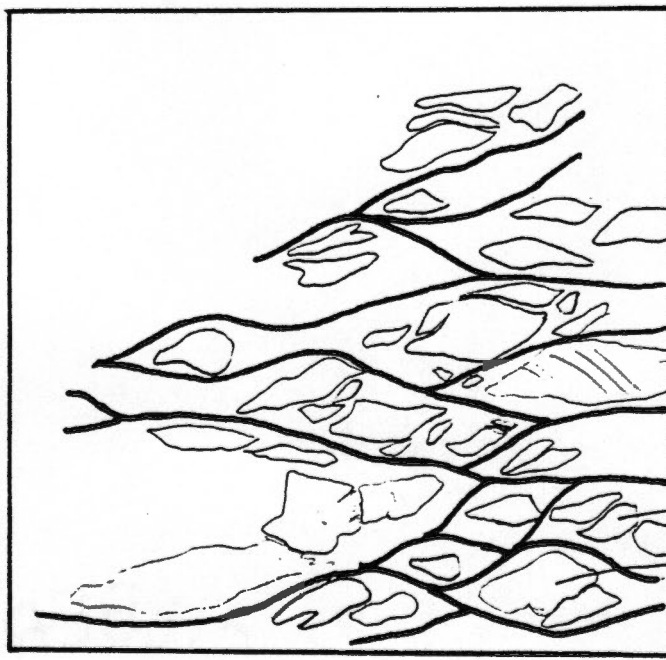
Figure 23 - Hand sample photo of quartz flattening fabric (S_1) in Cades Sandstone from Domain I of the overturned forelimb (Locality 1, Fig. 9). Scale bar is indicated.

Figure 24 - Photomicrograph of pressure solution features in Cades Sandstone from Domain I of the overturned forelimb (Locality 46, Fig. 9)

- a. Plane polarized light. Scale bar equals 1 mm.
- b. Overlay sketch.



—S₁



Pressure
seams

Quartz
ribbons

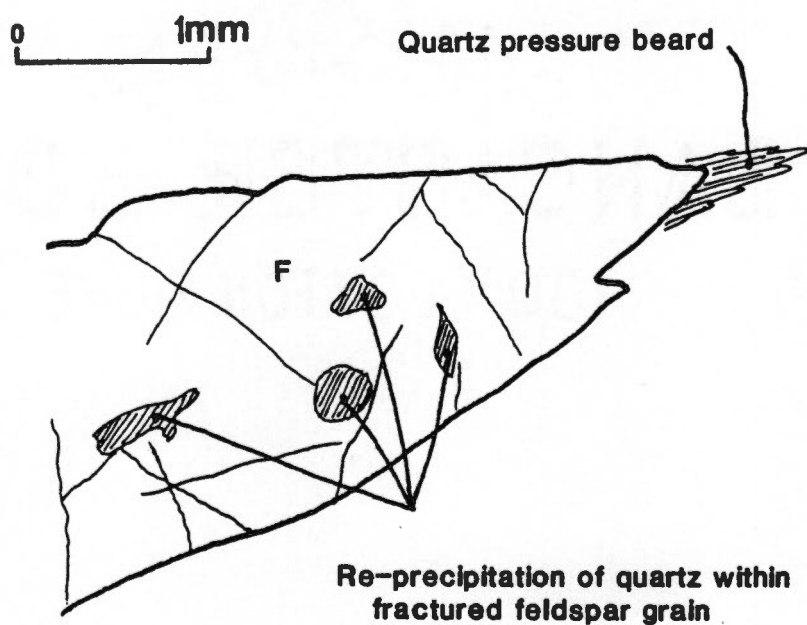


Figure 25 - Sketch of photomicrograph of Cades Sandstone showing re-precipitation of quartz in fractured feldspar (Locality 46, Fig. 9). Scale is indicated.

northwestward beneath this area (Neuman and Nelson, 1965) so that rocks exposed progressively from southeast to northwest in this domain are assumed to be progressively farther from the fault surface. Deformation fabrics in this domain become less intense from southeast to northwest.

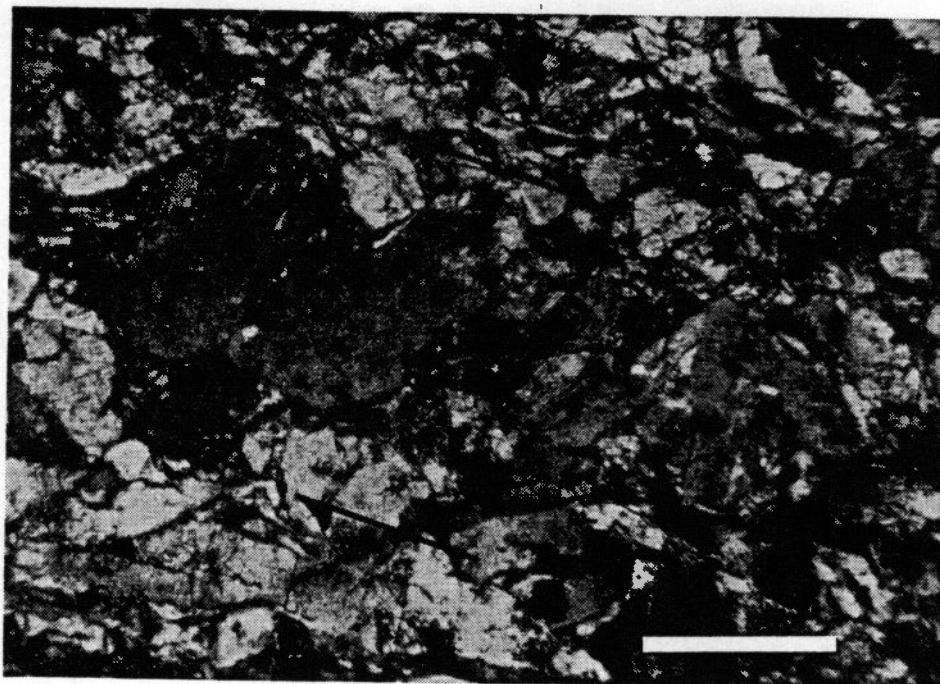
Sample 27 contains a well-developed quartz flattening, much pressure-solved material and extensive subgrain development. In addition, cracked and rotated feldspars are present and may be used as sense of shear indicators (Fig. 26).

Sample 35 (Fig. 27), located further away from the Great Smoky thrust trace, contains pressure solution and subgrain development in quartz; however, quartz flattening (cleavage) is not present.

Sample 62 (Fig. 28), that was collected the greatest distance from the Great Smoky thrust trace, exhibits dominantly pressure solution features, such as pressure seams and quartz pressure beards adjacent to large grains. It contains neither a quartz flattening fabric nor extensive subgrain development, such as in Samples 27 and 35 (respectively).

Figure 26 - Photomicrograph of fractured and rotated feldspar from Domain II of the overturned forelimb (Locality 27, Fig. 9).

- a. Crossed polars.
- b. Overlay sketch. Scale bar equals 1 mm.



SE

NW

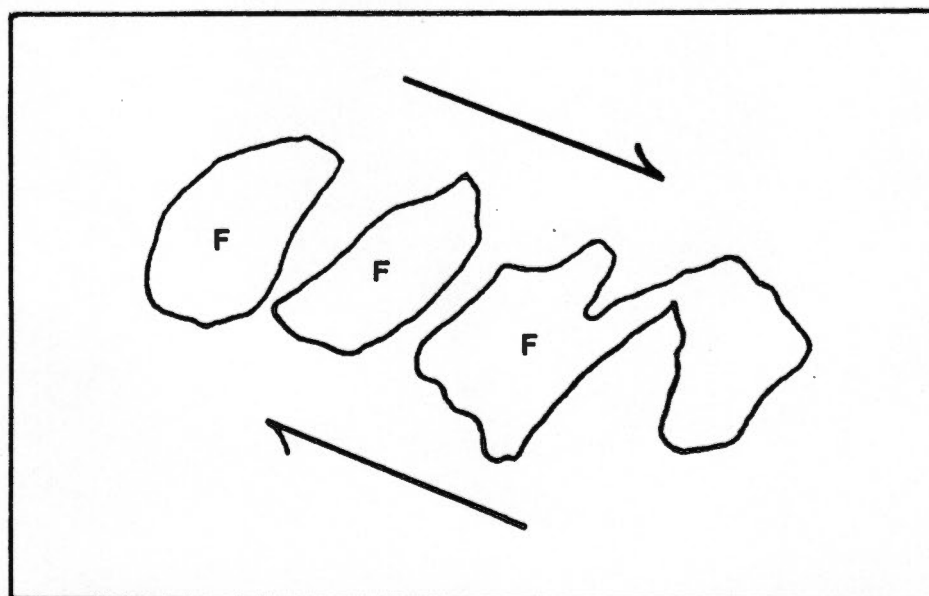


Figure 27 - Photomicrograph of subgrain development in quartz from Domain II of the overturned forelimb (Locality 35, Fig. 9).

- a. Plane polarized light. Dark lines in and around the quartz grain are areas of pressure solution.
- b. Crossed polars. Scale bar equals 1 mm.

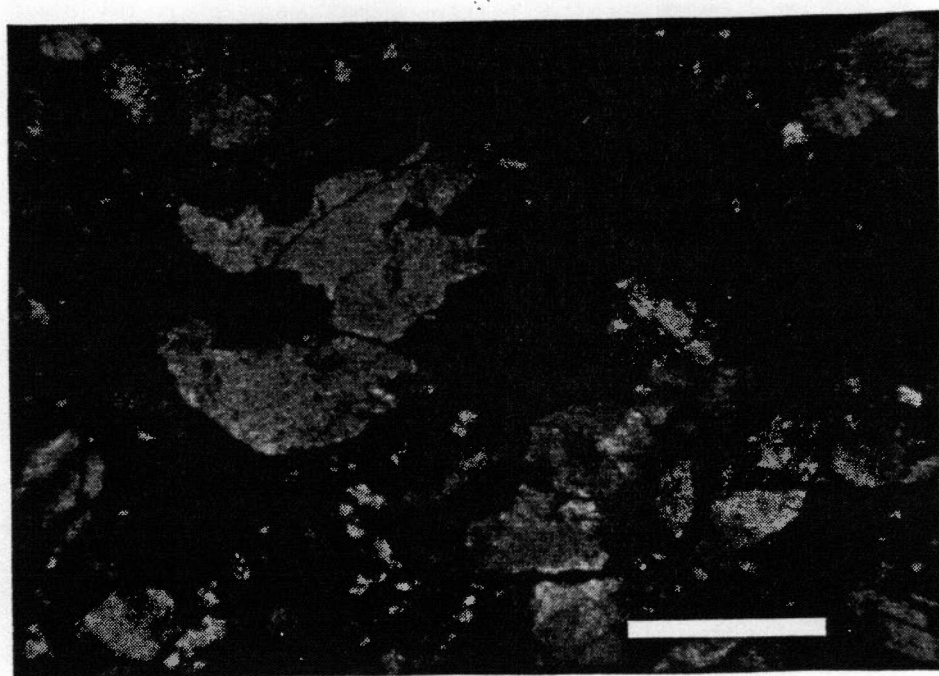
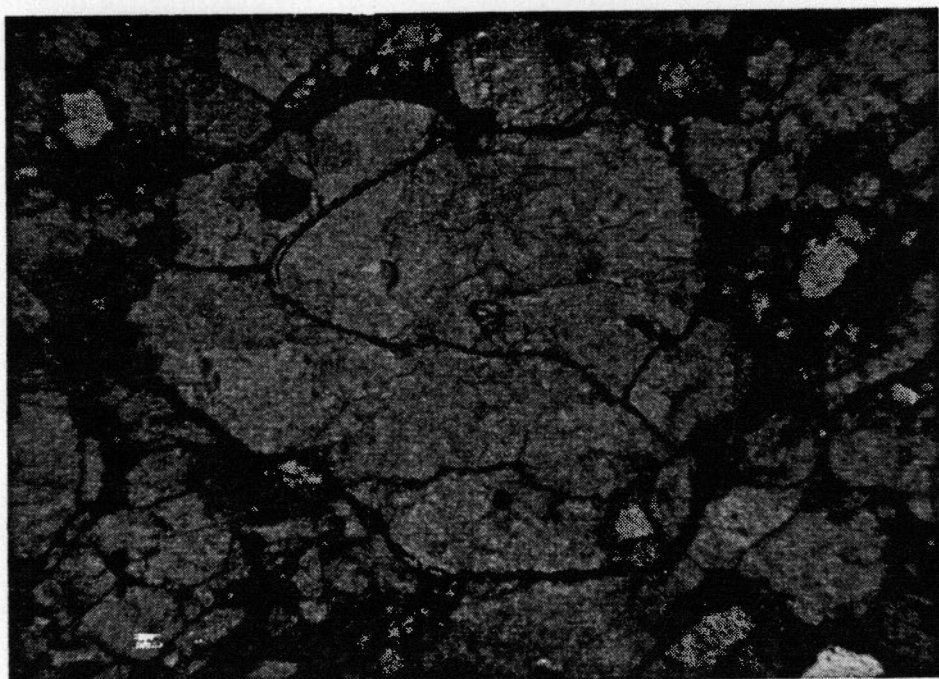
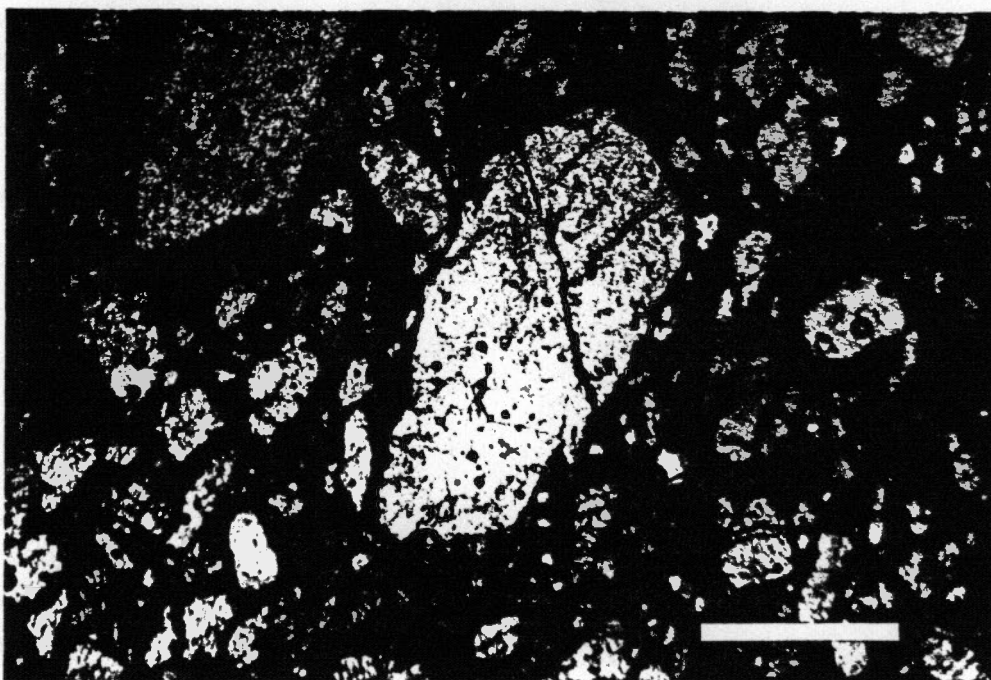


Figure 28 - Photomicrograph of pressure solution features from Domain II of the overturned forelimb (Locality 62, Fig. 9).

- a. Plane polarized light. Scale bar equals 1 mm.
- b. Overlay sketch.



Domain III - Fabrics associated with the Rabbit Creek thrust

Rocks in this domain tend to be finer grained (e.g., fine-grained sandstone, siltstone and shale/slate) than those from Domains I and II. Samples 77 and 94 are characteristic of this domain.

Sample 77 (Fig. 29) contains very few of the previously discussed features from Domains I and II. Subgrain development in quartz is rare and a flattening fabric is absent. Angular quartz is common but well-developed pressure solution seams are absent.

At Abrams Falls, abundant closely-spaced cleavage that dips more steeply than bedding occurs in a siltstone lithology in the Cades Formation (Fig. 30). Sample 94 exhibits a coarsening-upward sequence here (Fig. 31). In thin section, Sample 94 shows no pronounced flattening fabric, but pressure solution between quartz grains is more pronounced here than in the Elkmont (main Greenbrier thrust sheet) and may be seen throughout the thin section (Fig. 32).

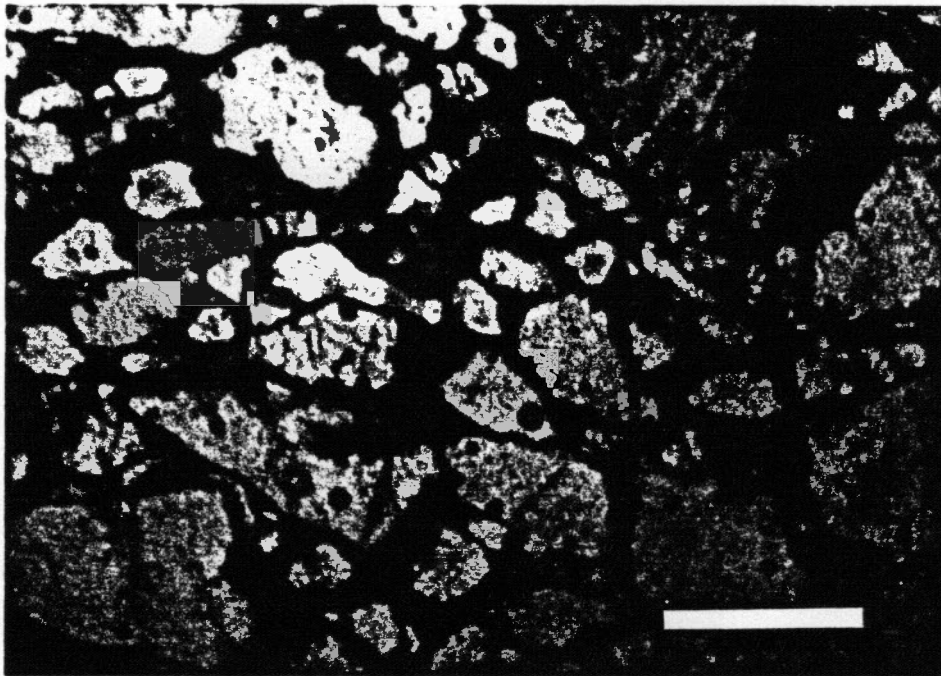


Figure 29 - Photomicrograph of Cades Sandstone from Domain III of the overturned forelimb (Locality 77, Fig. 9). Plane polarized light. Scale bar equals 1 mm.

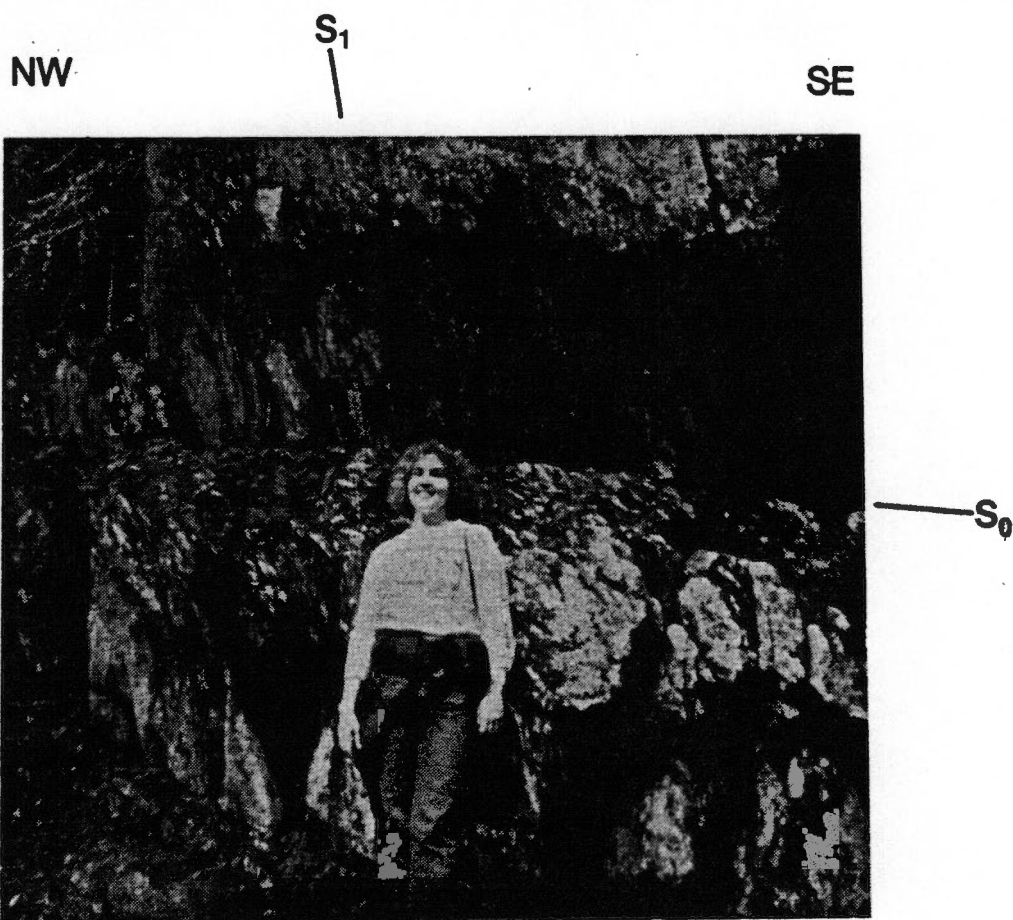


Figure 30 - Outcrop photo of extensive cleavage development in Cades Sandstone in Domain III of the overturned forelimb, within approximately 200 m of the Rabbit Creek thrust, at Abrams Falls (Locality 94, Fig. 9). Unknown girl for scale.

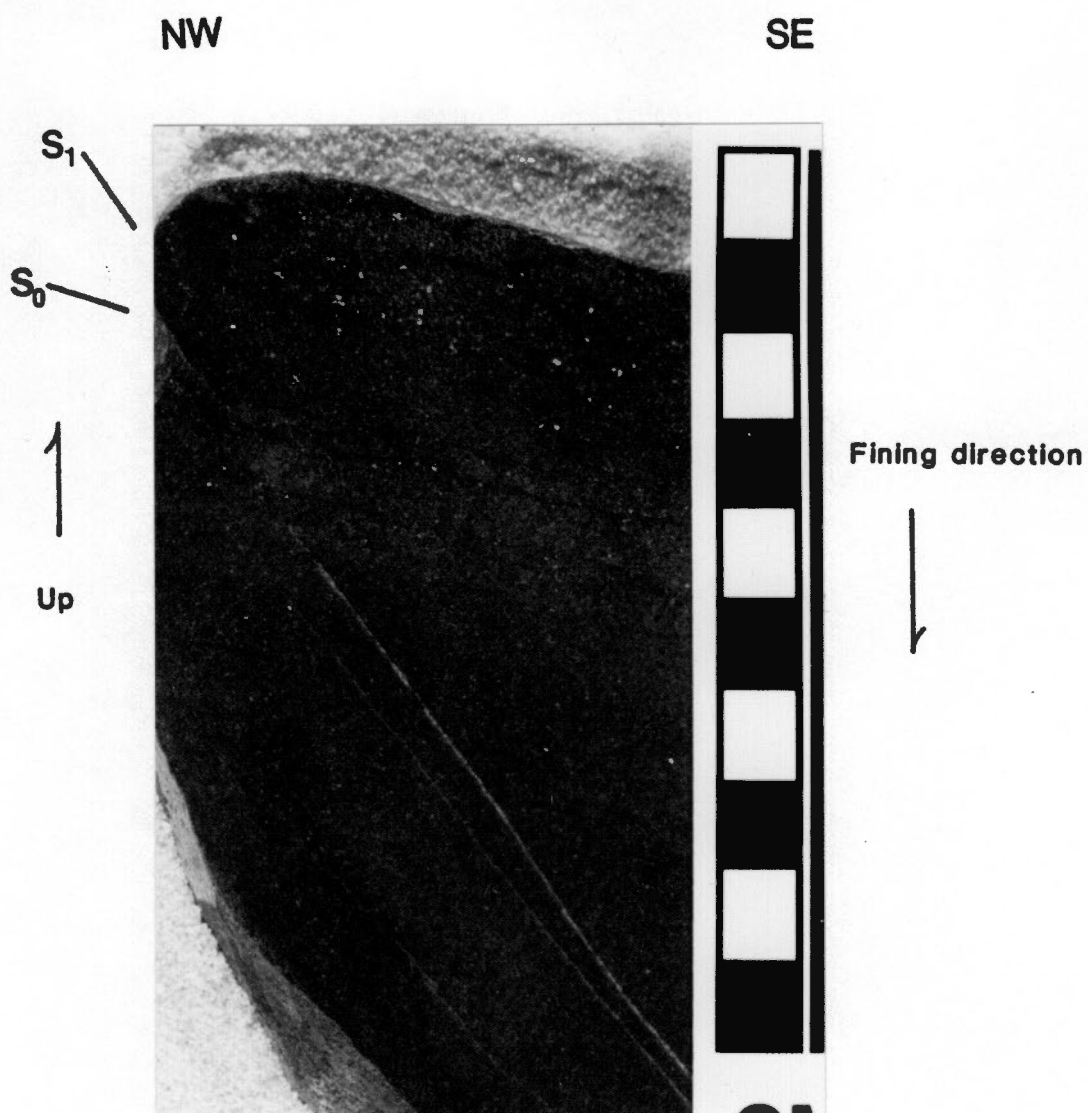


Figure 31 - Hand sample photo of coarsening-upward sequence in Cades Sandstone at Abrams Falls (Locality 94, Fig. 9). Scale bar is in cm.

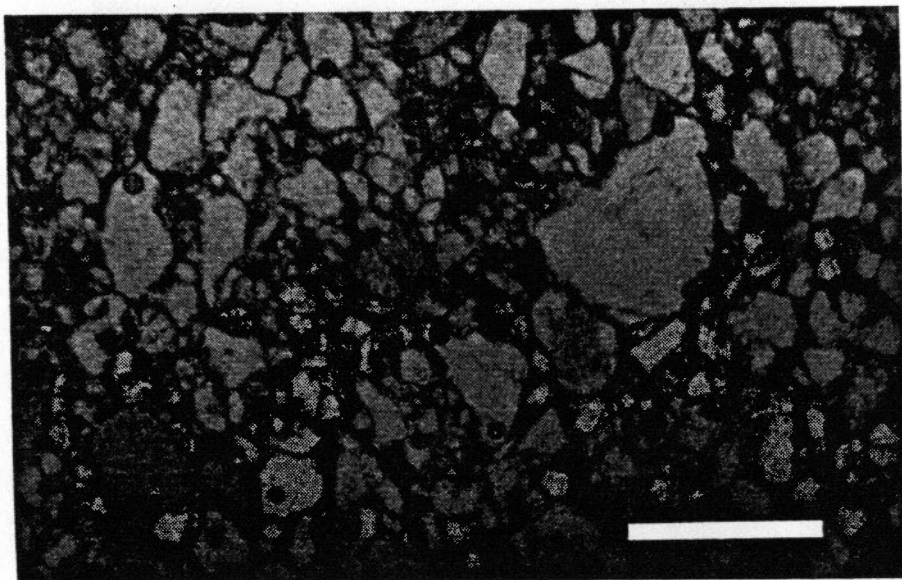


Figure 32 - Photomicrograph of pressure solution features between quartz grains at Abrams Falls (Locality 94, Fig. 9). Plane polarized light. Scale bar equals 1 mm.

Fabrics Associated with the Cades-over-Metcalf Contact

North of Cades Cove

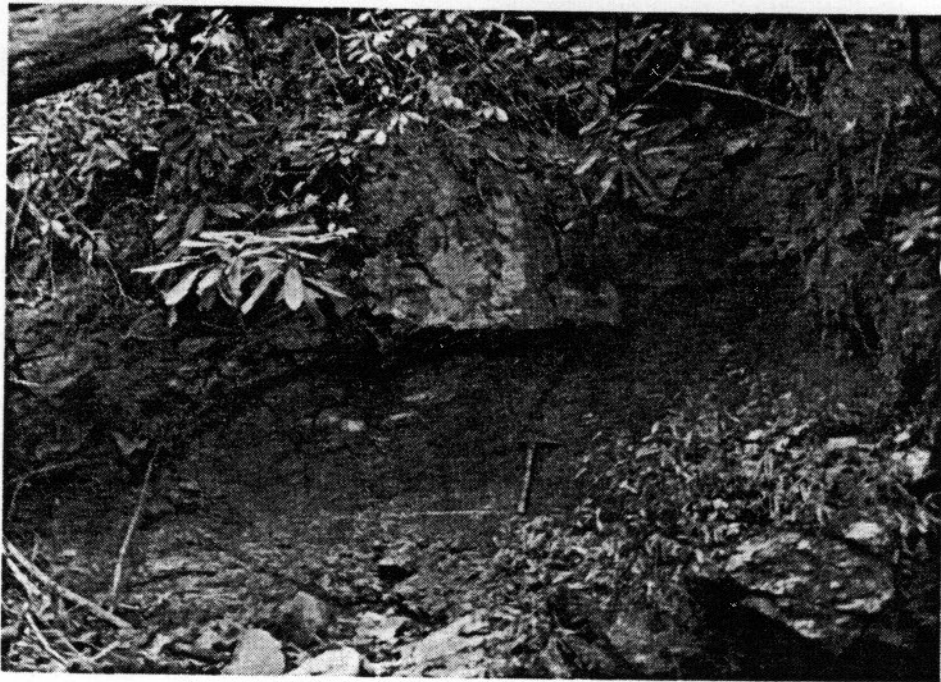
The contact of Cades Sandstone overlying Metcalf Phyllite on Tater Branch (Plate I, Z) is crucial in understanding the relationship between the Great Smoky and Snowbird Groups in the Cades Cove region. The outcrop photo (Fig. 33) of the contact contains a thick-bedded conglomerate overlying a reddish, phyllitic saprolite. The orientation of the contact is N 53°E, 17°NW. Outcrop-scale fabrics include a conjugate fracture set, small-scale contractional and extensional faulting, and apparent concordance of both the Cades and Metcalf units above and below the contact. The Metcalf also contains crenulations at a high angle to foliation and small (6") quartz veins parallel to foliation.

The Metcalf Phyllite could not be sampled because it is highly weathered, but the Cades Sandstone was sampled here. Sample 81 (Fig. 34) is characteristic of the Cades Sandstone at this outcrop. Mesoscopic features in Sample 81 include a quartz flattening cleavage (S_1) and pressure solution seams, both parallel to the contact. According to Sibson (1977), this sample would be a protomylonite.

Microscopic features in sample 81 include extensive quartz subgrain development and shear-band cleavage (S_2) oriented at low angle to foliation (S_1) (Fig. 35). In

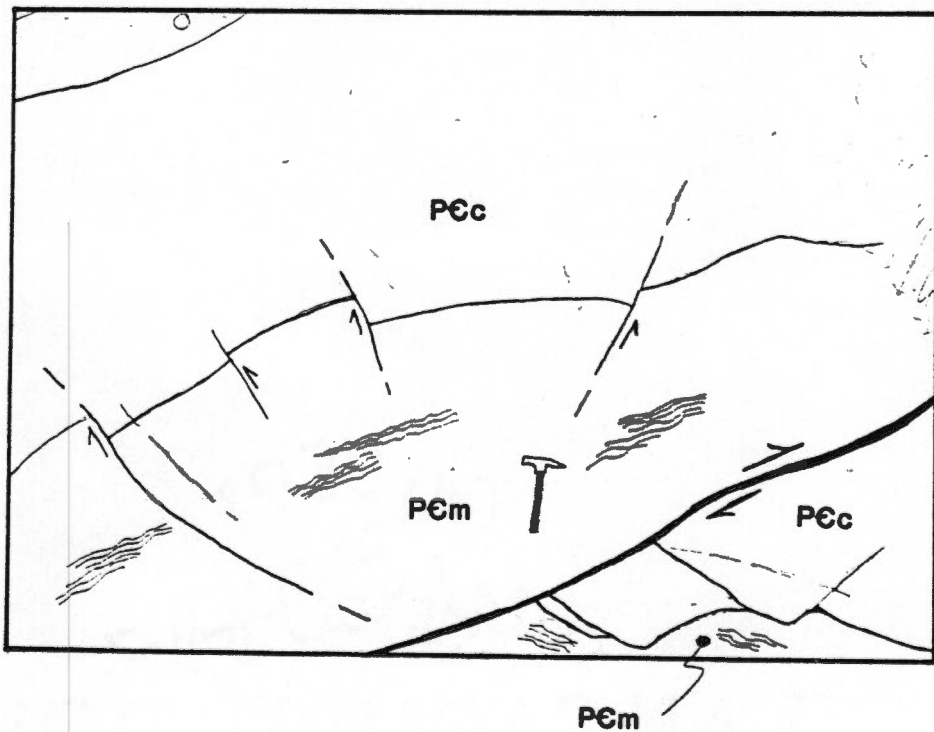
Figure 33 - Cades-over-Metcalf contact north
of Cades Cove (Locality 81, Fig. 9).

- a. Outcrop photo. Hammer for scale.
- b. Overlay sketch (P_{Cm}=Metcalf Phyllite;
P_{Cc}=Cades Sandstone).



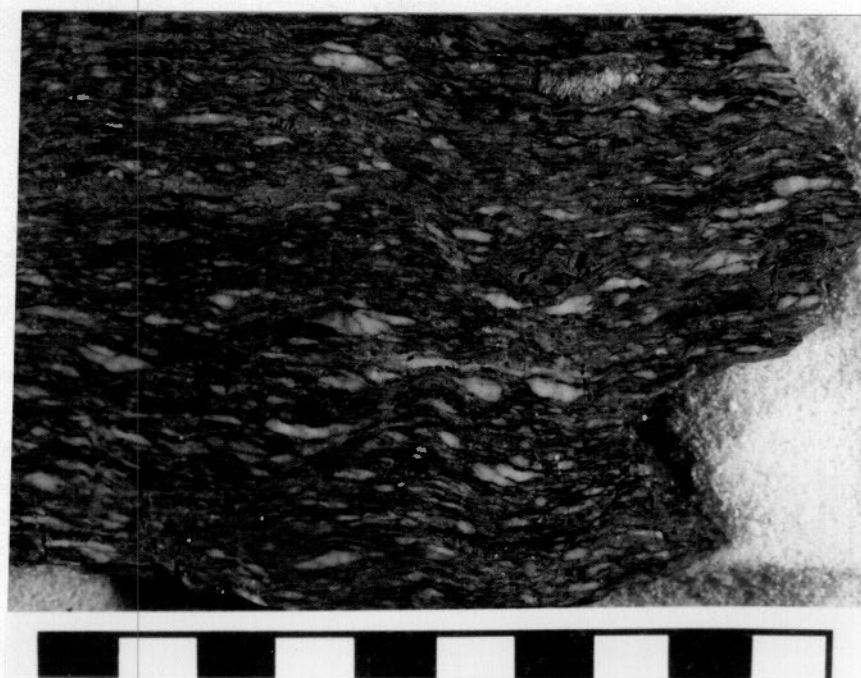
NW

SE



NW

SE



Shear
band
cleavage

S_2

Pressure
solution
seams
parallel
to S_1

S_1

Figure 34 - Hand sample photo of Cades Sandstone illustrating quartz flattening (S_1), shear band cleavage (S_2) and pressure solution seams (Locality 81, Fig. 9). Scale bar is in cm.

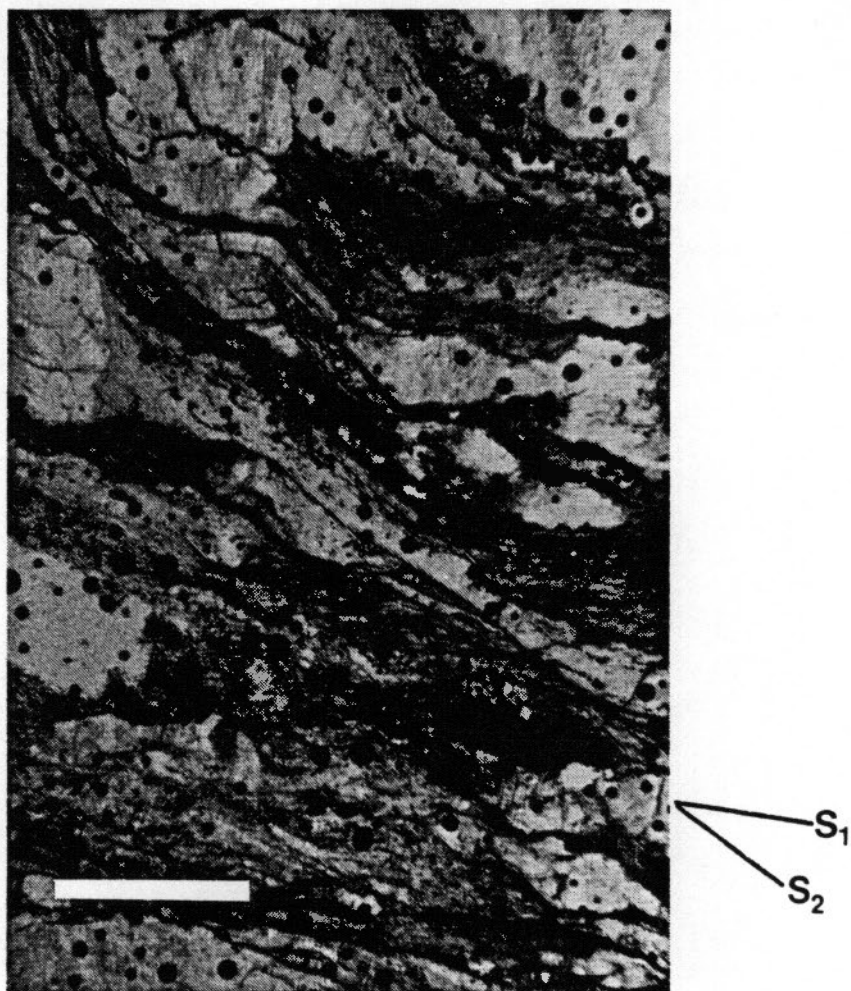


Figure 35 - Photomicrograph of shear band cleavage in Cades Sandstone (Locality 81, Fig. 9). Plane polarized light. Scale bar equals 1 mm.

addition, pressure solution seams (parallel to foliation) and quartz pressure beards occur throughout the thin section.

The presence of mylonitic fabrics and shear bands in the Cades suggest that this contact is tectonic, rather than stratigraphic as originally proposed by Neuman and Nelson (1965).

CHAPTER VI

STRUCTURAL GEOMETRIES IN THE CADES COVE REGION

OVERALL GEOMETRY

The Cades Sandstone in the Rabbit Creek thrust sheet has been demonstrated to be stratigraphically overturned and is inferred to represent the forelimb of a thrust nappe. In Domains I and II, cleavage (XY) is oriented at a gentler angle than bedding and appears related (axial planar?) to folding, but this does not appear to be the case at Abrams Falls. Bedding is overturned and dipping gently (8°) toward the southeast and cleavage dips steeply (80°) toward the southeast. Figure 36 shows a schematic drawing of cleavage at Abrams Falls (Domain III) related to cleavage in Domains I and II in the Rabbit Creek thrust sheet. In order for the Abrams Falls cleavage to be related to the recumbent fold, it would have to dip at a much gentler angle. The cleavage at Abrams Falls is, therefore, inferred to be unrelated to the fold. Its proximity to the Rabbit Creek thrust suggests that it may be related, instead, to Rabbit Creek thrust emplacement.

In contrast to the Cades, the Elkmont Sandstone in the main Greenbrier thrust sheet is stratigraphically upright.

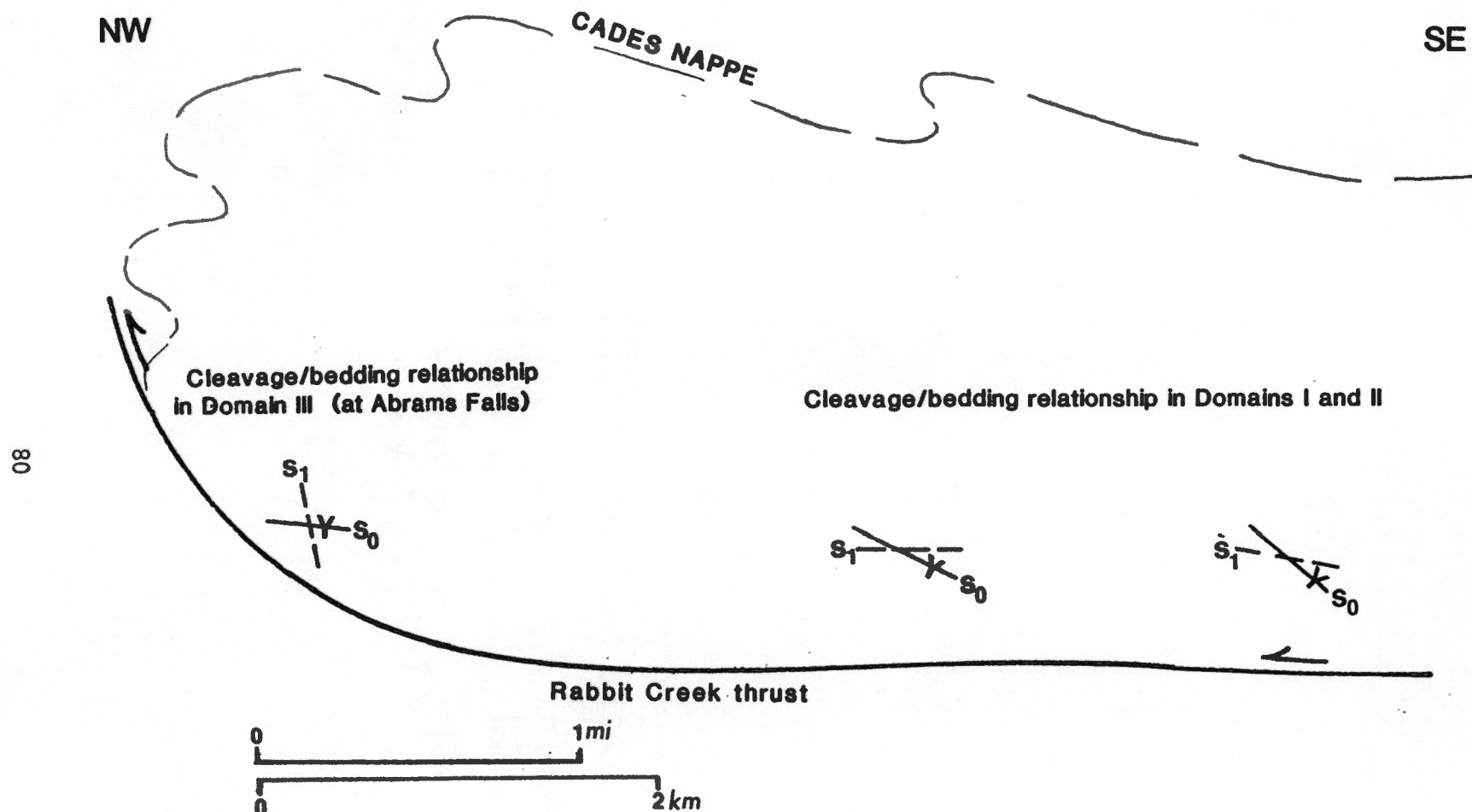


Figure 36 - Schematic diagram illustrating relationship of cleavage at Abrams Falls to cleavage in Domains I and II of the overturned forelimb.

My interpretation is that the Elkmont represents a part of the backlimb of the nappe. The nappe continues southeast of the study area approximately 30 km, extending into North Carolina. There, the backlimb is composed of the Anakeesta and Thunderhead Formations of the Great Smoky Group, both of which stratigraphically overlie the Elkmont (Fig. 37).

The core of the nappe occurs between the southeastern most occurrence of the Greenbrier thrust and the Coalen Ground thrust because: 1) Cades Sandstone (Rabbit Creek thrust sheet) and Elkmont Sandstone (main Greenbrier thrust sheet) represent the two limbs of the nappe in the study area and 2) the area between the Coalen Ground and Greenbrier thrusts contains Metcalf Phyllite, which is the oldest (core) unit in the study area (Neuman and Nelson, 1965).

The nappe was emplaced upon the Rabbit Creek thrust, which was interpreted as a pre-metamorphic thrust (King and others, 1968). Subsequent deformation related to Great Smoky thrust emplacement resulted in modification of the original nappe geometry.

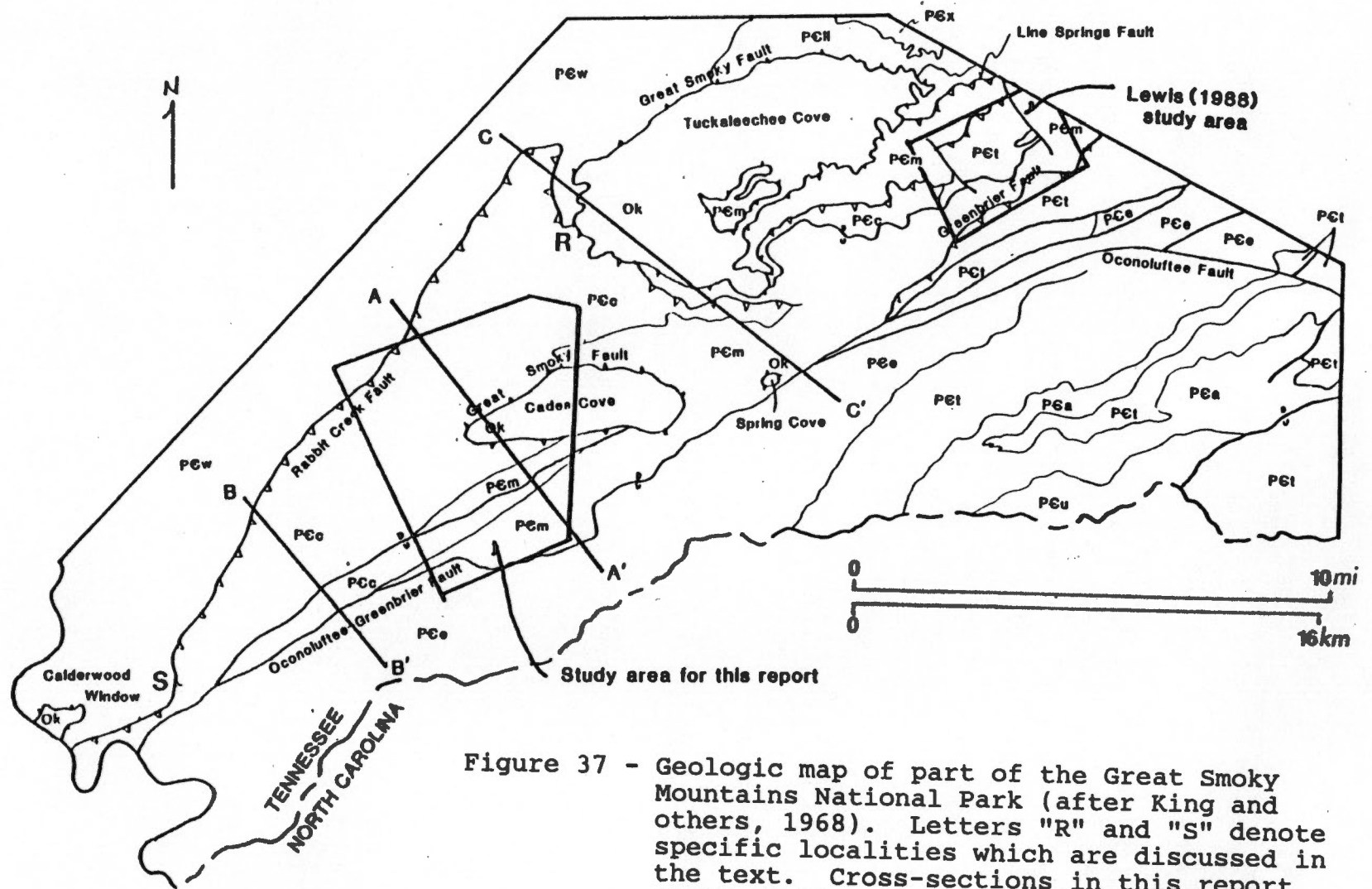
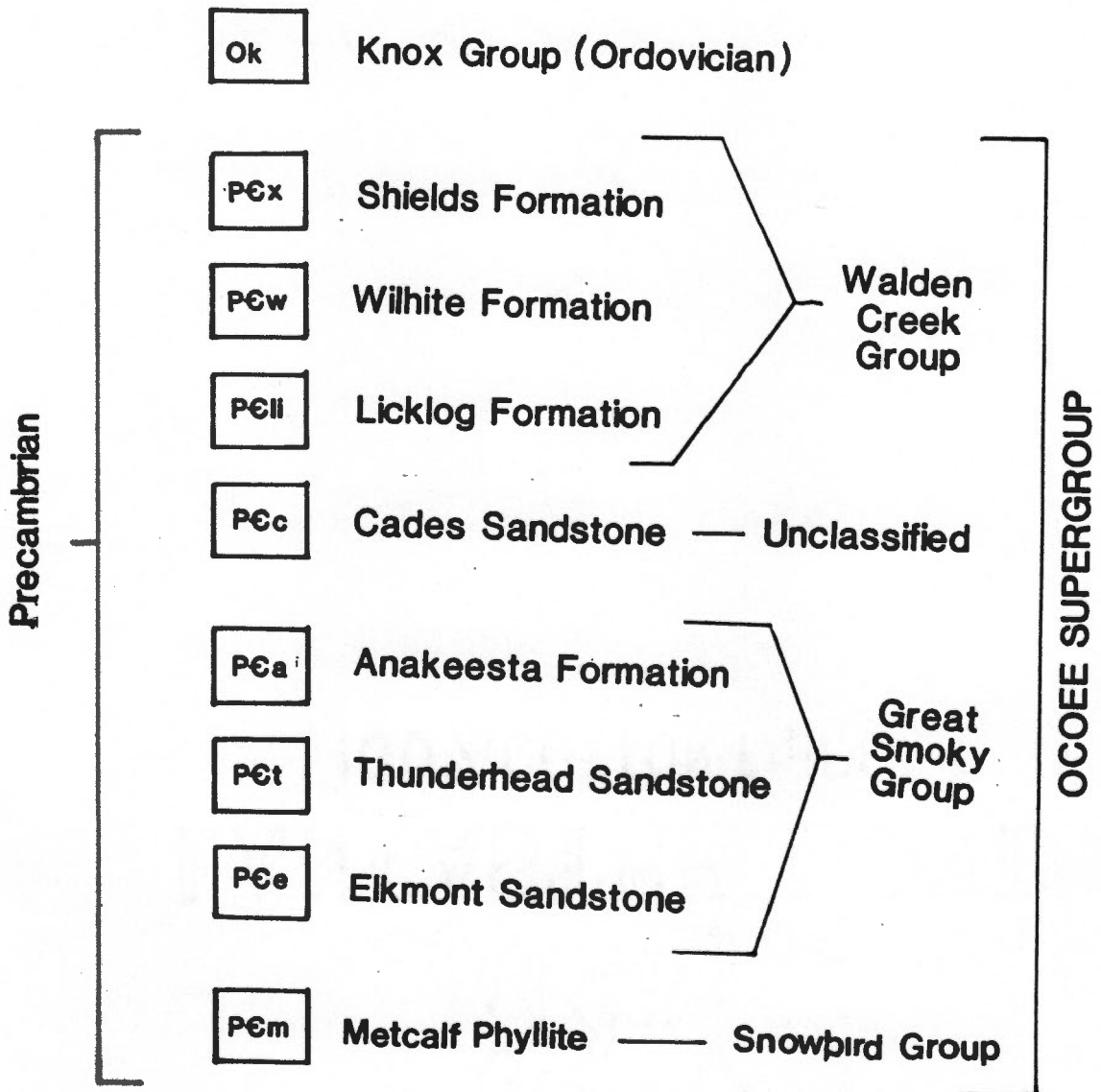


Figure 37 - Geologic map of part of the Great Smoky Mountains National Park (after King and others, 1968). Letters "R" and "S" denote specific localities which are discussed in the text. Cross-sections in this report (A-A', B-B', and C-C') are also keyed to this map.

MAP KEY



DEGREE OF DEFORMATION - BACKLIMB (ELKMONT) VS. FORELIMB (CADES)

Rock fabrics indicate that the overturned forelimb underwent a greater degree of deformation than did the upright backlimb. Deformation is partitioned sub-equally between pressure solution and crystal-plastic mechanisms on the forelimb. The dominant deformation mechanism on the backlimb is the crystal-plastic mechanism.

Undulatory extinction and subgrain development in quartz are more pronounced on the forelimb than on the backlimb, suggesting that dynamic recovery (and possibly recrystallization) progressed further on the forelimb than on the backlimb. Pressure solution features such as closely spaced cleavage (outcrop scale), pressure solution seams (mesoscopic scale), and pressure beards and re-precipitation of quartz in fractured feldspars (microscopic scale) are abundant on the forelimb. Cleavage is the dominant pressure solution feature on the backlimb.

SHEAR INDICATORS

The proposal of a nappe structure in the Cades Cove region would be weak without some evidence of shearing. The role of shear in the development of nappes in the

Helvetic fold and thrust belt has been well documented by Ramsay and others (1983). Several features indicative of shearing here are: 1) displaced broken grains, 2) composite planar fabric (shear-band cleavage), 3) asymmetric pressure shadows, 4) asymmetric augen structures, and 5) obliquity of elongate recrystallized grains and subgrains (Simpson and Schmid, 1983). The first two are present in the study area and, presumably, may be used to infer shear sense on the larger (map) scale.

Fractured and Rotated Feldspar Grains (Displaced broken grains)

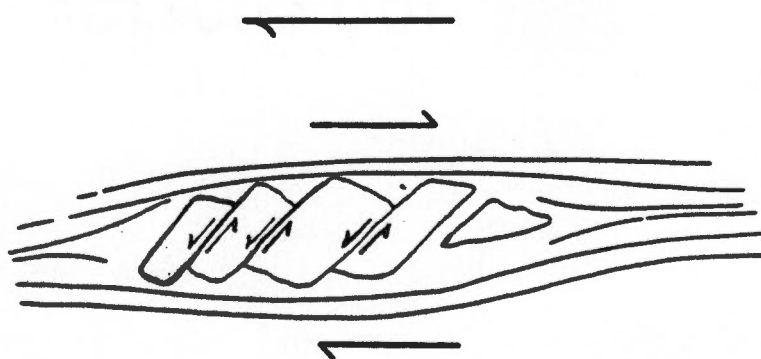
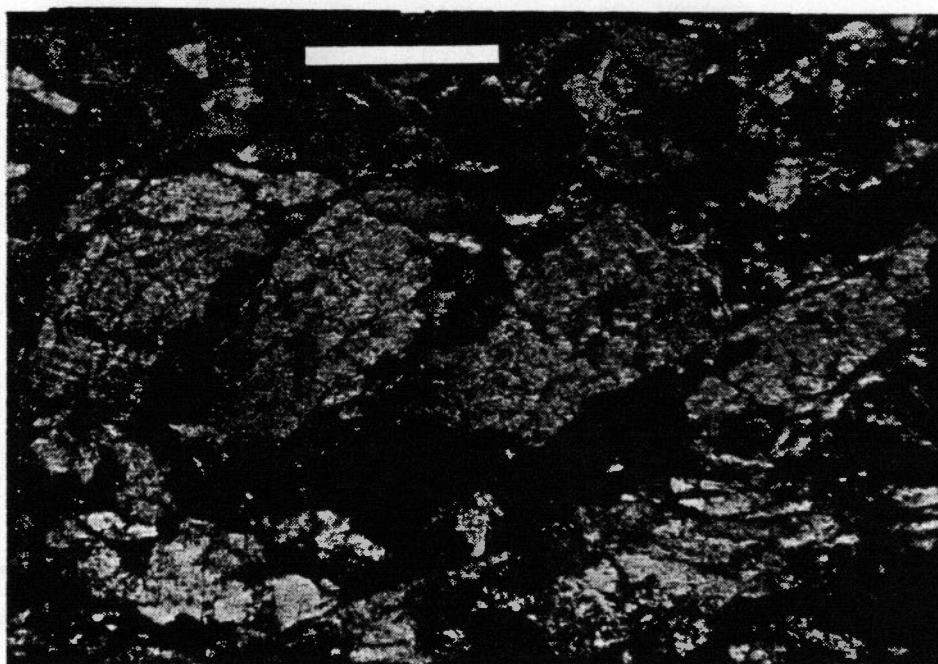
Fractured and rotated feldspars on the overturned limb may be used to indicate sense of shear. Three samples (27, 43 and 54) from the overturned forelimb, near the Rabbit Creek-Great Smoky thrust trace, contain fractured and rotated feldspars (Fig. 38a). Application of the method of Simpson and Schmid (1983) to Sample 27 indicates the sense of shear necessary to produce this feature (Fig. 38b), which suggests major shearing from southeast to northwest on the overturned fold limb.

Figure 38 - Shear sense indicator in Cades
Sandstone (Locality 27, Fig. 9) -
Fractured and rotated feldspar.

- a. Photomicrograph. Scale bar equals 1 mm.
- b. Diagram showing shear sense (from Simpson
and Schmid, 1983).

SE

NW



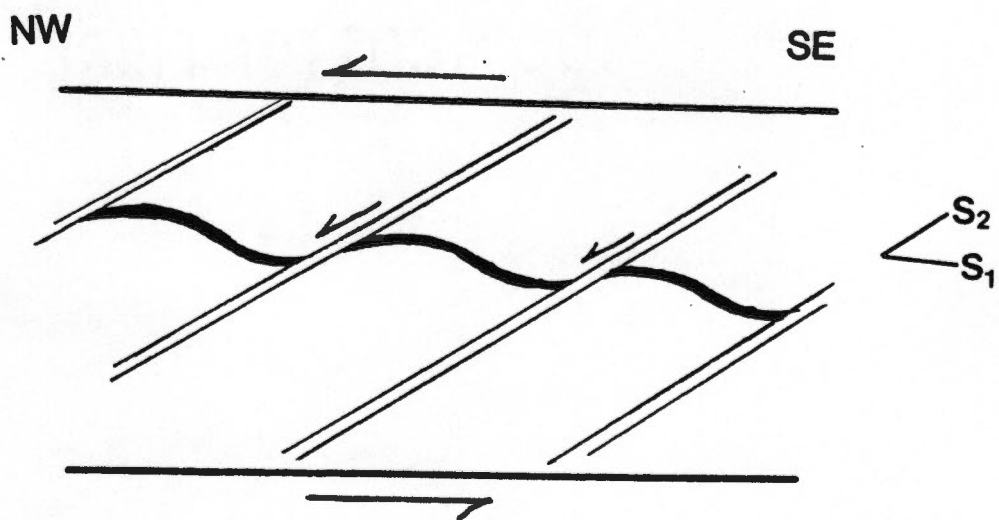
Shear-Band Cleavage (Composite planar fabric)

Shear-bands are observed in the hanging walls of both the Parson Branch and Coalen Ground thrusts (Fig. 39a). Figure 39b indicates the corresponding overall sense of shear of the shear bands using the method of Dennis and Secor (1987).

Plate II contains the above fabrics and their location with respect to the nappe geometry. These fabrics and their overall shear sense (southeast to northwest) make a strong argument for development and emplacement of the nappe structure in the study area.

Figure 39 - Shear sense indicator in Metcalf
Phyllite (Locality 19, Fig. 9) -
Shear band cleavage.

- a. Hand sample photo. Scale bar shown.
- b. Diagram showing shear sense (after Dennis
and Secor, 1987).



CHAPTER VII

STRAIN ANALYSIS

Variation in strain across a dip-parallel traverse was documented by measuring strain in eight samples. The geologic map of Cades Cove (Fig. 40) shows sample locations: a) two samples of Elkmont Sandstone from the main Greenbrier thrust sheet, b) one sample of Cades Sandstone from the zone of faulting of Cades and Metcalf and c) five samples of the Cades Sandstone from the Rabbit Creek thrust sheet.

METHOD

Strain analysis samples were collected along a southeast-northwest traverse from the southern limit of the study area to approximately 2 km southeast of Rabbit Creek. For all samples, the cleavage plane of section (XY plane of strain) is defined by the plane of flattening of quartz pebbles or grains. Additional cuts were made in the samples to determine the plane which contained the highest long to short axial ratios in quartz grains (i.e., the plane which contained the best developed prolate ellipse

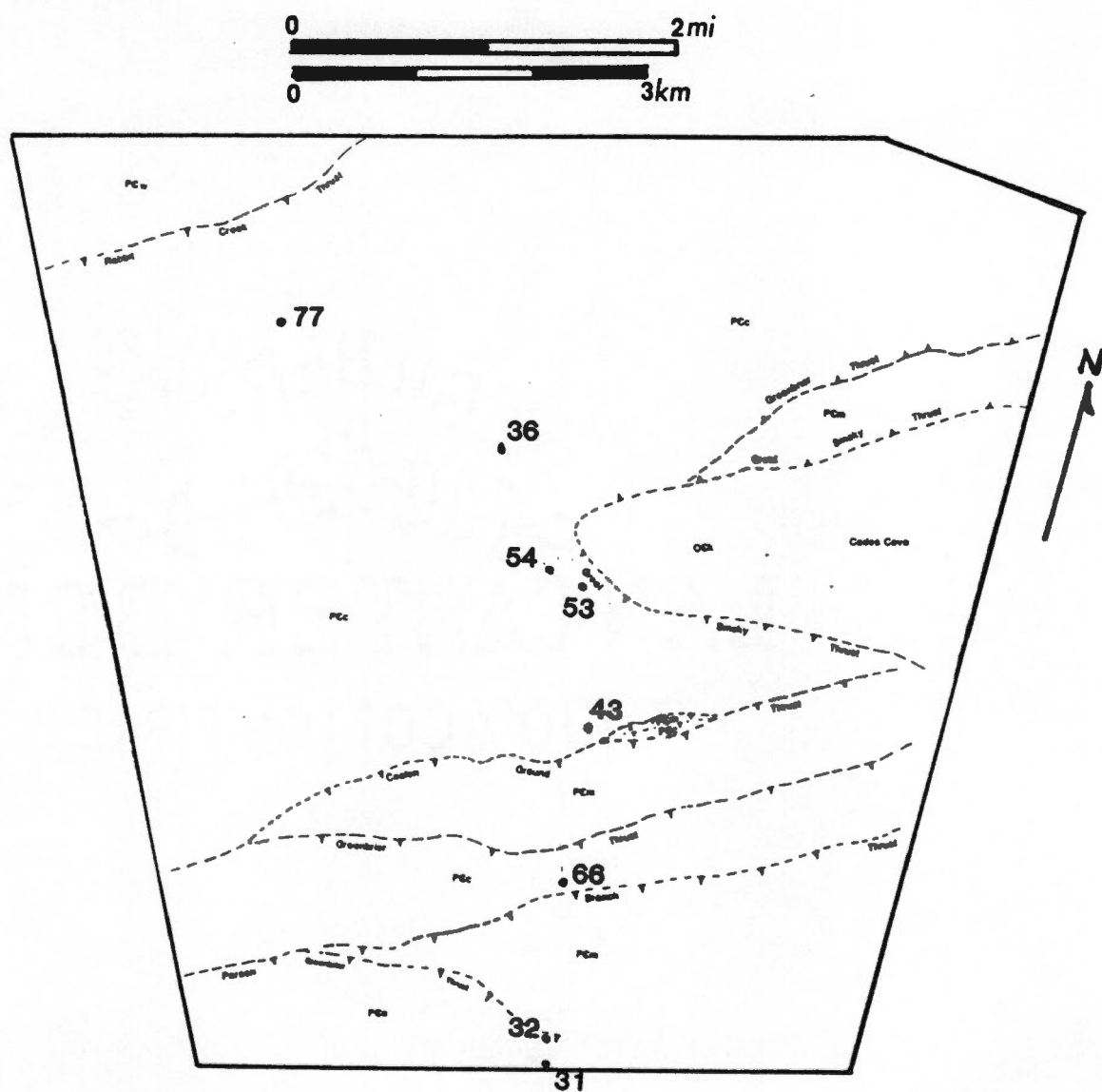


Figure 40 - Geologic map of Cades Cove showing strain analysis sample localities.

shape in quartz grains). This plane (perpendicular to the XY plane) is the XZ principal plane of section (Ramsay and Huber, 1983). The third principal plane of section (YZ) was cut perpendicular to these two planes (Fig. 41). Thin sections were prepared for two of the three principal planes (XZ and YZ). The thin sections were photographically enlarged and grain outlines were traced on a transparent overlay. The minimum number of grains used for strain analysis (for each principal plane) was 50 ($N \geq 50$).

Harmonic mean axial ratios (H) of quartz grains were calculated as a first order approximation of Rs values for use in the Rf/ϕ method:

$$H = N / (Rf_1^{-1} + Rf_2^{-1} + \dots + Rf_n^{-1})$$

where Rf = final axial ratio of quartz grains after deformation and N/n = number of grains measured for a given principal plane of section. This saved time because it expedited the search for the Rs graph which best fit the Rf/ϕ data. The XY plane H value was then calculated using data from the XZ and YZ planes:

$$H_{xy} = H_{xz} / H_{yz}$$

where H_{xy} = harmonic mean axial ratio in the XY plane, H_{xz} = harmonic mean axial ratio in the XZ plane, and H_{yz} = harmonic mean axial ratio in the YZ plane.

The Rf/ϕ method of strain analysis (Dunnet, 1969; Ramsay and Huber, 1983; Lisle, 1985) was then used as the

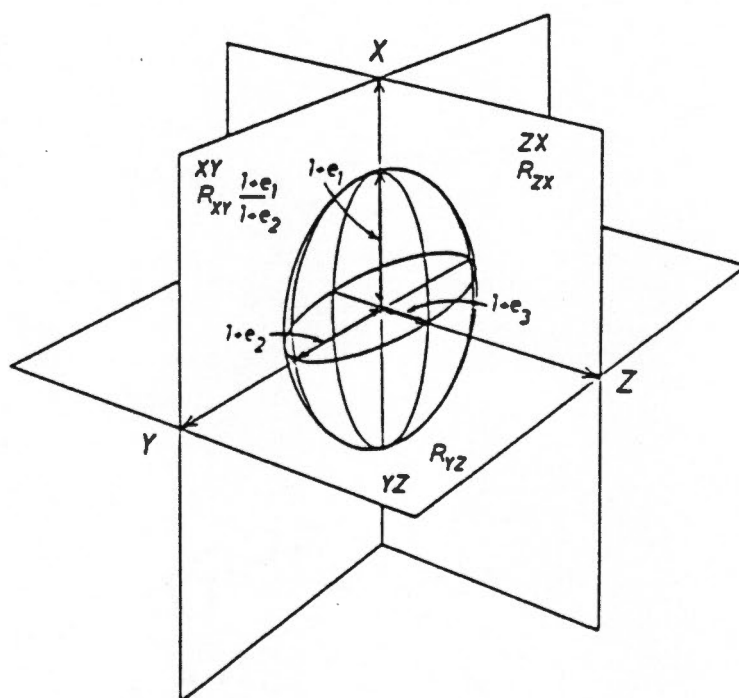


Figure 41 - Diagram illustrating three mutually perpendicular principal planes of section (XZ, YZ and XY) from Ramsay and Huber (1983).

primary means of determining the tectonic strains in the quartz grains. I chose a reference ϕ axis oriented in the general direction of the preferred orientation of grains (Lisle, 1985), and superimposed it onto the transparent overlays. To measure R_f , the dimensions of the long and short axes of individual quartz grains were measured (perpendicular to one another) and the ratio determined. The directions of the long axes may be expressed as an angle in the range of -90° to $+90^\circ$, measured from the reference ϕ axis. These angles are ϕ' angles. Final axial ratios (R_f) and ϕ' angles for each quartz grain were then recorded and plotted on standard R_f/ϕ diagrams, with ϕ' as abscissa (X-axis) and R_f as ordinate (Y-axis).

The R_f/ϕ plots were then used to calculate the values of R_s and R_i , where R_s is the tectonic strain ratio and R_i is the initial axial ratios of quartz grains prior to deformation. Lisle (1985) provided a list of R_s graphs, which correspond to different tectonic strains. The R_f/ϕ data for each plane of section was fitted to a corresponding R_s graph using three main criteria: 1) best fit of at least half of the data points within the "50% data" curve on the R_s graphs, 2) first-order approximation of R_s using H values, and 3) use of the symmetry test (explained in detail in Appendix II) to determine location of $\phi=0^\circ$ on the R_f/ϕ data plots. Once these three criteria are considered and the best fit to an R_s graph obtained,

then that R_s value is the tectonic strain for the plane of section in question.

Contours of equal R_i are also shown on the R_s graphs. The R_f/ϕ data will plot within the area of some R_i contour(s) value. Thus, the R_i value is shown by a clustering or range of R_f/ϕ data points and may be read directly from the R_s graph (Fig. 42).

Finally, the fluctuation F is the range of orientation of grain long axes. This is determined from the R_s graph also, and is the angular difference between the two points on the graph which show the greatest positive and negative deviations from the $\phi=0^\circ$ line. High F values indicate no preferred orientation and, therefore, probably weak deformation. Progressively lower F values show a lower angular deviation of quartz long axes from the reference ϕ axis (a preferred fabric) and, therefore, indicate progressively higher deformation (Ramsay and Huber, 1983).

The strain analyses are now presented based on geographic location of samples: a) backlimb, b) zone of faulting of Cades and Metcalf, and c) forelimb. Harmonic mean axial ratios (H) will be presented first (for each sample), followed by R_f/ϕ analyses.

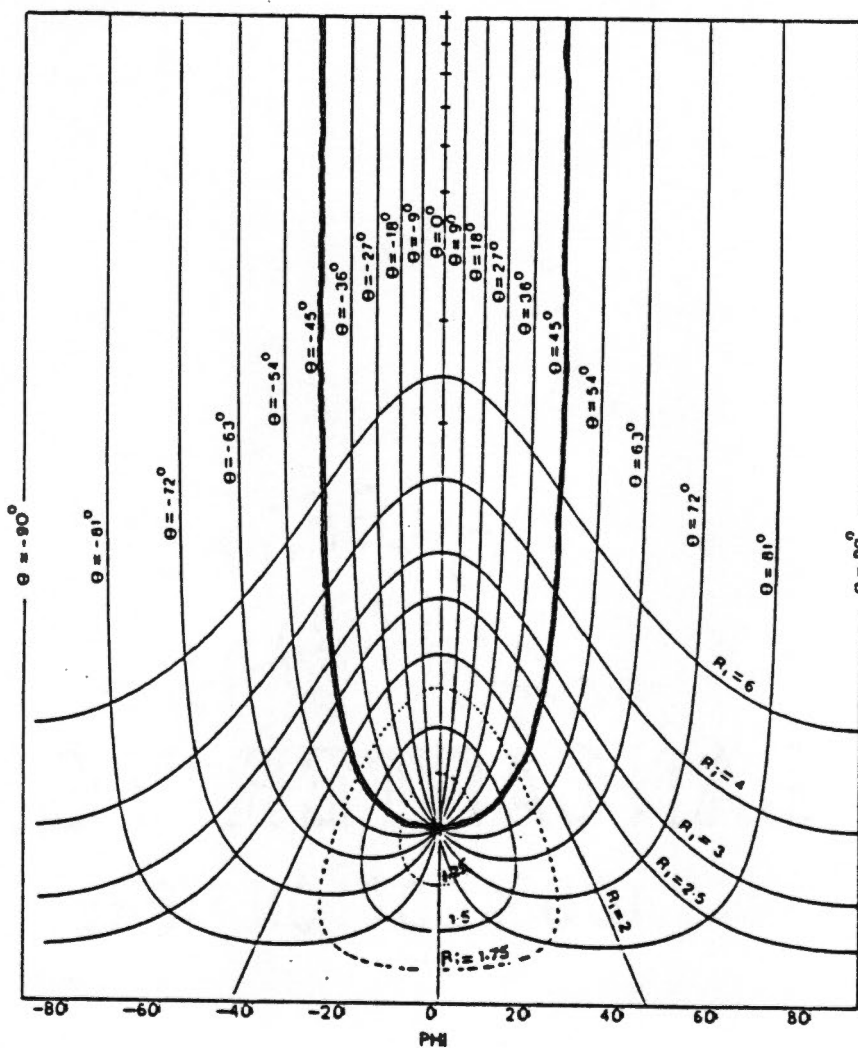


Figure 42 - Diagram of sample R_s graph ($R_s=2.0:1$) with R_i contours (from Lisle, 1985). The "50% data" contour is shown in bold outline.

STRAIN ANALYSIS DATA

Backlimb (Elkmont Sandstone)

Sample 31 occurs further from the Greenbrier thrust than Sample 32 and contains XZ and YZ plane quartz axial ratios (H) of 1.70:1 and 1.54:1, respectively. The XY plane ratio is 1.10:1, indicating a fairly equidimensional shape for quartz grains in the cleavage plane.

The R_f/ϕ analysis of Sample 31 indicates a superimposed strain ratio (R_s) of 1.45:1 and 1.20:1 in XZ and YZ planes, respectively. Initial axial ratios of quartz grains prior to deformation (R_i) average 1.25:1-1.50:1. The ϕ fluctuation angle (F) is 140° , indicating low strain.

Sample 32 contains XZ and YZ plane axial ratios (H) of 1.73:1 and 1.71:1 (respectively), with 1.01:1 in the XY plane.

The R_f/ϕ analysis indicates R_s values of 1.70:1 and 1.50:1 in XZ and YZ planes, respectively. The R_i for sample 32 averages approximately 1.25:1-1.50:1, with an average F of 100° .

Zone of Faulting of Cades and Metcalf

Quartz pebbles in Sample 66 contain higher axial ratios than in the Elkmont samples. The XY and YZ plane axial ratios (H) are 2.93:1 and 2.45:1 (respectively). The XY plane axial ratio is 1.20:1.

The R_f/ϕ analysis of Sample 66 indicates R_s values of 2.70:1 and 2.20:1 in XZ and YZ planes, respectively. The R_i averages 1.25:1-1.75:1, with an average F of 73° .

Forelimb (Cades Sandstone)

Sample 43 occurs between the Coalen Ground and Great Smoky thrust traces. Quartz pebble axial ratios (H) in the XZ and YZ planes are 5.74:1 and 3.67:1, respectively, and are much higher than those in the backlimb. The XY plane ratio is 1.56:1, revealing an elliptical quartz pebble shape in the plane of cleavage.

The R_f/ϕ analysis for Sample 43 indicates R_s values of 4.60:1 and 3.40:1 in the XZ and YZ planes, respectively. The R_i averages 1.40:1-1.75:1 and F is a low 40° .

Sample 53 occurs very near the Great Smoky thrust trace. Quartz pebble axial ratios (H) in the XZ and YZ planes are 4.75:1 and 3.66:1, respectively. The XY plane axial ratio is 1.30:1. To the northwest and towards the

Rabbit Creek thrust, quartz pebble axial ratios decrease in magnitude.

The R_f/ϕ analysis for Sample 53 indicates R_s values of 4.00:1 and 3.40:1 in the XZ and YZ planes, respectively. The R_i averages 1.25:1-1.75:1 and F is very low at 35° . Samples 43 and 53 exhibit the highest strains in the study area, as indicated by high R_s values and low F values.

Sample 54 contains XZ and YZ plane axial ratios (H) of 2.78:1 and 2.51:1, respectively. While these are much lower than for previously discussed samples from the forelimb, they are still high compared to those on the backlimb. The XY plane ratio is 1.11:1.

The R_f/ϕ analysis for Sample 54 indicates R_s values of 2.60:1 and 2.40:1 in the XZ and YZ planes, respectively. R_i averages 1.50:1 and F averages 72° .

Sample 36 contains quartz grain axial ratios (H) of 1.78:1 and 1.42:1 in the XZ and XY planes, respectively. The YZ plane ratio is 1.27:1.

The R_f/ϕ analysis of Sample 36 indicates R_s values of 1.70:1 and 1.05:1 in the XZ and XY planes, respectively. R_i averages 1.50:1. The F values are 115° in the XZ plane and 170° in the XY plane.

Sample 77, within 500 m of the Rabbit Creek thrust trace, contains quartz grain axial ratios which are slightly higher than those on the backlimb. The XZ and YZ plane axial ratios (H) are 1.84:1 and 1.71:1, respectively. The XY plane axial ratio is 1.08:1.

The R_f/ϕ analysis of sample 77 indicates R_s values of 1.80:1 and 1.60:1 in the XZ and YZ planes, respectively. The R_i averages 1.20:1-1.60:1 and F averages 140° .

Figure 43 contains a summary of the above data. R_f/ϕ plots are in Appendix II.

DISCUSSION

The symmetry test (Appendix II) shows that no samples contained a preferred fabric prior to deformation. Evidence for this is the symmetric distribution of data points (for all R_f/ϕ plots) with respect to the $\phi=0^\circ$ axis. In addition, average R_i values for the strain samples (overall) are approximately 1.5:1, as indicated from the R_s graphs. This compares favorably with observed initial axial ratios of quartz grains in rocks ($R_i=1.5:1$) by other workers (Griffiths, 1967; Bokman, 1957).

In general, superimposed strains in the Elkmont Sandstone on the backlimb are low. This is shown by low R_s values and fairly high F values in both samples. Strains

Figure 43 - Strain analysis results. (H-harmonic mean axial ratio in quartz; Ri-initial axial ratio in quartz prior to deformation; F-fluctuation angle of quartz long axes; Rs-tectonic strain).

	Sample	Value	XZ Plane	YZ Plane	XY Plane
Backlimb (Elkmont)	31	H	1.70:1	1.54:1	1.10:1
		Ri	1.25:1-1.50:1	1.25:1-1.75:1	
		F	140°	140°	
		Rs	1.45:1	1.20:1	
	32	H	1.73:1	1.71:1	1.01:1
		Ri	1.00:1-1.50:1	1.25:1-1.75:1	
		F	85°	120°	
		Rs	1.70:1	1.50:1	
Zone of Faulting	66	H	2.93:1	2.45:1	1.20:1
		Ri	1.10:1-2.00:1	<1.75:1	
		F	65°	80°	
		Rs	2.70:1	2.20:1	
Forelimb (Cades)	43	H	5.74:1	3.67:1	1.56:1
		Ri	1.50:1-2.00:1	1.10:1-1.75:1	
		F	35°	45°	
		Rs	4.60:1	3.40:1	
	53	H	4.75:1	3.66:1	1.30:1
		Ri	<1.75:1	1.25:1-1.75:1	
		F	25°	45°	
		Rs	4.00:1	3.40:1	
	54	H	2.78:1	2.51:1	1.11:1
		Ri	1.25:1-2.00:1	1.25:1-1.75:1	
		F	75°	70°	
		Rs	2.60:1	2.40:1	
	36	H	1.78:1	1.27:1	1.42:1
		Ri	1.20:1-1.50:1		1.50:1-2.00:1
		F	115°		175°
		Rs	1.70:1		1.05:1
	77	H	1.84:1	1.71:1	1.08:1
		Ri	1.10:1-1.50:1	1.25:1-1.75:1	
		F	135°	140°	
		Rs	1.80:1	1.60:1	

do, however, increase towards the Greenbrier thrust, as indicated by higher R_f values and lower F values in Sample 32 versus Sample 31. Emplacement of the main Greenbrier thrust sheet is most likely responsible for the strain gradient observed in the Elkmont on the backlimb.

Strains in the Cades Sandstone in the zone of faulting are about 200% higher than those on the backlimb, as indicated by R_s values. Lower F values also suggest higher strains in this region. Sample 66 is located approximately 100 m beneath the Parson Branch thrust, suggesting that the strains in the sample are dominantly related to emplacement of the Parson Branch thrust. Emplacement of the Greenbrier thrust (between Coalen Ground and Parson Branch thrusts) may also account for some of the strain observed in Sample 66.

The Cades Sandstone on the overturned limb of the nappe exhibits a variation in strain. Coarser-grained samples near the inferred Great Smoky-Rabbit Creek thrust trace reveal strains that are 200-300% those shown on the backlimb. Finer grained samples farther from the Great Smoky-Rabbit Creek thrust trace exhibit progressively less tectonic strain in the grains, probably related to an increase in shale and siltstone lithologies, and increased distance from the Great Smoky-Rabbit Creek thrust. In these finer-grained rocks, strain is (apparently) accommodated more by cleavage formation (pressure solution)

rather than by crystal-plastic deformation mechanisms in the grains. Evidence for this is the well-developed cleavage in Cades Formation (siltstone) at Abrams Falls. The rocks here contain pronounced pressure solution (cleavage) and a general absence of crystal-plastic deformation characteristics.

The origin of the high strains near the Great Smoky-Rabbit Creek thrust trace is an important question. Hanging wall-footwall relationships in Cades Cove indicate that the Great Smoky thrust either re-activated the Rabbit Creek thrust or cut up into the Rabbit Creek thrust sheet. Evidence for this is emplacement of Metcalf Phyllite (lower Rabbit Creek thrust sheet) against Knox carbonate units by the Great Smoky thrust in Cades Cove.

Samples 43 and 53 are located within approximately 200 m of the Great Smoky-Rabbit Creek thrust trace and contain the highest strains in the study area. Fabrics observed in these samples also indicate a high degree of crystal-plastic deformation. Deformation fabrics in the Wilhite Formation in the hanging wall of the Great Smoky thrust (west boundary of Tuckaleechee Cove and Calderwood Window exposures) (Fig. 37) exhibit very little evidence of crystal-plastic deformation or high strain. Thus, emplacement of the Great Smoky thrust was probably not responsible for the high strains observed in Samples 43 and 53.

Emplacement of the Rabbit Creek thrust is most likely responsible for the high strains and crystal-plastic deformation observed in Samples 43 and 53, based on observation of high strains and crystal-plastic deformation features in the Wilhite Formation in the footwall of the Rabbit Creek thrust, west of the study area (Neuman and Nelson, 1965) (Fig. 37, Locality S). The Great Smoky thrust occurred later and along or near the same fault plane as the Rabbit Creek thrust.

Shape of the Strain Ellipsoid

In general, quartz grains are oblate ellipsoids, based on observation of two elongate axes ($1+e_1$ and $1+e_2$) and one relatively short axis ($1+e_3$). Harmonic mean H values are low in the XY plane of cleavage and high in the XZ and YZ planes, indicating flattening. Initial flattening (cleavage) developed that was related (axial planar?) to the overturned fold, but flattening in the XY plane of cleavage is much more pronounced on the forelimb than on the backlimb. The most reasonable explanation for this is that the weight of the overlying nappe resulted in additional flattening of quartz grains in the XY plane on the overturned forelimb.

Although flattening in the XY plane is the rule, the long axes of the ellipses in this plane (as shown by H

values) show variable orientations (Fig. 44). This is most likely due to superposition of (heterogeneous) tectonic strains due to episodic thrust emplacement (Greenbrier, Parson Branch, Rabbit Creek, etc.).

STRAIN VARIATION IN THE NAPPE STRUCTURE

Although strain variations are present in the forelimb, the average R_s values and F values in this region support observed rock fabrics, indicating that the forelimb is much more deformed than the backlimb. This is the principal structural basis of the nappe hypothesis.

The calculated tectonic strains (in the direction of tectonic transport), and their locations and orientations relative to the overall structural geometries, are shown in the cross section through Cades Cove (Plate II).

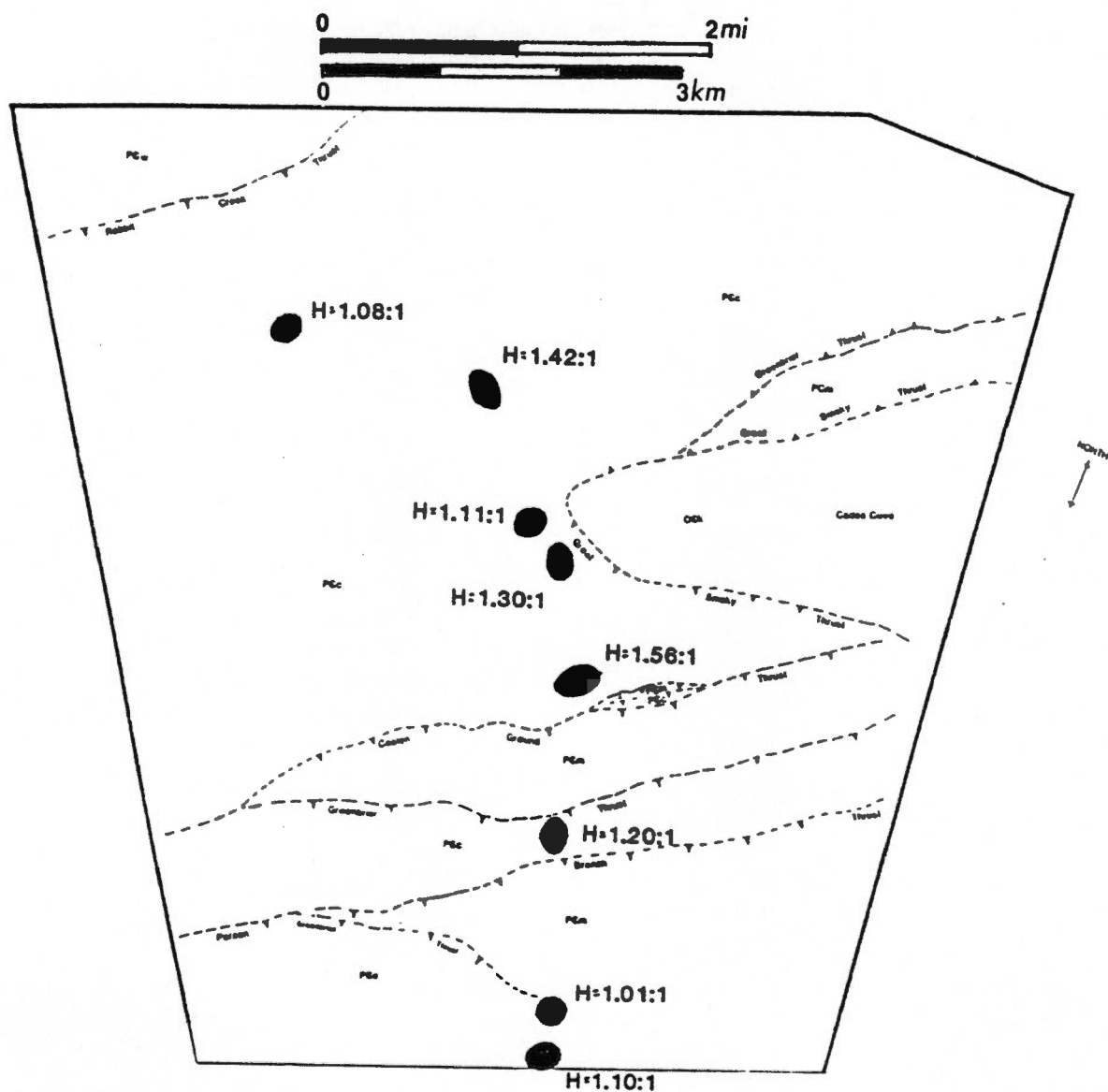


Figure 44 - Strain map depicting harmonic mean axial ratios (H) in the XY plane of cleavage for all strain analysis samples.

CHAPTER VIII

STRATIGRAPHIC AND STRUCTURAL SYNTHESIS

STRATIGRAPHIC SYNTHESIS

Of the four major stratigraphic units which occur in the study area, none are interpreted to be in original stratigraphic contact. Neuman and Nelson (1965) proposed that the Elkmont Sandstone is younger than the Metcalf Phyllite, based on Great Smoky Group-Snowbird Group correlations to the northeast and also on Oconaluftee-Greenbrier thrust relationships (Elkmont-over-Metcalf) in the study area.

A firm stratigraphic relationship between the Cades and Elkmont Sandstones is proposed here. Heavy mineral studies by Carroll and others (1957) suggested that both the Cades and Elkmont originated from similar source rocks. Overall mineralogical similarities noted by Neuman and Nelson (1965), also observed in this report, support this idea and suggest that the Cades and Elkmont Sandstones are, in fact, stratigraphic equivalents.

Structural relationships may also be used to support this assertion. Both the Cades and Elkmont overlie the Snowbird Group rocks (with the Greenbrier thrust, as

recognized here, as the contact) and, thus, are probably facies equivalents.

Finally, correlations along strike may be used, albeit indirectly, to show that Cades is stratigraphically equivalent to the Elkmont. In the central Great Smoky Mountains, Lewis (1988) determined that the contact between the Thunderhead and Cades Sandstones showed no mappable discordance or associated strain and, hence, is probably a facies transition between the two units (Fig. 37). Likewise, the Elkmont-Thunderhead contact to the southeast has also been demonstrated by King and others (1968) to be a facies transition (Fig. 37). Thus, if Elkmont is equivalent to Thunderhead and Thunderhead is equivalent to Cades, then Elkmont and Cades may also be facies equivalents.

The Walden Creek Group (Wilhite Formation) is inferred to be stratigraphically above the Great Smoky Group (Cades) in the study area. Two lines of evidence support this idea: 1) the Cades is emplaced upon the Wilhite by the Rabbit Creek thrust and 2) the Wilhite is stratigraphically overlain by the Chilhowee Group (Neuman and Nelson, 1965) and, thus, represents the youngest formation in the Ocoee Supergroup in the western Great Smoky Mountains.

Figure 45 gives the inferred stratigraphic relationships in the Ocoee Supergroup based on this report.

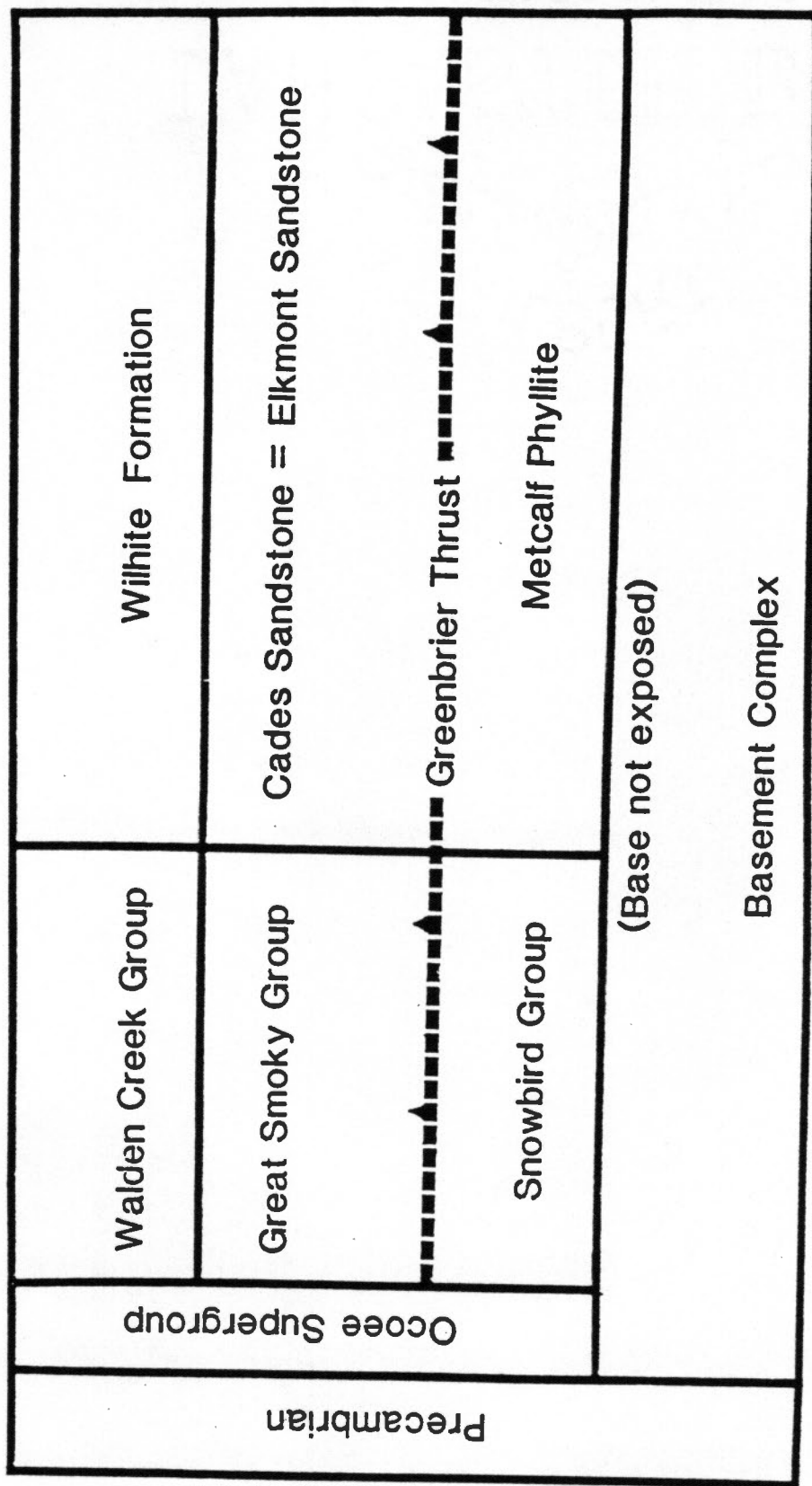


Figure 45 - Inferred stratigraphic relationships in the Ocoee Supergroup in the thesis study area.

STRUCTURAL SYNTHESIS

Cross-Section through Cades Cove (A-A')

The cross-section through Cades Cove (Plate II) passes through a part of the study area where rocks are best exposed (Fig. 37). It will be discussed from southeast to northwest. The cross-section extends approximately 3 km past the southeastern boundary of the study area so that more of the Elkmont Sandstone may be included. Bedding-cleavage relationships and tectonic strain ratios (in direction of transport) are also shown on the cross section.

Main Greenbrier thrust block

The Elkmont Sandstone occupies the extreme southern part of the study area. The Elkmont is stratigraphically upright, and its contact with the underlying Metcalf Phyllite is the Greenbrier thrust. The Greenbrier thrust is folded so as to be consistent with the Great Smoky Group-over-Snowbird Group thrust contact (Greenbrier thrust), which is shown folded in the central Great Smoky Mountains (King, 1964). A small area (not of map scale)

of coarse sandstone near the Parson Branch thrust seems most easily explained by folding of the Greenbrier also.

Parson Branch and Coalen Ground thrust blocks

Only the Metcalf Phyllite occurs in the Parson Branch thrust block. The Parson Branch thrust also displaces the Greenbrier thrust because of duplication of Great Smoky Group (Cades)-over-Snowbird Group (Metcalf) contact in the Coalen Ground block.

The Coalen Ground thrust block contains Cades overlying Metcalf, with the Greenbrier inferred as the contact between them (King, 1964). The Coalen Ground thrust is also shown to displace the Greenbrier thrust because of duplication of the Greenbrier in the Rabbit Creek block.

The Parson Branch and Coalen Ground thrusts were interpreted by Neuman and Nelson (1965) as stratigraphic contacts, but fault fabrics along each (e.g., mylonites) indicate that both are tectonic. They are inferred to converge above the erosion surface, based on their convergence downplunge on the map, west of the study area (Neuman and Nelson, 1965). At depth, both thrusts are inferred to sole out into the Rabbit Creek thrust because both bring Metcalf Phyllite to the surface.

A much smaller fault slice of Cades and Metcalf occurs

in the Coalen Ground thrust zone, which is interpreted to have been emplaced due to footwall plucking. This locality is particularly well exposed for the study area, and therefore suggests that horse blocks may be more common along the major thrusts than is shown.

Rabbit Creek thrust block

The Rabbit Creek thrust block contains dominantly Cades Sandstone, which has been eroded through to produce the Cades Cove window. The Cades Sandstone here is overturned. Presence of Metcalf Phyllite in the subsurface here is inferred based on: 1) Metcalf outcrops along strike to the northeast in the study area (Plate I) and 2) presence of Metcalf Phyllite in the hanging walls of the Parson Branch and Coalen Ground thrusts.

The contact between the Cades and Metcalf units is, here again, inferred to be the Greenbrier thrust based on mylonitic fabrics in outcrop (at the Cades-over-Metcalf contact) north of Cades Cove (Plate I, Locality 2). The Greenbrier thrust at this locale also dips to the northwest, in contrast to southeast dips elsewhere, indicating that the Greenbrier is folded here.

Great Smoky thrust

The Great Smoky thrust emplaces Precambrian Ocoee Supergroup rocks upon Ordovician carbonate strata of the Knox Group in Cades Cove. However, the presence of Metcalf Phyllite in the hanging wall (rather than Wilhite Formation) indicates that the Great Smoky thrust here occupied the earlier Rabbit Creek thrust plane or cut up into the Rabbit Creek thrust sheet. Subsurface relationships between the Great Smoky and Rabbit Creek thrusts have been inferred primarily based on map patterns northeast and southwest of the study area.

Tuckaleechee Cove and Hannah Mountain Cross-Sections

Two additional cross-sections were also constructed in order to compare with inferred relationships on the Cades Cove cross-section (A-A') and to illustrate structural variations along strike (Fig. 37). Map contacts and fabric information from the Kinzel Springs quadrangle (Neuman and Nelson, 1965) and from King (1964) have been shown on the Tuckaleechee Cove cross-section (C-C'). The Hannah Mountain cross-section (B-B') was constructed using contacts from the geologic map of Neuman and Nelson (1965), but no fabric information were available here.

Hannah Mountain cross-section (B-B')

Cross-section B-B' (Plate III) is 10 km southwest (and downplunge) of A-A', and passes through Hannah Mountain. Overall structural geometries here are similar to those in the Cades Cove cross-section (A-A'). The Cades Sandstone is overturned here and the Elkmont Sandstone is upright (Neuman and Nelson, 1965). This is consistent with the nappe geometry in the Cades Cove cross-section. The Coalen Ground thrust sheet (fault horse) is also shown, but the Metcalf Phyllite (at its base) does not crop out because it has plunged beneath the surface here. Because of the inferred plunge of the Metcalf, the Greenbrier thrust also does not reach the surface in this cross-section. The dome-shape in the Great Smoky-Rabbit Creek thrust is inferred because of the occurrence of Cades Cove along strike to the northeast (A-A').

Tuckaleechee Cove cross-section (C-C')

Cross-section C-C' (Plate IV) is 10 km northeast (and up-plunge) of A-A' and passes through Tuckaleechee Cove, near the study area of Lewis (1988) (Fig. 37). Apparent differences in overall structural geometry are related to a deeper level of erosion and re-folding of the nappe

structure by post-Rabbit Creek thrust deformation (Woodward, 1985).

A klippe of Cades Sandstone emplaced upon Wilhite northwest of Cades Cove indicates that the Rabbit Creek thrust is folded here. The map pattern northwest of Tuckaleechee Cove indicates that the Great Smoky thrust is structurally lower than the Rabbit Creek thrust. Southeast of Tuckaleechee Cove, however, presence of Metcalf Phyllite in the hanging wall of the Great Smoky thrust indicates that the Great Smoky thrust either occupies the earlier Rabbit Creek thrust plane or cuts up into the Rabbit Creek thrust sheet. In addition, a branch line between the Great Smoky and Rabbit Creek thrusts intersects the erosion surface west of Tuckaleechee Cove (Fig. 37, Locality R) (Neuman and Nelson, 1965). Based on these observations, a branch point between the Great Smoky and Rabbit Creek thrusts has been inferred above the erosion surface in this cross-section (C-C').

Metcalf Phyllite in the nappe core has been inferred above the erosion surface based on map data (klippes of Metcalf) along strike, to the northeast of cross-section C-C', in Tuckaleechee Cove.

An outlier of Cades Sandstone, southeast of Tuckaleechee Cove, is inferred to be a klippe in the hanging wall of the folded Greenbrier thrust in cross-section C-C'. This is consistent with the interpretation

of the folded Greenbrier in cross-section A-A' (Plate II) and also with evidence north of Cades Cove, where the Greenbrier thrust is definitely folded.

This geometry appears similar to structural geometries in the Thunderhead Sandstone klippe northeast of the study area, near the Sinks (Fig. 37). At that location, King (1964) proposed that the southeastern boundary of the klippe is a high-angle fault (Sinks fault), that cuts through and displaces the Greenbrier sheet. In addition, Lewis (1988) documented higher strains in the southeast part of the klippe than elsewhere in the klippe.

The Parson Branch thrust in the Cades Cove region (Plate II) is similar to the Sinks fault in several ways: 1) strains in the Cades Sandstone in the footwall of the Parson Branch thrust (Sample 66) are high, 2) the Parson Branch thrust displaces the Greenbrier thrust, and 3) Snowbird Group rocks (Metcalf) are emplaced against Great Smoky Group rocks (Cades) along the Parson Branch thrust. These similarities suggest that the Sinks fault, like the Parson Branch, may be a thrust that formed in the core of a nappe.

Timing and Nature of Faults

There are at least two distinct generations of faults in the study area. Greenbrier and related faults formed in

an early pre-metamorphic deformational event because they do not displace metamorphic isograds which are believed to be Ordovician (King and others, 1968; Rodgers, 1970; Dallmeyer, 1974; Hatcher, 1972). The Great Smoky thrust formed much later (King and others, 1968), and transported lower Cambrian Chilhowee Group rocks over Mississippian age rocks.

Greenbrier thrust

The Greenbrier is here inferred to be a bedding thrust for the majority of its extent. Northeast of the study area, it underlies the Thunderhead Sandstone for approximately 30 km of its length, emplacing the Thunderhead (Great Smoky Group) on Metcalf Phyllite (Snowbird Group). Dips of bedding in the Thunderhead Sandstone are nearly always similar to dips of the Greenbrier thrust. As the Greenbrier is traced into the study area, it cuts down section into the underlying, but partially time equivalent, Elkmont Sandstone.

In the study area, the Cades Sandstone (Great Smoky Group)-over-Metcalf Phyllite (Snowbird) contact in the Rabbit Creek fault block, north of Cades Cove, is also inferred to be the Greenbrier thrust because of: 1) mylonitic textures in the Cades Sandstone within 1 m of the contact and 2) similar hanging wall-footwall relationships

as the Greenbrier to the northeast (King, 1964). It is folded here and shows general concordance of foliation in the Cades and Metcalf across the contact.

Rabbit Creek thrust

The Rabbit Creek fault is most likely a thrust. Evidence for this includes: 1) typical thrust fault relationship of older rocks emplaced upon younger, 2) geologic map data (east of the field area) which show the Rabbit Creek thrust branching at a low angle to the Great Smoky thrust trace and a distinct klippe of Cades Sandstone overlying Wilhite Formation, and 3) high strains along the fault, with rocks at Abrams Falls (within 200 m of the inferred fault trace) being strongly cleaved. The cleavage is not axial planar to the recumbent fold (nappe) and, thus, is probably related to emplacement of the Rabbit Creek thrust.

King and others (1968) suggested that the Rabbit Creek thrust is related to the Greenbrier fault system. If this is the case, then the Rabbit Creek represents the foreland-most expression of pre-Ordovician, pre-metamorphic thrusting, but no isograds cross the thrust to permit resolution of its timing.

An alternative suggestion for the Rabbit Creek thrust is that it may represent a third distinct deformational

event in the Great Smoky Mountains that occurred between the Greenbrier and Great Smoky thrust emplacement episodes. In addition, the Rabbit Creek appears closely related to the Line Springs fault to the northeast (Fig. 37), in that both the Rabbit Creek and Line Springs contain similar hanging wall-footwall relationships (Metcalf Phyllite ← R.C.? emplaced on Walden Creek Group rocks). Thus, the Line Springs fault may actually be a continuation of the Rabbit Creek thrust.

Parson Branch and Coalen Ground thrusts

The Coalen Ground and Parson Branch thrusts are minor thrusts that sole out in the Metcalf Phyllite. Mylonites are common and well-developed along these thrusts. They cut the Greenbrier sheet (comprised of Elkmont and Cades rocks) on the southern side of Cades Cove, and imbricate the Greenbrier thrust surface. They never bring up rocks beneath the Metcalf Phyllite and appear to have minor displacements (100's of meters) relative to the Rabbit Creek thrust.

Definitive evidence for the timing of emplacement of the Parson Branch and Coalen Ground thrusts (relative to Rabbit Creek thrust emplacement) could not be determined in this study. Therefore, two possibilities exist for timing of these features: 1) the Parson Branch and Coalen Ground

thrusts may represent a simple hinterland-to-foreland sequence of thrusting which occurred between Rabbit Creek and Greenbrier thrust emplacements (and early in nappe formation) or 2) the Parson Branch and Coalen Ground thrusts may represent out-of-sequence thrusts which broke up from the Rabbit Creek thrust (post-Rabbit Creek) late in the development of the nappe structure.

Great Smoky thrust

Map data, both northeast and southwest of Cades Cove, illustrate that the Great Smoky thrust is lower structurally than the Rabbit Creek thrust. According to Neuman and Nelson (1965), and as shown in both the Tuckaleechee Cove cross-section (C-C') and Calderwood Window to the southwest, the Great Smoky thrust dominantly emplaces the Precambrian Walden Creek Group rocks (Wilhite Formation) against Ordovician rocks from the Knox Group (Plate I and Fig. 37). In Cades Cove, however, the Great Smoky thrust must either re-activate the same plane as the older Rabbit Creek thrust or cut up into its hanging wall. Evidence for this is emplacement of older Snowbird Group rocks (Metcalf) (Neuman and Nelson, 1965) against Knox carbonate strata (Plate II).

High strains and extensive crystal-plastic deformation fabrics occur near the Great Smoky-Rabbit Creek thrust

trace, on the overturned limb of the fold (Rabbit Creek thrust sheet). A general absence of high strain and crystal-plastic deformation features in hanging wall rocks of the Great Smoky thrust elsewhere suggests that emplacement of the Great Smoky thrust was not responsible for most of the strains and deformation fabrics observed near the Great Smoky-Rabbit Creek thrust trace. High strains and crystal-plastic deformation fabrics in the Wilhite Formation in the footwall of the the Rabbit Creek thrust west of the study area, illustrated by extensive quartz flattening (Neuman and Nelson, 1965), suggest that these same features in the Cades Cove region are also related to Rabbit Creek thrust emplacement.

CHAPTER IX

STRUCTURAL DEVELOPMENT

SEQUENTIAL DEVELOPMENT OF THE CADES NAPPE

The structural development of the Cades Nappe will now be discussed, starting at "TIME 0" and progressing through "TIME 7". Fabrics associated with a given "TIME" or event will also be mentioned briefly.

Time 0 - Pre-Deformation

At this time, rocks of the Ocoee Supergroup in the study area had not yet been exposed to a major deformational event. Snowbird Group (Metcalf) rested unconformably upon basement rocks and were, in turn, overlain by the Great Smoky Group. Cades and Elkmont Sandstones are shown as stratigraphic equivalents within the Great Smoky Group (Fig. 46a).

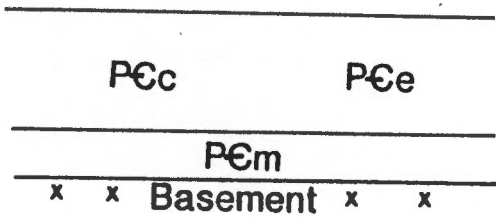
Time 1 - Greenbrier Thrust Emplacement

Initiation of the Greenbrier thrust. It propagated through the Great Smoky Group (Thunderhead Sandstone) to

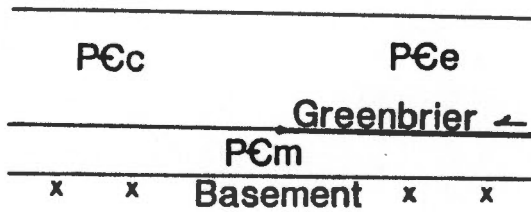
Figure 46 - Structural development in the Cades Cove region.

- a. Time 0 - Inferred stratigraphic relationships between the Great Smoky Group (Cades/Elkmont) and Snowbird (Metcalf) Group prior to deformation.
- b. Time 1 - Initiation of the Greenbrier thrust, which propagates near the original stratigraphic contact between Great Smoky and Snowbird Groups in the Cades Cove area.
- c. Time 2 - Metamorphism
- d. Time 3 - Folding of Ocoee Supergroup rocks in the Rabbit Creek thrust sheet results in overturned anticlinal geometry; Greenbrier thrust becomes folded.
- e. Time 4 - Initiation of the Rabbit Creek thrust at or near the basement-Metcalf contact.
- f. Time 5 - Thrust nappe emplacement; shearing of the overturned limb occurs in response to ramping of the Rabbit Creek thrust.
- g. Parson Branch thrust emplacement
- h. Coalen Ground thrust emplacement

a

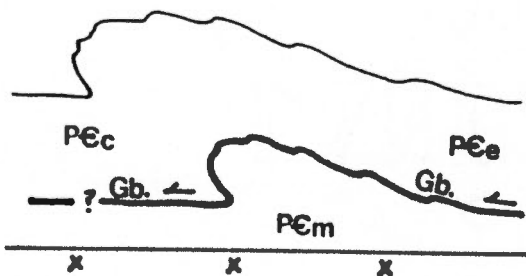


b

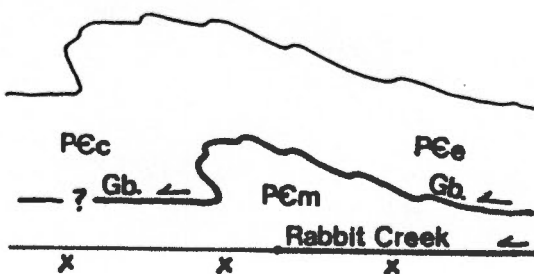


c Metamorphism

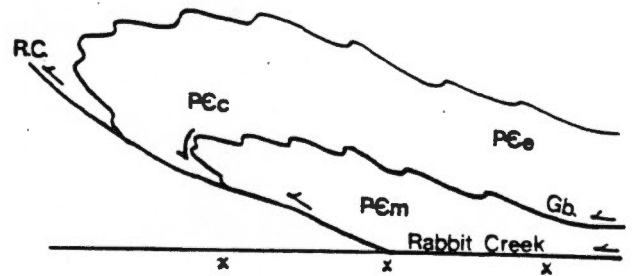
d



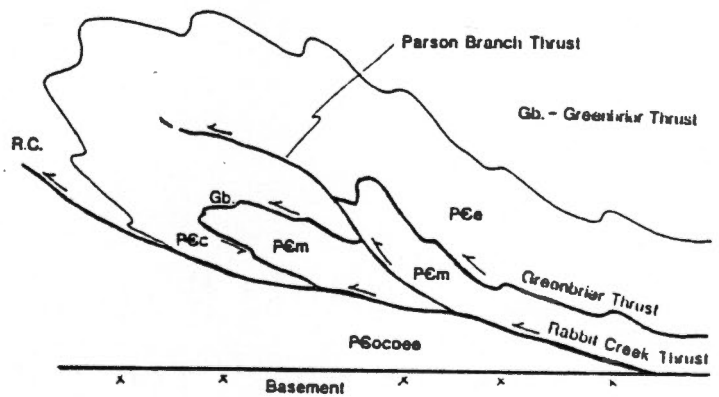
e



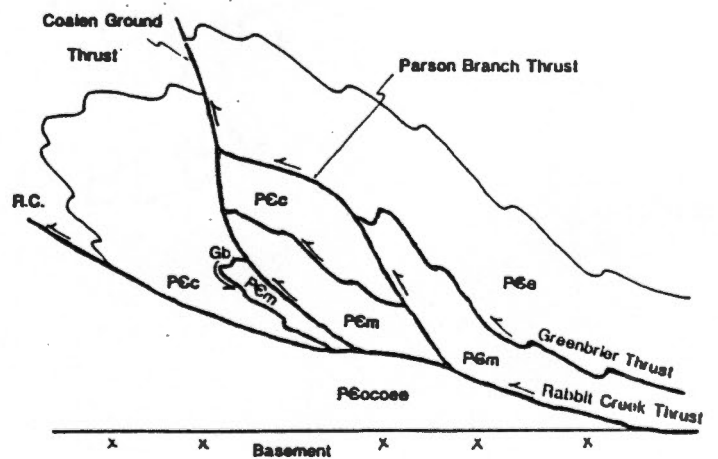
f



g



h



the northeast and at or near the Great Smoky Group-Snowbird Group contact in the study area. Great Smoky Group rocks (Cades Sandstone) are transported over Snowbird Group rocks (Metcalf) such that there is no stratigraphic separation on the Greenbrier in the Cades Cove region (Fig. 46b).

The phyllitic foliation (S_1) developed in the Metcalf Phyllite.

Time 2 - Metamorphism

A greenschist facies metamorphism (up to biotite grade) pre-dates folding, based on the presence of recrystallized, fold-related, quartz cleavage in the study area. If metamorphism occurred after folding, quartz subgrains would most likely have annealed, resulting in a general absence of quartz subgrain development (i.e., recrystallization) (Fig. 46c).

Time 3 - Folding

Folding of Ocoee Supergroup rocks resulted in an overturned anticlinal geometry. The Greenbrier thrust was also folded at this time (Fig. 46d).

Quartz foliation (S_1 in Cades and Elkmont Sandstones) developed which was related (axial planar?) to folding.

This is more pronounced in the Cades on the overturned limb.

Time 4 - Rabbit Creek Thrust Emplacement

The Rabbit Creek thrust initiated and propagated within the Metcalf Phyllite, or near the basement-Metcalf contact (Fig. 46e). Rabbit Creek thrust emplacement occurred after folding, as shown by cleavage in the hanging wall of the thrust which is not fold-related.

Time 5 - Thrust Nappe Emplacement

Shearing of the overturned limb occurred in response to ramping of the Rabbit Creek thrust. The Cades thrust nappe was emplaced over Walden Creek Group rocks (Wilhite Formation) of the Ocoee Supergroup (Fig. 46f).

Fractured and rotated feldspars developed in the overturned Cades Sandstone due to simple shear on the Rabbit Creek thrust.

Development of Core Thrusts

The Coalen Ground and Parson Branch thrusts propagated out of the nappe core at some time during nappe emplacement. Timing of these features relative to the

Rabbit Creek thrust emplacement is unclear (Figs. 46g and 46h).

Features related to these thrusts are mylonitic textures along both the Parson Branch and Coalen Ground thrusts.

Time 6 - Great Smoky Thrust Emplacement

The Cades nappe, which formed earlier, was transported to the northwest along the Great Smoky thrust. The Great Smoky thrust utilized the Rabbit Creek thrust trace in the area of Cades Cove (Plate II).

Previously formed fabrics were modified and re-oriented because of movement along the Great Smoky thrust.

Time 7 - Folding of the Great Smoky Thrust

Imbrication in the footwall rocks (Knox Group) of the Great Smoky thrust resulted in re-folding of the nappe structure and the Great Smoky thrust. The Coves (Cades, Tuckaleechee, Calderwood, Wear, and Spring) resulted from erosion through the highest (structurally) parts of the hanging wall of the Great Smoky thrust sheet.

CHAPTER X

CONCLUSIONS

The major conclusions of this thesis are as follows:

- 1) The Cades and Elkmont Sandstones are stratigraphic equivalents and, hence, should be classified as such within the Great Smoky Group of the Ocoee Series.
- 2) The Greenbrier is a "bedding plane" thrust that occurs near the original stratigraphic contact between the Great Smoky and Snowbird Groups in the Cades Cove region, based on mylonitic fabrics and concordance of units above and below the contact.
- 3) Microfabric and strain analysis data indicate that the Cades Sandstone is more highly strained than the Elkmont Sandstone.
- 4) The Cades and Elkmont Sandstones represent the overturned forelimb and upright backlimb (respectively) of the Cades nappe.

- 5) Metcalf-over-Cades contacts in the nappe core region (Parson Branch and Coalen Ground thrusts) are tectonic in nature, rather than stratigraphic. Evidence for this is extensive mylonitization along both the Parson Branch and Coalen Ground thrust traces.
- 6) Emplacement of the Cades nappe involved a shear mechanism which resulted from movement along the Rabbit Creek thrust.
- 7) The original geometry of the Cades nappe has been extensively modified by (at least) two subsequent episodes of deformation: 1) emplacement of the Great Smoky thrust and 2) post-Great Smoky thrust deformation due to footwall duplexing in the underlying Ordovician carbonates.

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APPENDICES

APPENDIX I

ABBREVIATIONS

For Geologic Maps

PCw	- Precambrian Wilhite Formation
PCc	- Precambrian Cades Sandstone
PCt	- Precambrian Thunderhead Sandstone
PCe	- Precambrian Elkmont Sandstone
PCa	- Precambrian Anakeesta Formation
PCm	- Precambrian Metcalf Phyllite
OEK/Ok	- Ordovician Knox Group

For Photos

F	- feldspar grain
Q	- quartz (may be a grain or pressure solved material, as indicated by figure caption)
S ₀	- original bedding
S ₁	- foliation/cleavage (as indicated)
S ₂	- shear bands/crenulation/kink axial plane (as indicated)
mm	- millimeters
cm	- centimeters
m	- meters
km	- kilometers
mi	- miles

For Strain Analysis

H	- Harmonic mean axial ratio of quartz grains
Rf	- final axial ratio of quartz grains after deformation
Ri	- initial axial ratio of quartz grains prior to deformation
F	- fluctuation (range of quartz long axis orientations)
Rs	- tectonic strain ratio

APPENDIX II

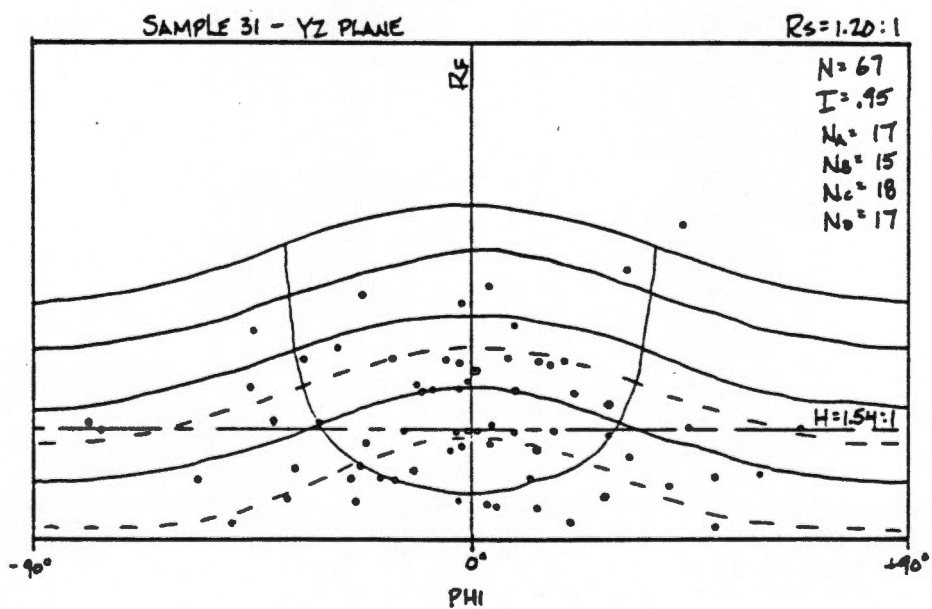
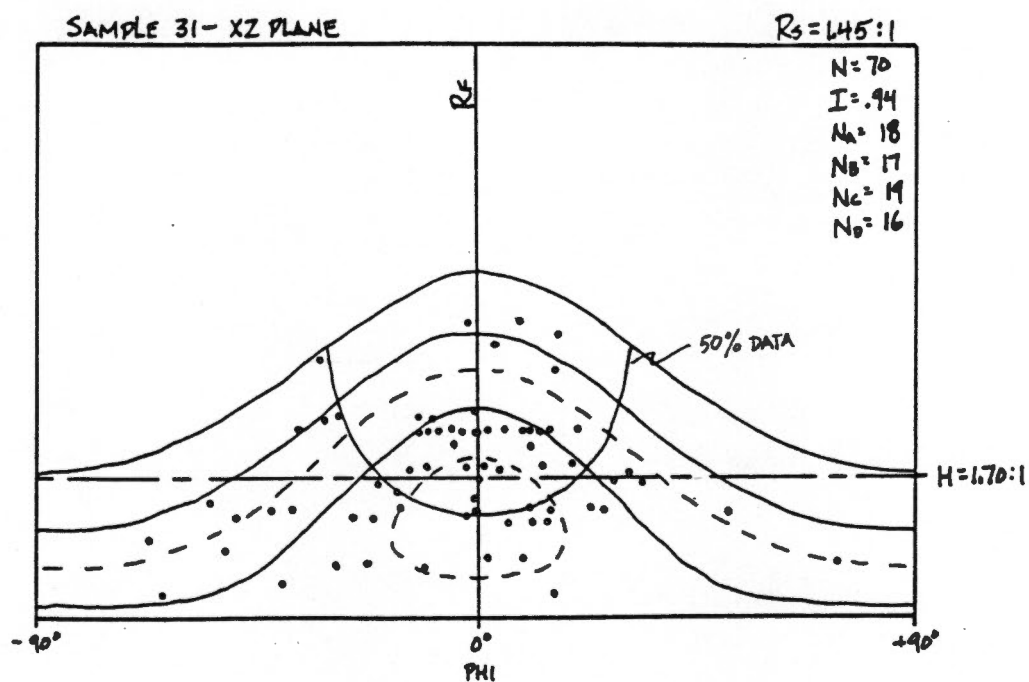
I determined the center of symmetry for all Rf/ϕ plots using the method described by Lisle (1985). First, the harmonic mean (H) of Rf (see CHAPTER VII, for H equation) and the vector mean ϕ' :

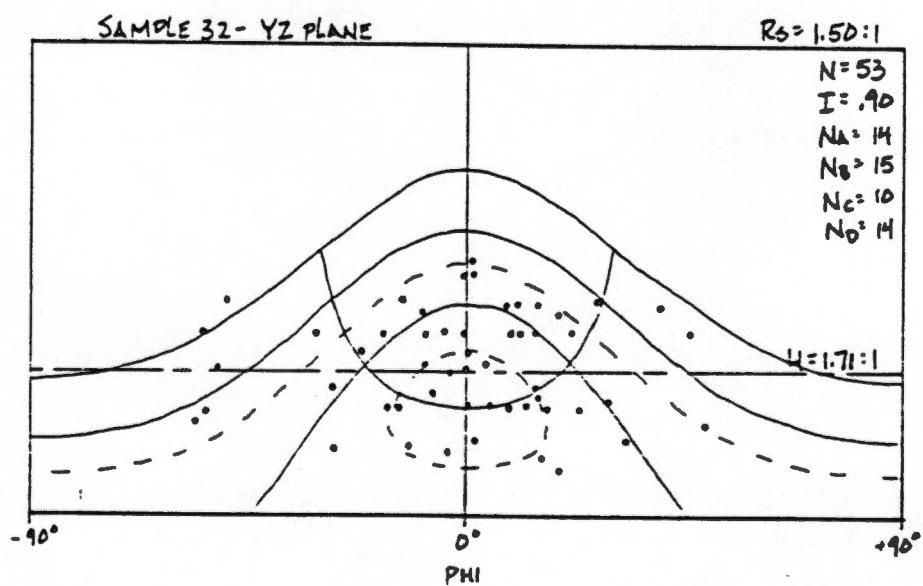
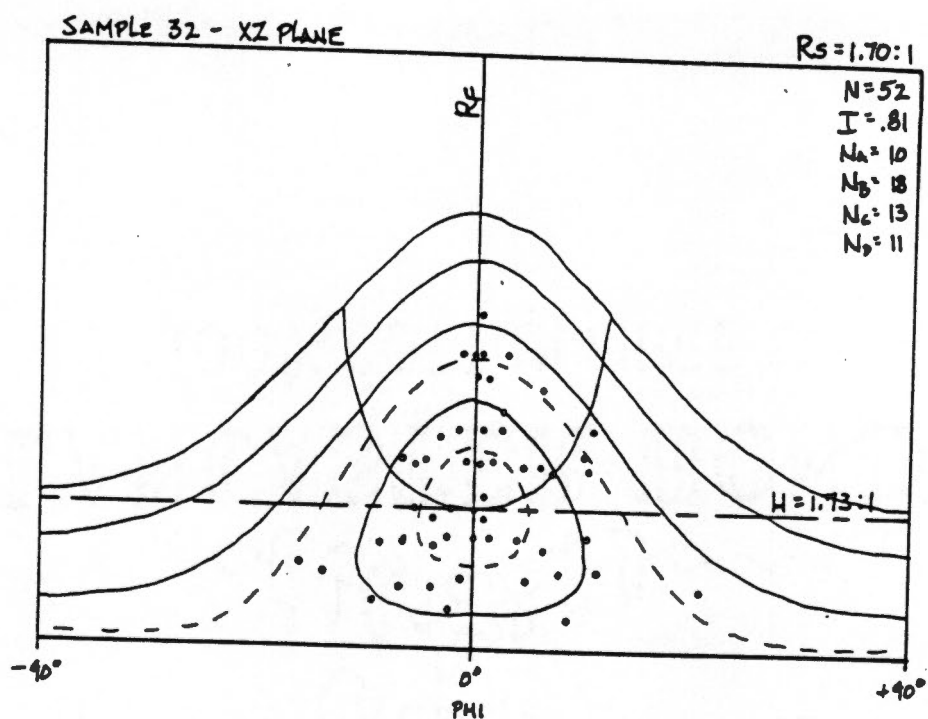
$$\text{Vector mean } \phi' = 1/2 \arctan(\sin 2\phi' / \cos 2\phi')$$

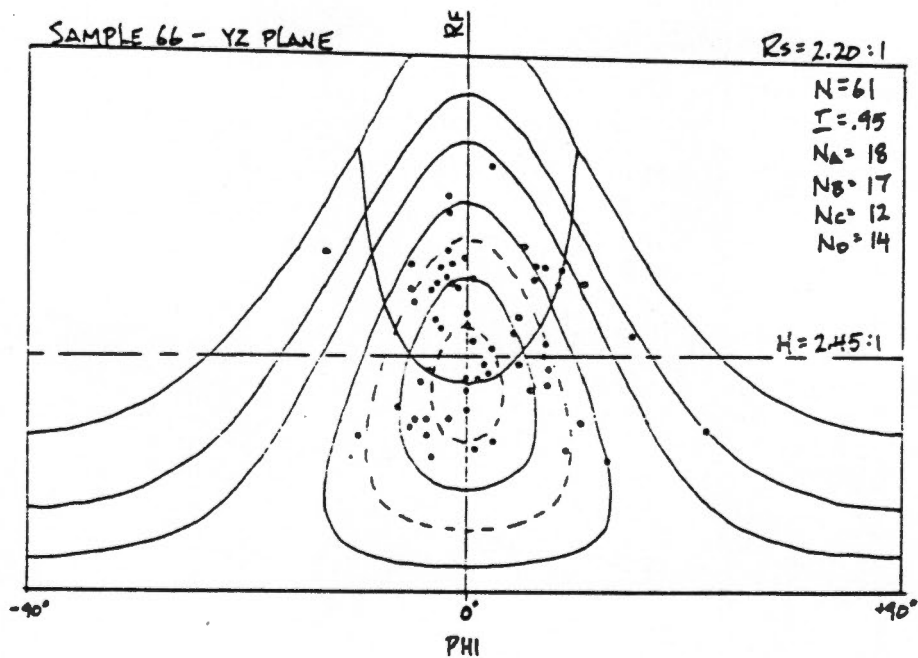
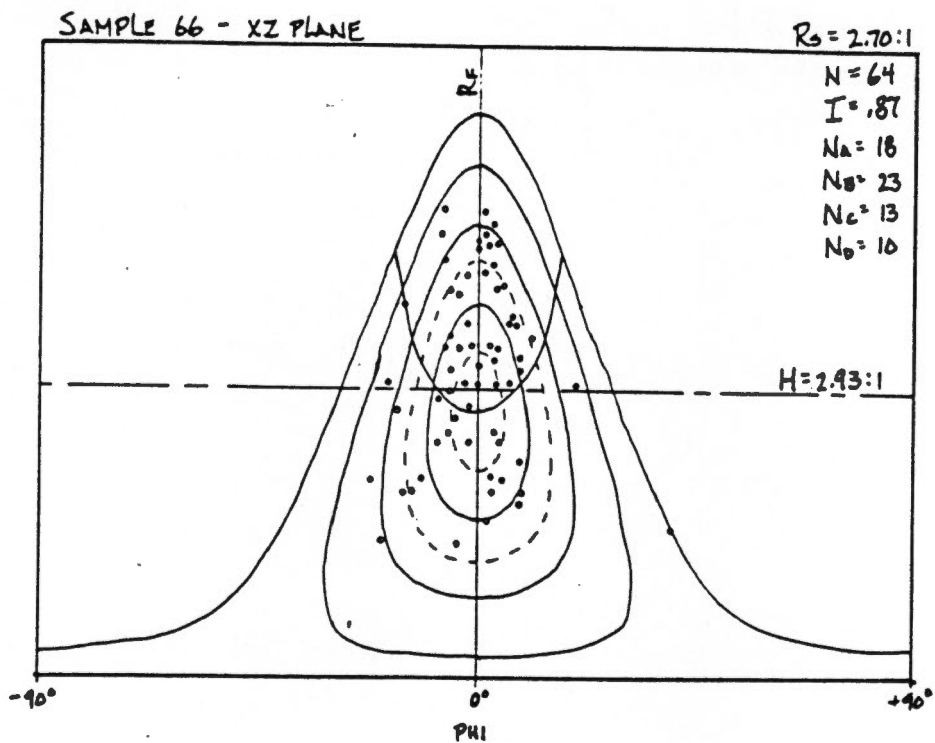
(where ϕ' -angular deviation of quartz long axis from the reference axis) were calculated for each plane of section to be used in the Rf/ϕ analysis. The line which represented the calculated value of H was then superimposed over the Rf/ϕ data (horizontal line) and the vector mean ϕ' was considered to be the $\phi=0^\circ$ axis on the Rs graphs (vertical line). These two lines divide the Rf/ϕ data into four quadrants (A-D). Symmetry of the data was then determined using the equation:

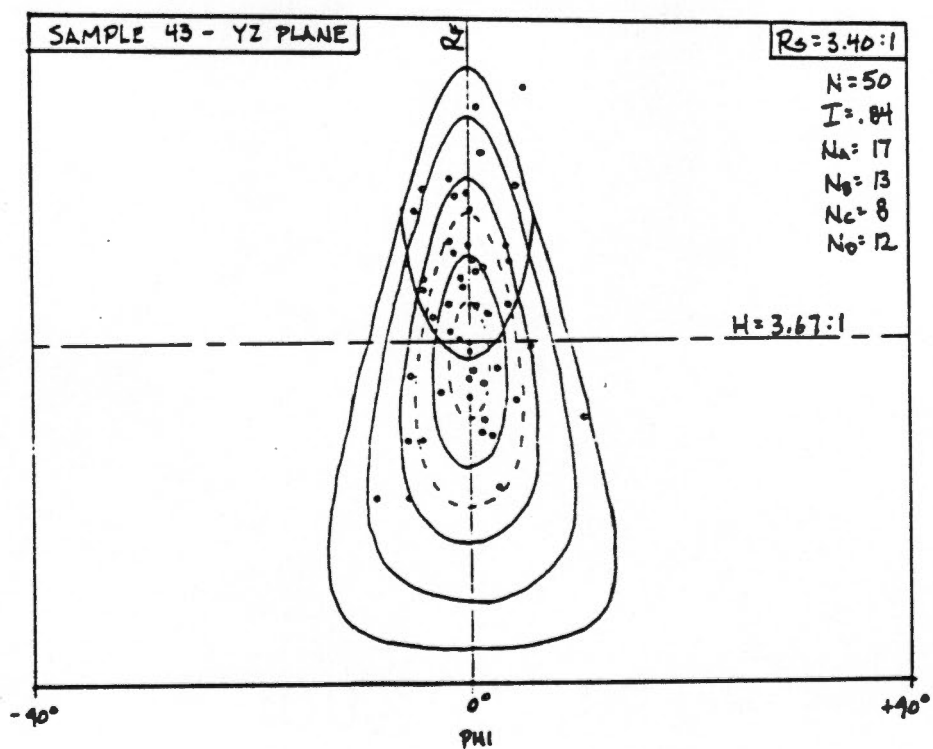
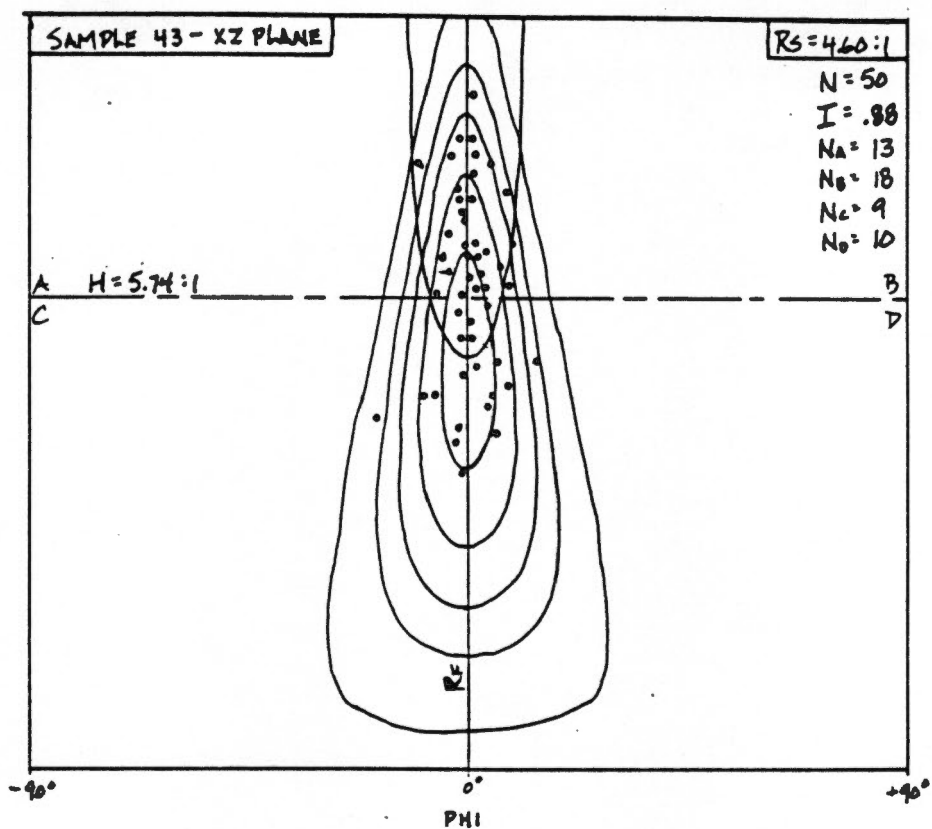
$$I_{\text{sym}} = 1 - (|N_A - N_B| + |N_C - N_D|) / N$$

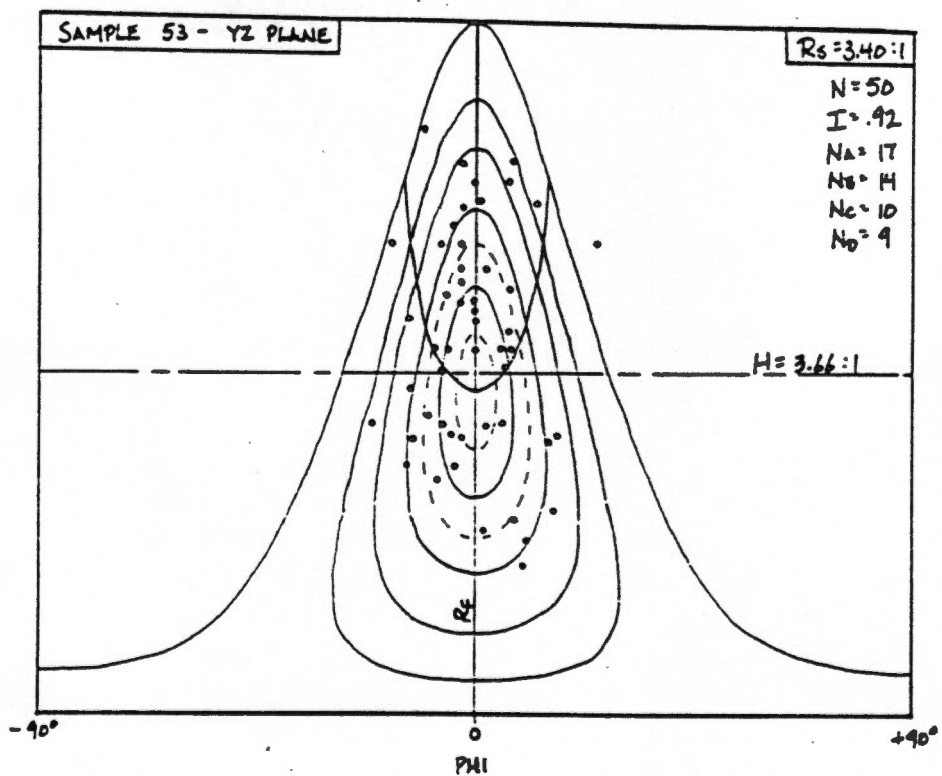
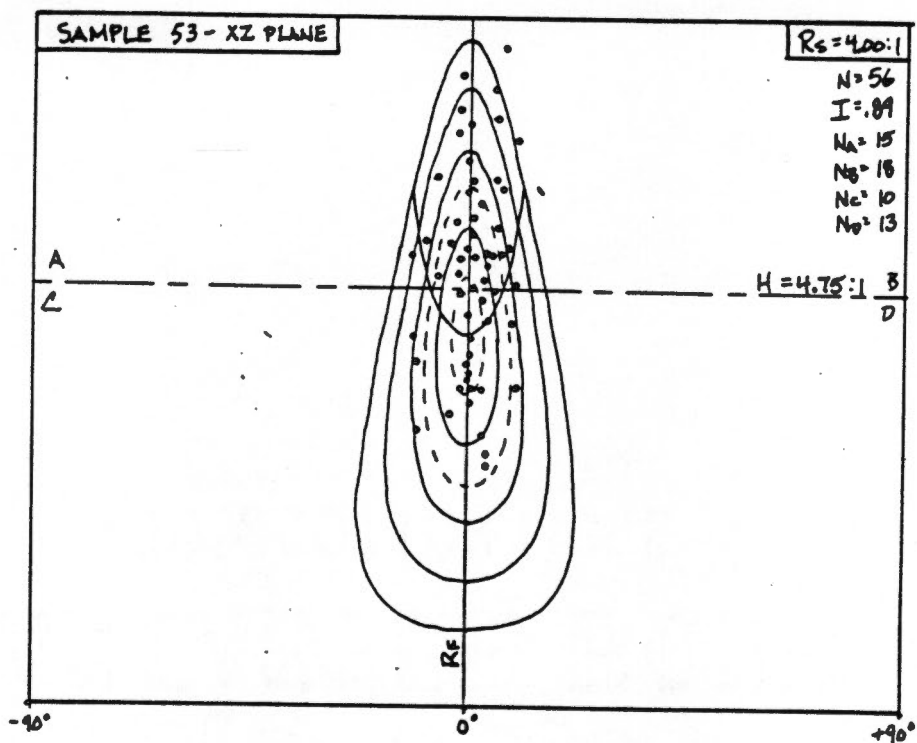
where N_{A-D} -number of points in the designated quadrant; N -total number of Rf/ϕ data points for a particular plane of section. An $I_{\text{sym}} > .75$ indicates that the data are highly symmetrical and, thus, satisfy one of the criteria for a "good fit" to an Rs graph (Lisle, 1985).

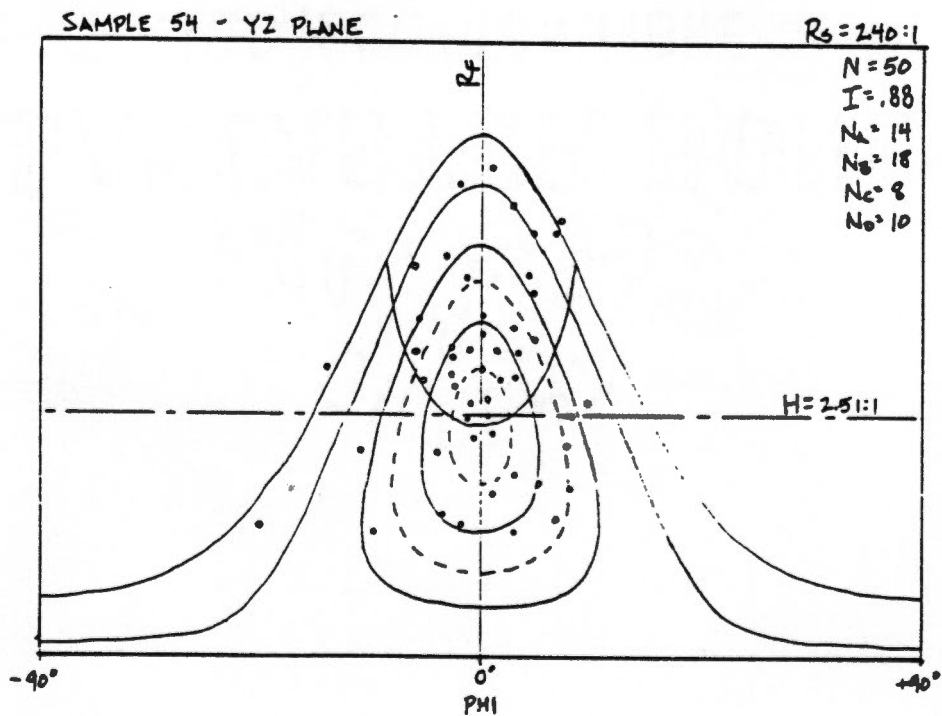
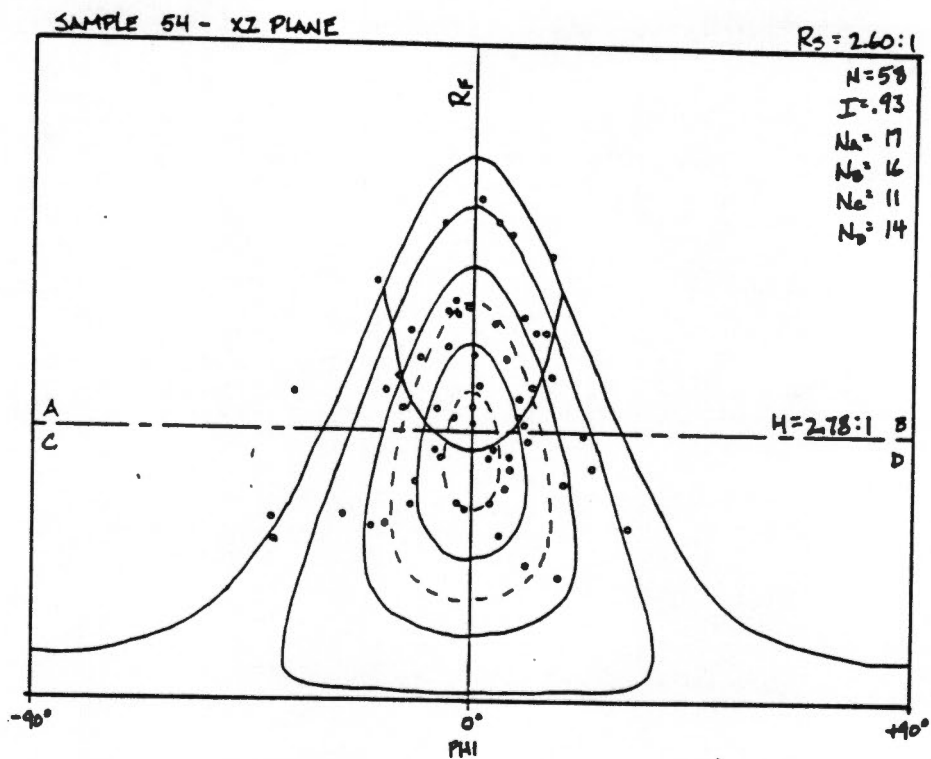






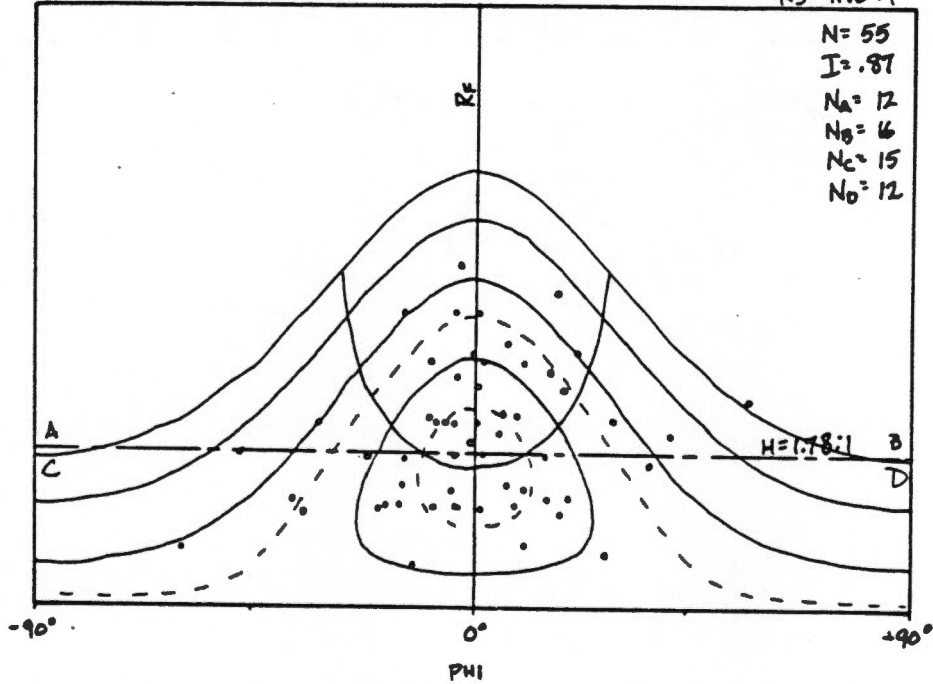






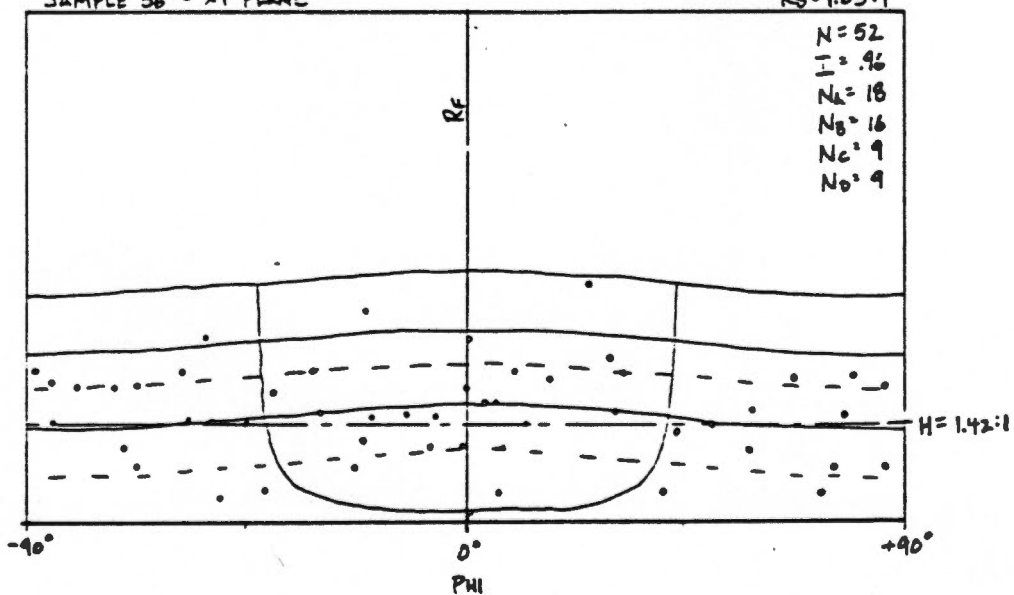
SAMPLE 36 - XZ PLANE

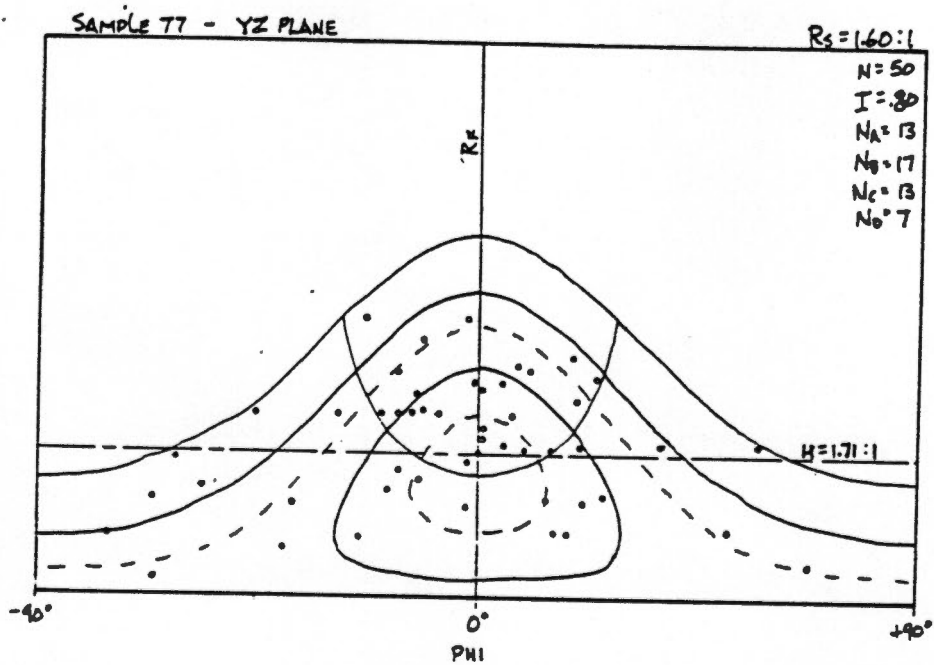
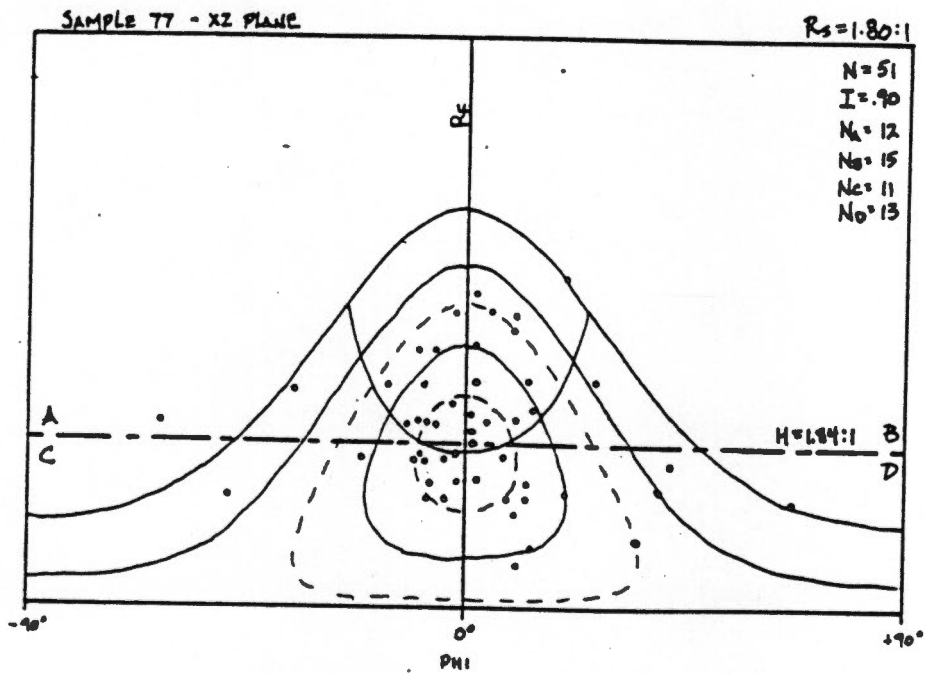
$R_s = 1.70:1$



SAMPLE 36 - XY PLANE

$R_s = 1.05:1$





APPENDIX III

ROAD LOG FOR CADES COVE

MILEAGE	DESCRIPTION
0.0	Parking Lot at entrance to Cades Cove (Scenic) Loop.
3.1	Pull off (to the right) just past Rich Mountain Road turnoff. Pass over barbed wire gate and across field to Tater Branch (Plate I). Follow Tater Branch north for 500 m. Stop 1: The outcrop on the east bank of Tater Branch here is an exposure of the folded Greenbrier thrust. Mylonitized Cades Sandstone in the hanging wall overlies Metcalf Phyllite (saprolite) in the footwall. Each unit appears concordant across the contact. Attitude: N 53°E, 17°NW The mylonitic fabric in the Cades (along with shear bands, which are not easily seen in outcrop), however, indicates that this contact is tectonic, rather than a stratigraphic (Figs. 33-35).
4.9	Continue on Cades Cove Loop until Abrams Creek turnoff. Turn right and follow this dirt road to the parking area at the Abrams Creek trailhead. Stop 2: One mile up Abrams Creek trail at meander neck (Plate I). The overturned Cades Sandstone crops out at this locale. Two lines of evidence indicate that it is overturned: 1) cleavage dipping at a gentler angle than bedding and 2) coarsening-upward sequences. Attitudes: S₀- N 42°E, 34°SE S₁- N 43°E, 11°SE

The Cades here is composed dominantly of medium- to thick-bedded, coarse-grained sandstone which may fine (to the northwest) into shale. A good example of cleavage refraction occurs 50 m before the high point in the trail (See Fig. 6b).

Stop 3: 2.5 miles up the trail at Abrams Falls (Plate I).

The Cades here is composed dominantly of dark gray-black siltstone, which is strongly cleaved. Cleavage is steeper than bedding; however, graded bedding indicates that this Cades section is overturned some 180° .
Attitudes: S_0 - N 59° E, 15° SE
 S_1 - N 20° E, 67° SE
(See Figs. 30-32).

This outcrop is within 200 m of the Rabbit Creek thrust trace and the cleavage is inferred to be related to thrust emplacement (Fig. 36).

The Cades Sandstone northwest of the Coalen Ground thrust represents the overturned forelimb of the Cades nappe.

5.8 Return to Cades Cove (Scenic) Loop.

6.3 Continue on Cades Cove Loop until Forge Creek Road (Plate I). The gate at the entrance to Forge Creek Road is closed during the winter.

6.6 Follow Forge Creek Road about 600 m to the Water Supply House (on the left, east side).

Stop 4: The mylonitized Cades Sandstone crops out here in the footwall of the Coalen Ground thrust. This

exposure is very near a contact (Metcalf-over-Cades) that was previously interpreted to be stratigraphic in nature (Neuman and Nelson, 1965). Mylonitic textures in the Cades here, however, indicate that it is tectonic.
Attitude: S_0 - N $54^{\circ}E$, $34^{\circ}SE$

- 8.5 Continue on Forge Creek Road until Parson Branch Road (one way). Follow Parson Branch Road (on foot) west for 500 m (Plate I). This road basically traces the Parson Branch thrust in this area.

Stop 5: Outcrops on either side of the road expose a shear band cleavage in the hanging wall of the Parson Branch thrust. The orientation of the foliation (S_1) is N $45^{\circ}E$, $42^{\circ}SE$. Shear bands are nearly horizontal (Fig. 12).

This Metcalf-over-Cades contact, like the one at Stop 4, was also interpreted as stratigraphic by Neuman and Nelson (1965). The shear band cleavage suggests, however, that it is a fault.

- 8.6 Continue on Forge Creek Road until it ends in a cul-de-sac. Forge Creek Trail starts here. Follow Forge Creek Trail approximately 1500 m (Plate I).

Stop 6: The outcrop on the right (about 25 m above stream level) is the Elkmont Sandstone in the main Greenbrier thrust sheet (Fig. 11).

Neuman and Nelson (1965) observed that the majority of beds in the Elkmont contain fining-upward sequences (towards the southeast). Cleavage steeper than bedding, in conjunction with fining sequences, indicates that the Elkmont is

stratigraphically upright here.
The Elkmont Formation represents
the backlimb of the Cades nappe.

Attitudes: S_0 - N 50° E, 52° SE
 S_1 - N 54° E, 82° SE

10.8 Return up Forge Creek Road to Cades Cove
 (Scenic) Loop.

15.7 End Cades Cove (Scenic) Loop.

VITA

Randy Robert Walters was born in Houston, Texas on May 12, 1962. Randy attended Parker Elementary school in Houston until age 12. Subsequently, he attended Fondren Junior High school for a year. By this time (1975), Randy was sick and tired of academia. He realized his true calling at this tender age of 13 and made the long trek to the swamps of Louisiana, where he was determined to become acquainted with the ways of the legendary Alligator Wrestling Cult.

For years Randy searched the swamps for any sign of the alligator wrestlers. It was futile. Dejected and defeated, he sat in the mud pondering his future. It was then that Randy inhaled an aroma which was to change his life forever; it was methane rising from the swamp. He now realized that his future lay in the field of Geology (in search of hydrocarbons).

Randy applied and was accepted at Trinity University in San Antonio, Texas in the Fall, 1980. He graduated with a B.S. in Geology from Trinity in the Winter, 1984. At this time, there was not a job to be found. Randy then pursued a Master's Degree in Geology at The University of Tennessee-Knoxville. He graduated with his M.S. in Geology in the Spring, 1988 and went on to work as an oil pig for Exxon Co., U.S.A. in Midland, Texas.